

Review

Augmenting Kombucha's Health Benefits with Plant and Honey Bioactive Molecules Enrichment

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Abstract

Kombucha, a traditionally fermented tea, has gained increasing scientific and commercial interest due to its sensory quality and bioactive metabolites profile associated with different health-related activities. Recent research highlights the value of enriching traditional and honey kombucha with plant-based biomolecules to create new functional beverages with enhanced functional and nutraceutical properties, improved flavor, and chemical stability. Therefore, this study aimed to review and update the research on the enrichment of kombucha with these natural biomolecules that have been shown to expand the spectrum of health-promoting activities (e.g., antioxidant, antimicrobial, anticancer, and anti-aging), while also enhancing the physicochemical stability of raw kombucha. Yet this innovation must be navigated with a thoughtful understanding of safety, biochemical stability, and sensory evaluation. Thus, this review strongly advocates that the integrative enrichment approach presents a promising strategy for developing next-generation functional beverages with synergistic nutritional and therapeutic benefits. Further controlled studies are needed to elucidate the mechanistic interactions between the kombucha's microbiome and these added bioactive substrates, as well as to optimize formulations for targeted health applications.

Keywords: kombucha; plant and herbal medicine enrichment; honey substrate; nutraceuticals; safety and sensory considerations

1. Introduction

Kombucha has gained global popularity not only for its refreshing and buoyant natural acidity but also for its association with gut health, antioxidant and anti-inflammatory activity, and mild antimicrobial effects. This is a traditional beverage made from sweetened tea through the fermentation metabolic activity of a microbial culture composed of bacteria and yeasts [1]. Kombucha production relies on a consortium of different species of acetic acid bacteria (AAB), osmophilic yeasts, and lactic acid bacteria (LAB) fixed in a cellulose matrix known as the “symbiotic colony of bacteria and yeast” (SCOBY). The beverage has attracted increased scientific and commercial interest due to its complex composition, which usually includes organic acids, vitamins, minerals, amino acids, and typically bioactive polyphenols. These components are used in new products with functional effects, known as postbiotics [2]. They have been associated with antioxidant, anti-inflammatory, antimicrobial, and potential metabolic regulatory effects, making kombucha a promising



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functional beverage within the broader category of health-promoting foods. Modulating humans' microbiota profile is an emerging trend that could provide nutraceutical benefits through innovative postbiotic products [1,3].

Despite its growing popularity, the health benefits of traditional kombucha mainly depend on substrate composition, fermentation conditions, and post-fermentation processes used for industrial valorization. There is a long history of research on kombucha where standard recipes are usually made with black or green tea and sucrose [4,5]. However, this may limit the variety and amount of bioactive compounds available to consumers [6]. Improving kombucha by adding plant parts (e.g., flowers, leaves, vegetal waste obtained from food industry) or botanical extracts and natural sweeteners, such as honey, offers a promising way to enhance both its functional benefits and sensory qualities. Plants and herbal medicines are rich in polyphenols, flavonoids, terpenes, and other phytochemicals known to influence oxidative stress, low-grade inflammation, and gut microbiota composition. When added to kombucha, these compounds can interact with fermentation-derived metabolites, enhancing antioxidant capacity and broadening biological activities. Honey, beyond serving as an alternative carbohydrate source, contains enzymes, phenolic compounds, and prebiotic oligosaccharides that support SCOBY microbial growth and provide additional health benefits [7,8].

