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REVIEW ARTICLE Open Access

Antioxidant, Antimicrobial, Anti-Inflammatory, and Gut Microbiota Modulation Effects of Kombucha: a Literature Review

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Abstract

Introduction: The interest in probiotics has increased significantly in recent years. While most probiotic-containing foods are dairy-based, an increasing number of non-dairy probiotic products have emerged, including kombucha. Kombucha is a fermented tea beverage originating from China, known for its high polyphenol content and potential health benefits.

Methods: This literature review aims to provide a comprehensive understanding of the health benefits of kombucha. A systematic search of published studies was conducted using the keywords "kombucha," "antioxidant," "anti-inflammatory," "antimicrobial," and "gut microbiota modulation." Only English-language articles were included, and there was no restriction on publication date to capture the full spectrum of research on kombucha.

Results: Kombucha exhibits significant antioxidant capacity, with green tea kombucha demonstrating the highest Ferric Ion Reducing Antioxidant Power (FRAP) due to its high polyphenol content. Additionally, kombucha possesses antimicrobial properties attributed to organic acids, lactones, aldehydes, fatty acids, and alkaloids, which act synergistically. It also exhibits anti-inflammatory effects by inhibiting nitric oxide production and downregulating pro-inflammatory cytokines such as IL-1β and TNF-α. Furthermore, kombucha modulates gut microbiota composition by inhibiting the growth of Gram-negative bacteria, leading to reduced systemic inflammation and oxidative stress.

Conclusion: Kombucha, a traditional fermented tea, has notable health benefits, including antioxidant, antimicrobial, anti-inflammatory, and gut microbiota-modulating properties. These findings highlight its potential as a functional beverage for health promotion.

Keywords: kombucha - antioxidant - anti-inflammatory - antimicrobial - gut microbiota modulation

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INTRODUCTION

The increasing global emphasis on health and well-being has driven interest in functional foods, particularly probiotics. Probiotics are live microorganisms that provide health benefits when consumed in adequate amounts, with Lactobacillus and Bifidobacterium being the most commonly used strains. While traditionally associated with dairy products, probiotics are now incorporated into various non-dairy foods, including kombucha.[1]

Kombucha is a fermented tea beverage produced by fermenting tea and sugar with a symbiotic culture of bacteria and yeast (SCOBY). This fermentation process yields bioactive compounds, including organic acids and polyphenols, which contribute to its health benefits. Kombucha is widely consumed for its purported antioxidant, antimicrobial, anti-inflammatory, and gut microbiota-modulating effects.[2,3]

In recent years, there has been a growing emphasis on probiotics and prebiotics in food products.[4] Probiotics, such as Bifidobacterium and Lactobacillus, are microorganisms that can provide health benefits to their host when consumed in sufficient amounts, including enhanced immune function[5] and gut microbiota modulation.[6] Initially, probiotics were commonly used in dairy products, but they are now being incorporated into various other foods, one of which is kombucha, a beverage that is gaining popularity.[7] Despite its rising popularity, regulations regarding kombucha production and safety remain limited.[8] Therefore, understanding its health benefits and mechanisms of action is crucial to establishing its role as a functional food. This review aims to provide a comprehensive analysis of kombucha's potential health benefits by synthesizing findings from existing literature.

METHODS

This systematic review evaluates the health benefits of kombucha by analyzing its antioxidant, antimicrobial, anti-inflammatory, and gut microbiota-modulating properties. The literature search was conducted across multiple electronic databases, including PubMed, Scopus, and Google Scholar, without a date restriction. The absence of a date limitation was intentional, as research on kombucha has gained momentum in recent years, and earlier studies provide foundational insights into its bioactive properties. Including older studies ensures a comprehensive analysis of its potential health effects over time.

The search strategy involved a combination of Medical Subject Headings (MeSH) terms and free-text keywords, including "kombucha," "antioxidant," "anti-inflammatory," "antimicrobial," and "gut microbiota modulation." Boolean operators (AND/OR) were employed to refine the search results. The

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inclusion criteria encompassed peer-reviewed English-language articles that provided experimental or clinical data on kombucha's health effects. Studies were excluded if they were review articles, conference abstracts, editorials, or did not contain quantitative data relevant to the topic.

The literature selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The initial search yielded a broad range of articles, which were screened based on title and abstract relevance. Duplicates were removed, and the remaining articles underwent full-text assessment to determine their suitability. Two independent reviewers assessed the eligibility of studies, resolving discrepancies through discussion or consultation with a third reviewer when necessary.

