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Research Article

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Effects of Kombucha Tea Consumption on Human Health

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Abstract Kombucha tea is a popular beverage consumed worldwide, available both commercially and homemade. It is enjoyed for its refreshing taste, the antioxidant properties derived from tea extracts, and the beneficial effects of fermentative bacteria, which also possess antioxidant properties. Traditionally, black tea, oolong tea, and green tea have been the main substrates used for kombucha fermentation. However, alternative ingredients such as Jerusalem artichoke tuber extracts, wine, milk, fruit juices, plant infusions, as well as black carrot juice concentrate, cherry laurel, blackthorn, and red raspberry can also be utilized.

Consumption of kombucha has been associated with positive effects on gastric, intestinal, and glandular activities, as well as potential therapeutic applications in arteriosclerosis, toxin excretion, diabetes, nervousness, rheumatism, intestinal disorders, aging-related issues, and cancer treatment. However, it is important to note that the available evidence raises concerns regarding potential health risks associated with kombucha tea, especially for individuals with compromised immune systems. The risk of contamination is higher when fermentation is conducted under non-aseptic conditions. Therefore, strict adherence to hygiene practices during production is crucial.

This review provides a comprehensive overview of kombucha, including its preparation methods, its potential health benefits and risks, and relevant research studies conducted in this field.

Keywords Kombucha, human health, fermentation, functional beverage

1. Introduction

Kombucha has been recognized as a beneficial health aid for centuries [1]. Classified as a functional beverage, kombucha tea offers health benefits beyond its nutritional value. It is characterized by a sour, slightly fruity taste with delicate sparkling notes, although its flavor may evolve into something similar to wine vinegar after a few days of storage [2]. The demand for kombucha as a functional beverage is on the rise due to its superior nutritional properties. The global kombucha market has experienced rapid growth, with a compound annual growth rate of 23% between 2014 and 2018, and it is projected to continue growing rapidly in the next five years [3].

Kombucha is typically produced by fermenting sweetened tea liquor using a symbiotic microbial consortium consisting of various acetic acid bacteria, yeasts, and sometimes lactic acid bacteria [4]. Black tea, oolong tea, and green tea are commonly used in kombucha fermentation. The composition of bioactive compounds and the resulting biological activities are influenced by the type of tea used, although the specific strains of the Symbiotic Culture of Bacteria and Yeast (SCOBY) and their fermentation time have not been definitively linked to tea type. Green tea, in particular, is rich in polyphenols, including epigallocatechin-3-gallate (EGCG), one of the strongest antioxidants in kombucha, owing to its higher content of polyphenols compared to black tea and oolong tea [5]. The phenolic substances found in tea leaves used for kombucha production also exhibit antimicrobial effects on various microorganisms [6,7].

The symbiotic life of bacteria and yeasts occurs within the cellulosic film layer, which thickens as fermentation progresses. This layer provides necessary oxygen for the microorganisms [8, 9]. The microorganisms in the film layer, including Gram-negative aerobic bacilli, yeasts, and lactic acid bacteria from the Acetobacteraceae family, play a crucial role in kombucha fermentation [8, 9]. As fermentation progresses, these microorganisms convert phenolic compounds in tea leaves into free phenolics, producing beneficial fermentation products such as organic acids, vitamins, and minerals that contribute to the health properties and sensory characteristics of the final product [10, 11]. The specific metabolites formed depend on the tea leaf variety, the microorganism strains within the symbiotic culture, and the fermentation conditions [4, 12, 13].

During kombucha production, a bacterial cellulose matrix known as SCOBY is added to the sweetened tea, providing a habitat for the bacteria and yeasts responsible for fermentation. The microbial composition of kombucha varies depending on the inoculum source and other factors, making it difficult to provide a definitive report on the microorganisms present. Yeasts isolated from kombucha belong to several species and genera, including Saccharomyces, Saccharomycodes, Schizosaccharomyces, Zygosaccharomyces, Brettanomyces/Dekkera, Candida, Torulaspora, Kloeckera/Hanseniaspora, Pichia, Torula, Torulopsis, Mycotorula, and Mycoderma. The predominant bacteria are those that produce acetic acid, primarily belonging to the genera Acetobacter, Gluconobacter, and Gluconacetobacter [13, 14]. Table 1 provides microbiological analysis results of kombucha teas produced from different herbal teas, as reported in previous studies.