Fermenting different non-traditional substrates represents an interesting and attractive opportunity to develop new beverages with functional properties. Different raw material (e.g., milk, fruit, vegetables, and herbs or different combinations of plant teas) have been fermented with SCOBY consortium and consumed as kombucha beverages providing different pharmacological effects, such as antioxidant, antimicrobial, anti-inflammatory and immunomodulatory, anticancer, and metabolic effects (antidiabetic, antihypertensive, and antihyperlipidemic) [9–11]. The biotransformation of phytochemicals, especially phenolic compounds from plant tea, is the main source of new bioactive chemical forms of nutraceutical molecules. For these techniques, carefully adjusting the original substrate is essential to adapt the culture to new substrates [7,8]. Therefore, another strategy is based on fermenting traditional tea substrate with various enrichment substrates (e.g., fruits, vegetables, medicinal plants, honey), obtaining a flavored beverage that has gained popularity. Thus, enriching kombucha with bioactive molecules from plant and honey could create new functional beverages with tailored bioactive profiles, improved flavor, and chemical stability [12]. However, augmenting kombucha by fermenting different substrates or enriching with exogenous bioactive compounds requires rigorous evaluation across three domains: microbial and toxicological safety, molecular and colloidal stability, and sensory performance. These interdependent factors ultimately determine whether improved kombucha remains both safe for consumption and functionally efficacious.

This study explores the scientific principles, technical aspects, and possible health benefits of the enrichment method, providing a comprehensive view of how kombucha can evolve from a traditional fermented tea into a versatile platform for delivering phytochemicals and other natural bioactive compounds produced through microbial fermentation. Additionally, this study documents whether enriching traditional and honey kombucha with plant-based biomolecules will create new functional beverages with enhanced functional and nutraceutical properties, improved flavor and chemical stability.

Our methodology involved searching online databases such as Web of Sciences, Scopus, Springer Link, Wiley, ScienceDirect, and Google Scholar for studies related to kombucha enrichment and health-related effects. The main search keywords included "kombucha plant," "kombucha honey," "kombucha enrichment," "flavored kombucha," "kombucha health benefits," "kombucha nutraceutical," and "kombucha fermentation." After the initial search, results were screened using a hierarchical approach based on titles,

abstracts, and full texts, while excluding letters to editors, editorials, book reviews, and protocols. The selected studies focused specifically on enriched kombucha containing biomolecules from plants and honey, as well as their health-related effects, while fermentations of different non-traditional substrates were excluded. All relevant articles were evaluated according to their content, publication year, and relevance to this review.

2. Role of Honey and Plant Bioactive Molecules Enrichment in Boosting Kombucha's Bioactivities

Augmenting kombucha by plant bioactives enrichment offers a promising path to boost its nutritional and functional value, as well as improve the stability of the fermented product or its sensory qualities. The biological activity of plant-enriched kombucha strongly depends on the type of tea substrate and the type of plant material (e.g., fruits, herbs, spices, flowers) used as enrichment, along with its phytochemical profile. These factors in turn influence the substrates available for microbial metabolism during fermentation. The main carbon source for traditional sweetened tea fermentation is sucrose, but honey might be an efficient alternative to refined sucrose in kombucha fermentation [8].

Tea substrate is especially critical because green, black, and oolong teas differ markedly in total phenolic content (TPC) and polyphenolic composition, affecting interactions with added bioactives and the fermentation-derived metabolites obtained. Green tea, due to its higher catechin and epicatechin composition, consistently yields higher antioxidant and cytotoxic effects after fermentation than darker teas [13]. Black tea is considered a fully fermented form of tea with barely higher caffeine content, lower TPC and flavonoids (total flavonoid contents—TFC) compared to green tea. The theaflavins and thearubigins are new compounds produced during black tea fermentation by catechins' oxidation, and both offer significant anti-inflammatory and antioxidant health benefits. Compared to green and black tea, oolong (semi-oxidized) tea offers a blend with more complex polymerized compounds during partial oxidation and unique antioxidants, such as theasinesins [11]. Moreover, the tea substrate influences microbial fermentation, as oolong tea supports balanced fermentation kinetics, while green tea tends to induce faster acidification due to higher catechin availability, and black tea polyphenols improve SCOBY stability and produce a robust cellulose matrix [13,14]. Therefore, compounds that are obtained during the production processes of different types of tea markedly affect the composition of the bioactive molecules that are found in kombucha tea [13]. Additionally, it is important to mention that the compatibility with botanical enrichment could be influenced by the tea substrate. Most studies were performed with black and green teas as substrates for kombucha fermentation, although oolong tea offers the most balanced platform for botanical enrichment. Based on the bioactives composition, it can be suggested that black tea substrate for plant-enriched kombucha provides the most stable matrix for bioactive molecules preservation, while green tea yields the highest antioxidant enhancement while increasing formulation challenges.