To ensure methodological rigor, studies were further evaluated based on experimental design, sample size, analytical methods, and statistical robustness. Preclinical studies, including in vitro and animal models, were included to complement clinical findings where human studies were limited. The final selection of studies was systematically documented in a PRISMA flowchart, which is included in this review to enhance transparency and reproducibility.

RESULTS AND DISCUSSION

Kombucha: Its Origin and Health Benefits

Kombucha is a fermented tea beverage with origins traced back to ancient China. Historical records suggest that kombucha was consumed during the Qin Dynasty (circa 220 BCE) as a tonic believed to promote longevity and vitality.[9] The beverage was later introduced to Japan, where it gained recognition as a health-promoting drink. Through trade and cultural exchanges, kombucha spread across Russia and Eastern Europe, where it was integrated into local diets. During World War II, kombucha gained renewed interest due to its purported health benefits, particularly in improving digestion and enhancing immune function.[10] In recent decades, its popularity has surged in Western countries, including the United States and various European nations, where it is marketed for its probiotic content, antioxidant properties, and potential metabolic health benefits.[11]

Kombucha is produced by fermenting sweetened tea with a symbiotic culture of bacteria and yeast (SCOBY). The fermentation process typically spans 7 to 14 days, during which microorganisms metabolize sugars and produce bioactive compounds such as organic acids, polyphenols, and various secondary metabolites.[12] These components are responsible for the beverage’s characteristic sour taste and potential health benefits. Notably, kombucha made from green tea has

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been shown to have higher levels of catechins and flavonoids compared to other tea bases, enhancing its antioxidant and antimicrobial potential.[13]

Antioxidant Properties of Kombucha

Phenolic compounds are widely recognized for their antioxidant properties, which play a crucial role in reducing oxidative stress and preventing chronic diseases. Polyphenols in kombucha, particularly those derived from green tea, include catechins, flavonoids, and tannins, all of which contribute to its free radical-scavenging ability.[14] Antioxidants in kombucha function by neutralizing reactive oxygen species (ROS) that contribute to cellular aging and neurodegenerative diseases such as Alzheimer's and Parkinson's disease.[15]

A previous study demonstrated that kombucha exhibits strong antioxidant activity, as measured by the 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) assay, with inhibition levels ranging from 70.62% to 94.61%.[16] Among different tea bases, green tea kombucha was found to have the highest Ferric Ion Reducing Antioxidant Power (FRAP) and total polyphenol content, which positively correlated with its reductive potential.[17] This suggests that kombucha, particularly when made from green tea, can provide substantial antioxidant benefits, potentially reducing the risk of cardiovascular and metabolic disorders.[18]

Antimicrobial Properties of Kombucha

Several bioactive compounds in kombucha contribute to its antimicrobial effects. These include organic acids (acetic acid, gluconic acid, and glucuronic acid), lactones, aldehydes, fatty acids, and alkaloids.[19] These compounds exhibit broad-spectrum antimicrobial activity by targeting bacterial cell walls, inhibiting enzyme function, and disrupting microbial metabolism.[20]

Lactones and hydroxylactones have been reported to inhibit pathogenic bacteria such as Staphylococcus aureus, Pseudomonas aeruginosa, and Candida albicans by deactivating essential microbial enzymes.[21] Fatty acids, due to their hydrophobic nature, interact with bacterial membranes, leading to cell lysis and loss of viability.[22] Additionally, 5-hydroxymethyl-2-furaldehyde, a heterocyclic aldehyde present in kombucha, has shown antibacterial activity against Gram-negative plant pathogens by interacting with bacterial DNA.[23] Alkaloids contribute to antimicrobial action by disrupting cell membranes, leading to nutrient leakage and cell death.[24]

Anti-Inflammatory Potential of Kombucha

Kombucha has demonstrated potential in modulating inflammatory responses, particularly through its influence on immune system regulation. Research by Wang et al. highlighted kombucha's ability to enhance cellular immune function in septic mice, primarily by promoting the growth of

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beneficial butyrate-producing bacteria and reducing systemic inflammation.[25]

Another study by Cabral et al. explored the effects of kombucha fermented with oak leaves, showing that it significantly reduced the production of nitric oxide (NO), a key inflammatory mediator, and downregulated pro-inflammatory cytokines, including interleukin-1 beta (IL-1β) and tumor necrosis factor-alpha (TNF-α).[26] This suggests that kombucha, particularly when combined with plant-derived bioactive compounds, may serve as a potential dietary intervention for inflammation-related conditions.