Kombucha tea is a beverage that offers health benefits beyond its inherent nutritional value. It is known for its sour, slightly fruity taste with delicate sparkling notes. However, with prolonged storage, its flavor may evolve and become reminiscent of wine vinegar [2]. The demand for kombucha as a functional beverage is on the rise due to its exceptional nutritional properties. The global kombucha market has witnessed rapid growth, with a compound annual growth rate of 23% between 2014 and 2018, and this trend is expected to continue over the next five years [3].

Kombucha is typically produced by fermenting sweetened tea liquor using a symbiotic microbial consortium consisting of various acetic acid bacteria, yeasts, and sometimes lactic acid bacteria [4]. The main teas used in kombucha fermentation are black tea, oolong tea, and green tea. The composition of bioactive compounds and the resulting biological activities depend on the type of tea used. Green tea, in particular, has a higher content of polyphenols compared to black tea and oolong tea, which contributes to its stronger health-promoting properties, particularly due to the presence of epigallocatechin-3-gallate (EGCG), one of the most potent antioxidants in kombucha [5].

The phenolic substances found in the tea leaves used for kombucha production also exhibit antimicrobial effects on various microorganisms, including Aeromonas, Bacillus, Clostridium botulinum, Clostridium perfringens, Enterobacter, Klebsiella, Proteus, Pseudomonas, Shigella, Staphylococcus aureus, and Streptococcus [6,7]. The fermentation of kombucha tea occurs in a cellulosic film layer where symbiotic bacteria and yeasts reside. This layer consists of gram-negative aerobic bacilli, yeasts, and lactic acid bacteria from the Acetobacteraceae family [8, 9]. As fermentation progresses, this cellulose structure thickens and provides the necessary oxygen for the microorganisms [10, 11]. These microorganisms convert phenolic compounds in the tea leaves into free phenolics and produce beneficial fermentation products such as organic acids, vitamins, and minerals that contribute to the health properties and sensory characteristics of the product. The specific metabolites formed depend on the tea variety, the microbial composition in the symbiotic culture, and the fermentation conditions [4, 12, 13].

To initiate fermentation, a bacterial cellulose matrix called SCOBY (Symbiotic Culture of Bacteria and Yeast) is added to the sweetened tea. However, the microbial composition of kombucha can vary depending on the source of the inoculum and other factors. Yeasts isolated from kombucha belong to various species, primarily including Saccharomyces, Saccharomycodes, Schizosaccharomyces, Zygosaccharomyces, Brettanomyces/Dekkera, Candida, Torulaspora, Kloeckera/Hanseniaspora, Pichia, Torula, Torulopsis, Mycotorula, and Mycoderma. The predominant bacteria responsible for acetic acid production belong mainly to the genera Acetobacter, Gluconobacter, and Gluconacetobacter [13, 14]. The microbial composition of kombucha can vary depending on factors such as the type of tea used, fermentation conditions, and other environmental factors.

Green and black tea have gained significant attention as functional beverages in recent years due to their high content of functional compounds, including polyphenols, flavonoids, and saponins [19]. Kombucha, being derived from tea, also contains these bioactive compounds, and their levels generally increase during the fermentation process [20, 21]. The oxidation of polyphenolic compounds in kombucha leads to the formation of beneficial compounds for the body, such as catechins, flavonoids, and other derivatives [4, 22, 23].

Table 1. Microbiological analysis results of kombucha teas produced from different plant oils.