To increase health benefits and bioactive contents, different medicinal plants and spices have been used as enrichment, such as *Terminalia catappa* L., *Aegle marmelos* L. [15], minth, hibiscus, *Clitoria ternatea* [16,17], cinnamon, cardamom, Shirazi thyme [18], *Humulus lupulus* L., *Polygonum cognatum*, and *Crataegus monogyna* [19–21]. Medicinal plants and culinary spices contain diverse functional bioactive components that exert pharmacological and physiological effects beyond basic nutrition. These components (e.g., polyphenols, alkaloids, terpenoids and essential oils) are primarily classified into secondary metabolites, which plants synthesize for defense and environmental adaptation, but which also confer therapeutic benefits in humans. Most studies used various fruits for kombucha enrichment, while vegetables (e.g., black carrot, garlic) were tested less. Fruits and vegetables contribute

a distinct biochemical profile dominated by dietary fibers and prebiotic substrates, vitamins, carotenoids and anthocyanins. They provide both nutritional and functional enrichment, unlike herbs which are primarily used for pharmacological purpose (Table 1). However, their bioactive molecules are often more sensitive to oxidation and fermentation degradation. Still, fruits and vegetables usually enhance the sensory properties (color, aroma, taste) of the fermented beverage, affecting consumer acceptance. A low number of studies used honey as a substrate and plant enrichment [22,23]. These functional components contribute to plant-enriched kombucha and can increase health benefits and improve the flavor and chemical stability of the beverages.

A comparative overview of plant-enriched kombuchas and their reported health benefits are presented in Table 1. Each enrichment category (medicinal plants, spices, fruits, vegetables and honey) introduces distinct classes of bioactive molecules, changing the fermentation dynamics and functional outcomes within the kombucha matrix. Therefore, the distinct biochemical profile of each enrichment could explain the differences in phytochemistry, fermentation interactions, and health-related effects.

The summarized studies reveal that methodological heterogeneity (e.g., in substrate and enrichment type, concentration, inoculum size, and fermentation parameters) strongly influences the reported biological activities, especially the antioxidant effect. Most studies assessed the antioxidant effect using various methods: 2,2-Diphenyl-1-picrylhydrazyl (DPPH) inhibition assay, ferric-reducing antioxidant power (FRAP) method, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) free radical scavenging capacities, and the CUPRAC (CUPric Reducing Antioxidant Capacity) method. The antioxidant activities of enriched kombucha are determined by the total phenolic concentration and mostly by the types of metabolites produced during fermentation that may have a decisive effect. The total phenolic concentration of the final product is influenced by the plant used as enrichment. Thus, the TPC was 3151 µg/mL for madimak-flavored kombucha, 291 mg/L for the hibiscus infusion enrichment, while in kombucha combined with *T. catappa* or *A. marmelos* the phenolic content varied between 37.55 ± 1.78 mg/mL and 23.15 ± 1.44 mg/mL [15,17,20]. Also, the phenolic profile at the end of fermentation is plant-specific. Thus, hibiscus, *T. catappa* and *A. marmelos* significantly increase the flavonoid content, mint and *Clitoria ternatea* produced phenolic acids and flavonoids, while gallic acid was the major phenolic compound in hop and hawthorn enriched kombucha and chlorogenic acid in madimak-flavored kombucha [15,17,19,20]. Therefore, there was a significant difference between the antioxidant activities of different plant-enriched kombuchas, but most of them showed higher antioxidant activity than traditional kombucha.