Kombucha as a Gut Microbiota Modulator

Emerging evidence indicates that kombucha may play a role in modulating gut microbiota composition. A study conducted by Costa et al. demonstrated that rats fed a high-fat, high-fructose diet exhibited improved gut microbiota profiles following kombucha supplementation. The high-fat diet groups had elevated levels of Proteobacteria and Bacteroides, which were reduced upon kombucha intake, suggesting that kombucha may exert selective antimicrobial activity against Gram-negative bacteria.[25]

The reduction of Gram-negative bacteria is particularly beneficial, as their endotoxins can trigger inflammatory cascades through nuclear factor kappa B (NF-κB) activation, leading to increased levels of pro-inflammatory cytokines such as TNF-α, IL-6, and IL-1β.[26] By inhibiting the growth of pro-inflammatory microbial species, kombucha consumption may contribute to lower systemic inflammation and improved metabolic health.

The following table summarizes the health benefits of kombucha, the mechanisms involved, the active compounds responsible, and the references supporting these findings.

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Table 1. The health benefits of kombucha, the mechanisms involved, the active compounds responsible, and the references supporting these findings.

Health Benefit	Mechanism of Action	Active Compounds	References
Antioxidant	Scavenges free radicals, reduces oxidative stress	Polyphenols, flavonoids, catechins	Shahidi & Ambigaipalan (2015), Jakubczyk et al. (2020), Antolak et al. (2021)
Antimicrobial	Inhibits pathogenic bacterial growth, disrupts bacterial membranes	Organic acids (acetic, gluconic), alkaloids, lactones	Al-Mohammadi et al. (2021), Wińska et al. (2016)
Anti-inflammatory	Inhibits nitric oxide production, downregulates pro-inflammatory cytokines	Polyphenols, flavonoids, organic acids	Jakubczyk et al. (2020), Batista et al. (2022), Vázquez-Cabral et al. (2017)
Gut microbiota modulation	Enhances beneficial gut bacteria, inhibits harmful bacteria	Probiotics, acetic acid, lactic acid	Costa et al. (2022), Koirala & Anal (2021), Khaneghah et al. (2020)
Anti-diabetic	Enhances insulin sensitivity, reduces fasting blood glucose	Polyphenols, organic acids	Bhattacharya et al. (2020), Mensi & Udenigwe (2021), Zhao et al. (2015)
Hepatoprotective	Enhances liver detoxification, reduces oxidative stress	Glucuronic acid, polyphenols, flavonoids	Gaggìa et al. (2019), Kallel et al. (2012), Espinoza et al. (2008)
Neuroprotective	Reduces neuroinflammation, prevents oxidative damage	Polyphenols, flavonoids, probiotics	Gaggìa et al. (2019), Wang et al. (2021)
Cardioprotective	Improves endothelial function, lowers cholesterol	Polyphenols, flavonoids, catechins	Watawana et al. (2015), Chakravorty et al. (2016)
Anti-cancer	Induces apoptosis, inhibits tumor proliferation	Polyphenols, flavonoids, organic acids	Leal et al. (2018), Morales-Luna et al. (2017), Harrison et al. (2021)

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CONCLUSION

Kombucha is a fermented tea-based beverage that undergoes a bioconversion process through the activity of Symbiotic Culture of Bacteria and Yeast (SCOBY) over a period of 7 to 14 days. During fermentation, the added sugar is broken down into various bioactive compounds, including organic acids, polyphenols, and other secondary metabolites, which contribute to its potential health benefits. Based on the findings of this study, kombucha exhibits antioxidant, antimicrobial, and anti-inflammatory properties, as well as plays a role in gut microbiota modulation. Its antioxidant activity is mainly attributed to polyphenols and organic acids produced during fermentation, which help counteract oxidative stress and inflammation in the body. The antimicrobial effects of kombucha are primarily due to acetic acid and other bioactive compounds that inhibit the growth of certain pathogens. Additionally, the presence of probiotic microorganisms in kombucha supports gut microbiota balance, positively influencing digestive health and immune function.

Considering these findings, kombucha has the potential to serve as a functional beverage that promotes health. However, further research with broader and more controlled methodologies is necessary to ensure its efficacy and long-term safety.

The findings of the analysis, discussion, and conclusion lead the researchers to recommend that more studies be done with a wider range of age groups and in diverse settings. More representative and diversified results are anticipated as a result. In addition, additional research is required to take into account other variables that have not been examined by earlier researchers but may be related to the development of dyspepsia. Thus, we can gain a deeper and more thorough understanding of the connection between eating spicy food and dyspepsia.

CONFLICT OF INTEREST

The author declares that there was no conflict of interest.

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