	Total Bactria log cfu/ml	**Lactobacilli log cfu/mL**	**Lactococci log cfu/mL**	**Yeast log cfu/mL**	**Acetic acid bacteria log cfu/mL**	**Ferm. days**	**Ref.**
Black Tea	4.16-7.04	5.56-7.08	5.00-5.37	2.48-7.78	2.00-7.90	7-15	[15-18]
Green Tea	-	6.26-6.65	5.03-6.30	6.23-7.64	4.49-7.90	7-15	[15,16]
Oolong Tea	-	-	-	7.74	7.54	15	[16]
Mint tea	-	5.37-5.98	4.97-5.70	4.97-5.77	2.98-5.77	7-14	[15]
Linden Tea	-	6.12-6.50	4.01-5.61	5.86-6.90	2.22-4.79	7-14	[15]
Sage tea	-	5.56-6.22	6.01-6.05	6.04-6.19	5.53-6.13	7-14	[15]
Black Tea+ Origanum bilgeri	6.23-7.46	6.64-8.20	-	5.20-7.15	5.97-7.15	7-14	[17]
O. basilicum L.	3.94	-	-	2.30	-	10	[18]

The composition of kombucha is diverse, encompassing a wide range of chemical compounds. It contains organic acids, with acetic acid, gluconic acid, glucuronic acid, citric acid, L-lactic acid, malic acid, tartaric acid, malonic acid, oxalic acid, succinic acid, pyruvic acid, and usnic acid being the main acids present. Sugars like sucrose, glucose, and fructose are also found in kombucha. Additionally, it contains water-soluble vitamins, amino acids, biogenic amines, purines, pigments, lipids, proteins, hydrolytic enzymes, ethanol, carbon dioxide, polyphenols, minerals (such as manganese, iron, nickel, copper, zinc, lead, cobalt, chromium, and cadmium), anions (including fluoride, chloride, bromide, iodide, nitrate, phosphate, and sulfate), D-saccharic acid-1,4-lactone, and metabolic products of yeasts and bacteria [10].

These components contribute to the unique nutritional and sensory properties of kombucha, and their concentrations may vary depending on the fermentation conditions and the specific ingredients used.

2. Methodology

Preparation of kombucha tea

Kombucha is prepared by fermenting sweetened black or green tea with a consortium of acetic acid bacteria and yeast [24]. The standard procedure for making kombucha involves boiling tap water (1 L) and stirring in 50 g of sucrose during boiling. Then, 5 g of tea leaves are added and filtered out after 5 minutes. Once the tea cools to room temperature (20 ºC), it is inoculated with 24 g of tea fungus (the culture) and transferred to a sterilized beaker (1 L) using boiling water. To inhibit the growth of undesirable microorganisms, 0.2 L of previously fermented kombucha is added, which helps lower the pH [13]. The tea fungus (SCOBY) is placed on the surface of the tea, and the jar is covered with a clean cloth and secured tightly. The preparation is then incubated at room temperature (20 ºC-30 ºC) for 7-10 days [25]. During fermentation, a daughter tea fungus forms on the surface of the tea, and it can be separated and kept in a small volume of fermented tea. The beverage is strained through cheesecloth and stored in capped bottles at 4 ºC.

The taste of kombucha undergoes changes during fermentation. It starts with a pleasant, lightly sparkling, and slightly fruity sour flavor after a few days. With prolonged incubation, the taste transitions to a mild vinegar-like flavor [2, 26]. However, if fermentation exceeds 10 days, the beverage can become unpleasant and taste more like vinegar [26]. It's important to maintain sanitation practices to prevent the growth of harmful bacteria. While the low pH of kombucha can inhibit various pathogenic bacteria, it has been reported that unsanitary fermentation conditions can lead to the presence of bacteria like *Bacillus anthrax*, as well as fungi such as *Penicillium* and *Aspergillus* in kombucha [27].

In this study, previous research on kombucha tea was compiled, and the important findings were summarized. The preparation method, fermentation process, taste changes, and potential risks associated with unsanitary conditions were discussed.

Previous Studies on Kombucha Tea

The composition of kombucha is influenced by various factors such as the type of material used, the amount of material used, fermentation time, and fermentation conditions.