Table 1. Comparative overview of plant-enriched kombucha based on the substrate type, enrichment materials, fermentation strategies, and reported bioactivities.

No.	Substrate Type	Enrichment Type	Fermentation Parameters	Principal Findings	Reference
<i>Medicinal plants enriched kombucha</i>					
1	Green tea,	Medicinal plants: cinnamon (CIN), cardamom, Shirazi thyme (50:50 with green tea)	Fermentation 16 days, 28 °C	Increased TPC, organic acids, TFC, Elevated antioxidant activity (DPPH) antimicrobial effects against pathogens Effects were concentration-dependent CIN has the highest antioxidant and antimicrobial activities, more organic acids, and better sensorial scores	[18]
2	Black tea leaves	Plant extracts (500 mg/mL) from medicinal plants <i>Terminalia catappa</i> L. (KT) and <i>Aegle marmelos</i> (L.) (KA)	Fermentation 15 days	Higher the beneficial compounds, such as phenolics, various flavonoids and six organic acids Increase antioxidant activities Cytotoxicity against Caco-2 cells and induction of apoptosis signaling in colorectal cancer cells	[15]
3	Green tea Gunpowder variety, 70% (v/v)	Medicinal plant infusions 30% (v/v) from spearmint (<i>Mentha spicata</i> -K2), hibiscus (<i>Hibiscus sabdariffa</i> -K3), and butterfly pea (<i>Clitoria ternatea</i> -K4)	Fermentation 4 days, aerobic, 24 ± 1 °C, in a dark room (relative humidity of 60–70%)	Increased TPC Type of herbal infusion significantly modulate the composition of fermentation microbiota and the polyphenolic profile enhanced sensory properties	[17]
4	Oolong tea leaves	Kitchen mint leaves (<i>Mentha cordifolia</i> Opiz. Ex Fresen)	Fermentation 7–10 days	Increased antioxidant effect (DPPH and ABTS) Upregulated antioxidant enzymes (SOD, CAT, GPx)	[16]
<i>Fruit- and vegetable-enriched kombucha</i>					
5	Green tea	Amazonian fruits, cupuassu <i>Theobroma grandiflorum</i> (KC), tapereba <i>Spondias lutea</i> L.(KT) and bacuri <i>Platonia insignis</i> (KB) nectar or syrup (20% v/v)	Fermentation 1–3 days, without light	Physicochemical characterization (acetic acid in all flavored kombucha) KC with highest ethanol content Increased populations of mesophilic bacteria, yeast and molds KT with highest TPC antioxidant capacity and vitamin C	[24]

Table 1. Cont.

No.	Substrate Type	Enrichment Type	Fermentation Parameters	Principal Findings	Reference
6	Black tea	Pineapple peels and cores (PPC) as partial sugar substrate	Fermentation 14 days	Higher amounts of beneficial substances and volatile compounds that contributed to flavor, and beneficial health properties (e.g., sugars, polyphenols, organic acids, vitamins, minerals, esters, carboxylic acids, phenols, alcohols, aldehydes, ketones) Increased TPC and antioxidant activity Higher populations of <i>Acetobacter</i> and <i>Komagataeibacter</i> (AAB), <i>Bacillus</i> and yeast <i>Dekkera</i>	[25]
7	Green tea	Various fruit extracts (30%): grape, caja, cashew apple, genipap, passion fruit, tamarind	Fermentation 3 days	Phenolic profile analysis—25 phenolics and one caffeine derivative identified Tamarind kombucha with the highest flavonoid content	[26]
8	Green tea	Black carrot Konya vs. Hatay variety, carrot juice in two concentrations (10 and 20%) and 2 controls (control A—sucrose and SCOBY, control B—organic green tea leaves, sucrose, and SCOBY)	Fermentation 7 days	Increased TPC and antioxidant capacity Kombucha tea containing black carrot juice (20%) had the highest anthocyanin content, antioxidant capacity (ABTS, CUPRAC) and more bioaccessible phenolics TPC and antioxidant activity in carrot juice kombucha was 2–3 times higher compared to controls Hatay kombucha had a pleasant flavor and better color	[27]
9	Green tea	Cerrado fruits pulps (10% <i>v/v</i>) of the guavira (<i>Campomonesia adamantium</i>), and seriguela (<i>Spondias purpurea</i>)	Fermentation 14 days	Lower TPC than green kombucha (control) Guavira kombucha had superior antioxidant activity (ABTS, DPPH) compared to seriguela In all the formulations the counts of yeasts and LAB were higher than those of AAB	[28]

Table 1. Cont.

No.	Substrate Type	Enrichment Type	Fermentation Parameters	Principal Findings	Reference
10	Black tea	Fruit pulp from pitanga <i>Eugenia uniflora</i> L. (PFK) and umbu-cajá <i>Spondia tuberosa</i> (UCFK) (10–15% <i>v/v</i>)	Fermentation 7 days	Enhanced antioxidant activity and bioactives content (all kombuchas have acetic, butyric, citric, succinic, and malic acids, except for the malic acid in PFK) Terpenes were the main volatile compounds, epigallocatechin gallate in all beverages (above 63%) After in vitro gastrointestinal digestion, the phenolic contents antioxidant capacity reduced Sensory evaluation	[29]
11	Black tea	Indian gooseberry (<i>Phyllanthus emblica</i>) fruit homogenate 10–50% (<i>v/v</i>)	Fermentation 14 days, 25 °C	Increased TPC, TFC, and total acidity Detected several volatile organic compounds associated with the flavor, aroma, and health benefits Increased antioxidant and antimicrobial activities	[30]
<i>Kombucha enriched with hop</i>					
12	A mixture of ground tea leaves of green Sencha of Japanese origin (70% <i>w/w</i>) and black Yunnan of Chinese origin (30% <i>w/w</i>)	Polish aromatic Cascade hops (<i>Humulus lupulus</i> L.) 0.5–2 g/L added pre- or post-fermentation	Fermentation 7 days, 28 °C	Increased antioxidant activity (DPPH) Hop α -acids display higher antioxidative properties than polyphenols Pre-fermentation hop addition yielded highest oxidative stability Sensory evaluation of hop enriched the taste and increased the presence of fruity and citrusy aromas	[19]

Table 1. Cont.

No.	Substrate Type	Enrichment Type	Fermentation Parameters	Principal Findings	Reference
13	Black tea 5% dry black tea leaves (m/V)	Herbal infusion (prepared with 5% dry herbal leaves) of hop (<i>Humulus lupulus</i> L.) (KH), hamthorn <i>Polygonum cognatum</i> (KH), and madinaka <i>Crataegus monogyna</i> (KM)	Fermentation 14 days	Enhanced TPC, flavonoid content (highest KM) Antibacterial activity, with KM active against all six tested bacterial species Antioxidant activity (highest KH) Increased total counts in all samples, except for KHa Cellulose production (highest KHa) Cytotoxic effect (KM, KH) against two different cancer cell lines Sensory acceptance, KH rated as the tastiest of all beverages	[20]
14				HK attenuated genotoxicity induced by hydrogen peroxide MK reduced genotoxicity induced by hydrogen peroxide and potassium dichromate (VI) Lifespan-prolonging effects in <i>Drosophila melanogaster</i> after the treatment with H ₂ O ₂ and K ₂ Cr ₂ O ₇	[21]
Plant and honey kombucha					
15	Barry's gold tea (tea leaves from Rwanda, Kenya, and the Assam Valley of India)Acacia honey 7% (w/v) (HK) Sucrose 10% (w/v) (SK)	<i>Laminaria digitata</i> (brown seaweed), cinnamon, lavender and ginger (<i>Zingiber officinale</i> Roscoe)	Fermentation 7 days, 25 °C	HK higher titratable acidity and SCOBY weightSK higher alco- hol concentration Increased antioxidant activ- ity (DPPH, FRAP), especially in HK samplesHK higher Shelf- life studies for 3 months Sensory evaluation, higher acceptabil- ity for SK samples, with seaweed and cinnamon re- ceived the highest scores and ginger HK the lower accep- tance rate	[22]
16	Black tea 6 g/Lhoney (20 °Brix)	dried olive leaf (0–5%)	Fermentation 12 days, 30 ± 2 °C in dark condition	Higher TPC, hydrolysable extracts and antioxidant activity (ABTS)in sugar-based kombucha with olive leaf variants Higher bioavailability of phenols in the honey-based kombucha and olive leaves	[23]