In a study by Chun et al. [28], kombucha made from Zijuan tea (sun-dried leaves) received higher sensory scores for color and general acceptability compared to kombucha made from Longjing green tea and Keemun black tea. The attractive color of Zijuan tea makes it suitable for preparing kombucha with appealing color and potential health benefits. Barbosa et al. [29] explored the use of blueberry as an alternative substrate for kombucha fermentation. They found that using blueberry led to increased phenolic compounds, tannins, and anthocyanins in the fermented beverage. However, the fermentation process resulted in a decrease in antioxidant activity compared to the unfermented beverage. The study also reported gastroprotective effects of the fermented blueberry kombucha, although further research is needed to fully understand its antioxidant potential and gastroprotective effects. Değirmenci et al. [11] investigated kombucha tea produced using Pu-erh tea leaves. They found that kombucha made from Pu-erh tea exhibited the highest antibacterial effect against investigated microorganisms such as *Staphylococcus spp*., *Salmonella spp*., *Listeria monocytogenes*, and *E. coli*. A study by [17] examined the use of *Origanum bilgeri*, an herb endemic to Antalya and commonly used in traditional medicine, in the production of kombucha tea. The study found that kombucha tea prepared with the addition of *O. bilgeri* exhibited antioxidant activity similar to traditional kombucha. Additionally, it had a higher total flavonoid and phenolic content compared to traditional kombucha. Furthermore, the *O. bilgeri* added kombucha showed antibacterial effects against bacterial strains that traditional kombucha did not have an effect on. The sensory analysis also indicated positive acceptance of the *O. bilgeri* kombucha. Ulusoy and Tamer [30] produced kombucha beverages using various substrates, including green tea, cherry laurel, blackthorn, black carrot juice concentrate, and red raspberry. They found that the total phenolic content and antioxidant activities of the kombucha products increased compared to the uncultivated substrates. However, the total monomeric anthocyanin content decreased during storage. The study suggested that using different raw materials in combination with green tea improved the antioxidant capacity of the beverages, with black carrot juice concentrate, cherry laurel, blackthorn, and red raspberry identified as alternative substrate sources for functional fermented beverages. Yıkmış and Tuğgüm [18] evaluated the physicochemical changes, bioactive components, microbial quality, and sensory properties of kombucha produced from black tea and different proportions of purple basil (Ocimum basilicum L.). The study found that incorporating purple basil into kombucha positively affected the bioactive components and antioxidant capacity of the beverage. Purple basil kombucha exhibited higher phenolic content and antioxidant activity, suggesting its potential as a functional beverage with enhanced health benefits. In their study, Ahmed et al. [31] conducted research on the production of three different types of kombucha using black tea, rice, and barley as substrates. The objective was to compare the biological and chemical properties, along with the antioxidant activity of these kombucha variations. The findings revealed that black tea kombucha exhibited superior biological properties when compared to rice kombucha and barley kombucha. This was evident through higher counts of yeast and acetic acid bacteria, mushroom dry weight, and total protein content in the black tea kombucha. Furthermore, the chemical properties, including acetic acid and ethanol content, were also found to be higher in black tea kombucha. Notably, black tea kombucha demonstrated a significantly greater antioxidant activity against DPPH (2,2-diphenyl-1-picrylhydrazyl) compared to the other types of kombucha. The antioxidant activity of black tea kombucha was approximately three times higher than that of rice kombucha and barley kombucha. These results suggest that black tea serves as a more favorable substrate for kombucha production, leading to improved biological and chemical properties, as well as enhanced antioxidant activity, in comparison to rice and barley substrates. In a study by Leonarski et al. [32], kombucha beverages were prepared using an acerola (Malpighia emarginata) by-product at various concentrations (1%, 3%, and 5%). The researchers noted that as the concentration of the acerola by-product increased, the levels of polyphenols and vitamin C in the beverage also increased. These beneficial compounds are naturally found in acerola fruit, and their presence was enhanced with higher concentrations of the by-product. Kayişoğlu and Coşkun [33] conducted a study where kombucha was produced using various herbal teas, including black tea, green tea, mint tea (*Mentha piperita* L.), linden tea (*Tilia cordata*), and sage tea (*Salvia fruticosa Mill*). The fermentation process lasted for 14 days. After fermentation, the kombucha prepared with mint tea exhibited the highest phenolic content, followed by the kombucha prepared with green tea. Sensory evaluation results revealed that the kombucha prepared with mint tea was the most preferred among the participants, with the kombucha prepared with sage tea following closely behind.