Antimicrobial activities, especially antibacterial potential, cytotoxic and genotoxicity, were evaluated by few papers [15,18,20,30]. Antimicrobial activity in plant-enriched kombucha serves both as a health benefit and a safety function. Antimicrobial activity has a primary technological role as it contributes to microbial stability and product safety by inhibiting pathogenic and spoilage organisms. This effect arises from plant-derived antimicrobials (e.g., phenolics, essential oils), fermentation products that lower pH (e.g., acetic, lactic acids), and the production of ethanol or bacteriocin-like compounds. In this context, it is a food safety and preservation attribute, ensuring safe consumption and extended shelf-life. Moreover, enriched kombucha's antimicrobial activity against gastrointestinal pathogens or dysbiosis-associated microbes can be considered a functional health benefit.

Distinct enrichment strategies modulate kombucha's bioactivity through different dominant mechanisms, but little research has been done to understand these mechanisms. While all depend on the microbial–phytochemical interactions, the nature of these interactions varies with the plant enrichment source, type of substrate, and fermentation design. Despite growing evidence supporting the beneficial biological effects of fortified kombucha, several limitations constrain the strength and generalizability of existing findings. A substantial proportion of studies rely on in vitro experiments, while only one work tested the lifespan-prolonging effects of the hop-enriched kombucha in *Drosophila melanogaster* [21]. Although sensory evaluation was performed by some studies, no clinical trial has been reported to draw causal conclusions regarding the health-promoting activities of plant- and/or honey-enriched kombucha and to compare the results with the traditional beverage.

2.1. Characteristics and Health Benefits of Medicinal Plant and Herb Enrichment of Kombucha

Traditional tea-based kombucha (e.g., green, oolong, and black teas) remains the most studied baseline for medicinal plant-enriched kombucha. The addition of medicinal plants, herbs and spices induced physicochemical and microbiological modifications that further enhances kombucha's functional properties, especially antioxidant and antimicrobial activities [15–21]. The antiproliferative and cytotoxic effect on the cancer cell lines was investigated only by two studies, while hop-flavored kombucha was reported to protect the genome and prolong the lifespan of *Drosophila melanogaster* [15,21,24].

Studies employing tea-based kombucha and medicinal plant matrices proved that the species of plant significantly affects the fermentation process and the metabolite profile and subsequently influences the biological activities of kombucha, especially its antioxidant, antimicrobial and antitumoral potential. As previously reported [17], the enrichment with different herbal infusions influenced the level of converted sugars into fermentation products, with lower sugar consumption in the case of kombucha with hibiscus infusion (variant K3) and *Clitoria ternatea* (variant K4), compared to spearmint (variant K2); while the green tea infusion had the highest degree of sugar utilization [17]. Moreover, variant K2 with spearmint produced a beverage with the lowest caffeine content (114 mg/L). The kombucha with hibiscus infusion had the highest polyphenol content, especially catechins [17]. All flavored kombucha obtained showed consistent enhancement of antioxidant activity. The specific phytochemical composition of the mint plants, especially quercetin which was found in the highest concentration in the K2 samples (11.16 ± 0.75 mg/L), could explain the elevated antioxidant activity of mint-enriched kombucha, proven by different studies [16,17]. Similarly, it has been shown that kitchen mint-enriched oolong tea kombucha upregulated key antioxidant enzyme superoxide dismutase (SOD), catalase (CAT), and glutathione reductase (GPx) and increased radical scavenging activity, suggesting that plant-derived bioactives synergize with microbial metabolism to enhance cellular oxidative defenses [16]. Also, the concentration of phenolic compounds and flavonoids were increased in all kombucha samples (oolong tea, kitchen mint, and mixtures of both).