These studies demonstrate how different materials used in kombucha production can affect its composition, including sensory attributes, antioxidant properties, antibacterial effects, and bioactive components. It highlights the potential for utilizing various substrates to create unique kombucha products with enhanced health benefits.

Table 2 provides information on the total polyphenol content, total flavonoid content, and antioxidant capacities of kombucha prepared from different herbal teas in previous studies.

Table 2: Total Polyphenols Content, total Flavonoids and antioxidant capacities determined in the kombucha tea prepared from different herbal teas.

	Total Flavonoids Content (TFC) mg/L	**DPPH (%)**	**Total Polyphenols Content (TPC) mg/L**	**Antioxidant activity %**	**References**
Black Tea	20.45-126.7	61.04-70.63	63-1469	~73	[17,18,31,33,47]
Green Tea	146.8-181.3	88.23-91.40	116.8-320.1	-	[45,33]
White tea	83.8-111.6	70.42-79.13	205.6-228.1	-	[45]
Red Tea	198.1-242.5	74.84-77.37	270.5-271.9	-	[45]
Black Tea+ Origanum bilgeri	68 µ/ml-74 µ/ml	62	1614-1730	-	[17]
Origanum bilgeri	44 µ/ml-46 µ/ml	58-61	1240-1245	-	[17]
Ocimum basilicum L.	30.45	66.23	263.92	-	[18]
Mint tea	-	-	189.55	-	[33]
Linden Tea	-	-	16.06	-	[33]
Sage tea	-	-	2.54	-	[33]
Rice	-	-	~27	~37	[31]
Barley	-	-	~66	~62	[31]

3. Discussion

Benefits of kombucha tea

Kombucha has gained significant popularity as a functional beverage in the health food industry and is frequently included in alternative medicine practices. With the expected continued growth in kombucha consumption, it is crucial to provide accurate information to both individual consumers and commercial distributors about the proper care and cultivation of this unique symbiotic culture, as well as its potential medicinal properties [1]. The microbial activity in kombucha plays a crucial role in the biochemical reactions that occur within the human body. Research suggests that kombucha may have preventive effects against chronic diseases and exhibit various beneficial properties, including anti-hyperglycemic, antimicrobial, antioxidant, anticarcinogenic, and anti-hyperlipidemic effects, as demonstrated in experimental models [34]. Kombucha has been shown to possess antimicrobial activity against pathogens, indicating its potential as a natural antimicrobial agent [35]. The antimicrobial properties of kombucha are well-documented in scientific literature. Studies have attributed the antibacterial effects of fermented teas to organic acids, especially acetic acid resulting from the low pH, as well as large proteins and catechins [21, 36]. Additionally, unfermented teas have also demonstrated antibacterial properties [37]. Kombucha tea has gained a reputation as an ultimate health drink and is often considered a therapeutic agent for various conditions, including rheumatism, intestinal disorders, and cancer [38]. Reports suggest that the consumption of kombucha may have positive effects on the blood pH of cancer patients, potentially helping to rebalance it. Furthermore, kombucha is believed to have beneficial effects in preventing conditions such as headache, nervousness, insomnia, geriatric depression, and epilepsy crises [39]. One of the reasons for these perceived benefits is the presence of probiotics in kombucha, which contribute to its overall health-promoting properties. Kombucha is derived from the fermentation of tea, which leads to changes in the composition and concentration of its beneficial compounds [40]. It is worth noting that tea is a widely consumed beverage enjoyed by people from all walks of life. In addition to its probiotic content, kombucha has been shown to have effects on immune responses and liver detoxification [41]. It is believed to regulate intestinal flora, strengthen cells, help maintain acid-alkaline balance in the body, and even act as a natural antibiotic [42]. Kombucha is not only known for its potential health benefits but also for its refreshing taste, leading consumers to perceive it as beneficial for digestion when consumed regularly [25]. One important aspect that contributes to the health-promoting properties of kombucha tea is its probiotic nature, which is a result of the presence of living microorganisms [43]. These beneficial microorganisms are believed to play a role in supporting gut health. In terms of antioxidant properties, fermented kombucha tea has been found to contain main antioxidants such as polyphenols, vitamins, and organic acids derived from tea fungus metabolites [44]. As a result, fermented kombucha tea typically exhibits higher antioxidant potential compared to non-fermented tea. This suggests that kombucha shares similar health benefits to tea while also providing beneficial probiotics. The fermentation process of kombucha involves the symbiotic action of various microorganisms, primarily acetic acid bacteria and yeasts, and occasionally lactic acid bacteria, in a sugared tea liquor [4]. n a study conducted by Kaewkod et al. [16], kombucha prepared from green tea and black tea showed toxicity towards Caco-2 colorectal cancer cells. These findings suggest that kombucha tea has the potential to provide health benefits by inhibiting pathogenic enteric bacteria and promoting the healthy function of the gastrointestinal tract. Additionally, kombucha exhibited antioxidant activity against DPPH radicals, further highlighting its potential as a source of compounds with antioxidant properties and inhibitory effects on pathogenic enteric bacteria, as well as selective toxicity towards colorectal cancer cells. Furthermore, Ivanisova et al. [23] found that kombucha beverage can serve as a source of alternative medicine, offering health benefits to the human body. While the exact mechanisms underlying these potential therapeutic effects are still being studied, the rich composition of kombucha, including its organic acids, enzymes, and antioxidants, may contribute to its perceived health benefits.

Negative aspects of Cambodian tea

While kombucha teas are often believed to have health benefits, it is important to note that several metareviews of published literature have found that the purported health benefits of kombucha are not supported by well-designed, controlled clinical trials [46]. In fact, there is limited evidence suggesting that kombucha tea may pose serious health risks, particularly for individuals with compromised immune systems. Consumption of this tea should be discouraged due to the potential risk of life-threatening lactic acidosis. Case reports have highlighted instances of severe hepatic dysfunction and lactic acidosis occurring shortly after the ingestion of kombucha tea. Microbiological studies have also detected various types of yeast and bacteria, including Aspergillus, during the fermentation process. Furthermore, the use of lead-based ceramic pots for fermenting kombucha tea has been associated with lead toxicity. It is worth noting that kombucha's acidity (pH 2.5) inhibits the growth of many microorganisms, including pathogens. Some individuals have reported adverse effects such as dizziness and nausea after consuming certain kombucha products. Additionally, there have been cases of unexplained severe illness following kombucha consumption. Pregnant and lactating women are advised against consuming kombucha due to the risk of lead poisoning and gastrointestinal toxicity, which has been observed in some individuals. The presence of *anthrax Bacillus* has also been reported in kombucha tea fermented under unhygienic conditions [27]. Homemade kombucha tea has been associated with dizziness, headache, nausea, and allergic reactions. Therefore, caution should be exercised when consuming kombucha, particularly for individuals in vulnerable populations [13].

4. Conclusion

In conclusion, kombucha beverage, with its microbiological activity and beneficial properties, plays a significant role in biochemical reactions in the human body. While kombucha is gaining popularity due to its delicious taste and the antioxidant properties of tea extracts and fermentative bacteria, it is important to note that some published studies have cast doubt on its supposed health benefits. It has been found that kombucha tea may pose serious health risks, especially for individuals with weakened immune systems. Therefore, caution should be exercised, particularly when consuming homemade kombucha, as pathogenic microorganisms can contaminate the tea. Adherence to hygiene practices during production is crucial.

However, according to tests conducted by the U.S. Food and Drug Administration, kombucha tea has been deemed safe for human consumption. It is worth noting that kombucha is easy to propagate, non-toxic, and relatively affordable, making it an excellent choice for those who enjoy its taste and potential health benefits. It is advisable for individuals to stay informed about the latest research findings and consult with healthcare professionals for personalized advice regarding the consumption of kombucha.

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