Antioxidant activity, measured by DPPH and ABTS methods, increased during the fermentation time, with the highest effect in the last day of fermentation (day 14). In addition, all kombucha samples exhibited an antioxidant effect by inducing the enzymatic activity of glutathione reductase in the HEK-293 cell line [16]. Fortification with spices and herbs such as cinnamon, cardamom, Shirazi thyme, *T. catappa*, *A. marmelos*, and mint modulated microbial metabolism to increase total phenolic content, organic acid contents and antioxidant activity of the final product [15,16,18]. Thus, consistent with earlier findings, supplemented kombucha with medicinal plant extracts from *T. catappa* (KT) and *A. marmelos* (KA) was reported to enhance antioxidant activity and polyphenol content, as well as the activation of apoptosis signaling pathways in colorectal cancer cells, indicating potential functional bioactivity beyond antioxidation [15]. The beneficial compounds that support the enhanced beneficial properties were phenolics, various flavonoids and six organic acids (glucuronic, gluconic, succinic, ascorbic and acetic acids, D-saccharic acid 1,4-lactone). Another study investigated kombucha enriched with medicinal plants including cinnamon (*Cinnamomum verum*), cardamom (*Elettaria cardamomum*), and Shirazi thyme (*Zataria multiflora*) at different concentrations, finding that plant type and concentration significantly influenced TPC, total flavonoid content, antioxidant capacity, antimicrobial activity against foodborne pathogens, and sensory properties [18]. The presence of higher amounts of acetic (2675.36 mg/L), malic, lactic, citric, and glucuronic acids explained the lowest pH observed in cinnamon-flavored kombucha (CIN variant) at the end of fermentation. The highest oxalic acid and malic acid contents was in the Shirazi thyme-flavored kombucha, with a milder antioxidant profile. At the end of fermentation, the TPC of CIN product was similar to the kombucha tea (0.582 mg GAE/mL) while lower TPCs were observed in the other kombuchas. Also, the CIN variant had strong inhibitory effects on *Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Staphylococcus aureus* that can be correlated with total flavonoid content (0.312 mg CTE/100 mL), while the cardamom-flavored kombucha demonstrated a the lower inhibitory effect [18]. Comparing kombucha containing 25% to 100% concentrations of cinnamon, the authors noted that increasing the medicinal plant concentration enlarged the amounts of organic acids and antioxidants, besides the higher antimicrobial activities [18]. The significant boost in the antimicrobial properties could be related to concentrated bioactive compounds, such as eugenol, cinnamaldehyde, and coumarin from cinnamon [31].

Addition of botanical substrates in kombucha influenced the fermentative microbiota SCOBY and the cellulose production, but few studies performed the microbiological analysis of kombucha beverages or the symbiotic consortium. Previously reported documents concluded that the lowest count of AAB were recorded in the kombucha variant with hibiscus infusion (K3) and the highest yeast, molds, and LAB population in the variant with butterfly pea infusion (variant K4) [17]. Still, the total viable counts were significantly lower in the K3 and K4 variants with infusions of plants with mild antimicrobial activity, compared to spearmint kombucha or green kombucha. Likewise, another study confirmed that the populations of AAB and yeast in kitchen mint-enriched kombucha had gradually raised during 7–14 days of fermentation [16]. These results highlighted the dual functional role of medicinal plants or spices as both bioactive enhancers and microbial modulators. The microbiological profiling of kombucha with herb infusion of hawthorn (KH_a), hop (KH), and madimak (KM) have demonstrated that the total counts increased in all samples except Kha, which has the highest cellulose production (10.23 ± 0.51 g/L) [20].

A number of studies evaluated medicinal plant-flavored kombuchas, including *Polygonum cognatum* L. (hawthorn—KH_a), *Humulus lupulus* L. (hop—KH), and *Crataegus monogyna* (madimak—KM) [19–21]. Consistent with earlier findings, they concluded that all herbal-enriched kombucha increased TPC and flavonoid content, with the highest TPC in

KM samples (3151 µg/mL) [20]. In this study, gallic acid was the major phenolic compound in all kombucha samples, except for KM where chlorogenic acid had a higher concentration. Also, a strong correlation between the increase in total flavonoid concentration and enhanced antioxidant and antimicrobial activities was found. Thus, KM demonstrated strong antimicrobial activity against all six tested bacterial species, while KH showed antibacterial effects against *Klebsiella pneumonia*, *Pseudomonas aeruginosa*, *Bacillus cereus*, *Staphylococcus epidermidis* and *Escherichia coli*; HaK showed effects against *S. aureus*, *S. epidermidis*, *B. cereus*, *K. pneumonia* and Gram-negative *E. coli*. Moreover, antiproliferative potential of KM and KH products has been assessed against cancer cell lines HCT116 and Mahlavu [20]. Moreover, hop-flavored kombucha attenuated genotoxicity induced by hydrogen peroxide, while madimak-flavored kombucha reduced genotoxicity induced by both hydrogen peroxide and potassium dichromate (VI) [21]. The authors concluded that the chlorogenic acid found in higher amounts in the KM product could be responsible for the antigenotoxic effects by reducing oxidative stress and maintaining enzymatic antioxidant activities. Two different works reported that hop-flavored kombucha increased antioxidant activity [19,21]. The last study demonstrated that fortification of kombucha with Cascade hops (*Humulus lupulus* L.) at 0.5–2 g/L, added either at the onset of tea infusion (pre-fermentation) or post-fermentation, significantly reduced radical formation compared to the control, with pre-fermentation addition yielding the highest oxidative stability. This reduction correlated with increased DPPH antiradical activity and elevated levels of bitter α -acids, suggesting that α -acids contribute more to antioxidative potency in this system than polyphenols [19]. Moreover, a new study demonstrated antigenotoxic, lifespan-prolonging and protective effects in vivo (*Drosophila* model), providing the benefits of hop-enriched kombucha [21]. However, additional studies that underscore the anti-aging and lifespan-prolonging effects of kombucha with these specific enrichments are required to evaluate the safety of the product and clarify the mechanism.

A more recent study highlighted the importance of fermentation strategy, showing that pre-fermentation addition of Cascade hops (0.5–2 g/L) maximized oxidative stability and antiradical capacity, while post-fermentation addition improved sensory properties. The research has indicated that both pre- and post-fermentation addition of hops enhances the antioxidative properties of the fermentative product. However, herbal addition in the pre-fermentation stage significantly reduced radical formation (measured by electron spin resonance spectroscopy) and enhanced oxidative stability of kombucha, suggesting that specific medicinal plant bioactives, particularly α -acids in hops, act as natural stabilizers by chelating pro-oxidant metal ions and protecting fermentation-derived phenolics from degradation [19]. Hops can be considered a relatively novel additive for kombucha, and this study proved the potential of hop bioactive molecules (e.g., polyphenols, α -acids, prenylflavonoids, xanthohumol, and essential oils) to stabilize the physicochemical properties of raw kombucha based on the increased content of antioxidant substances, which also demonstrated health benefits. Another paper reported that green tea kombucha enriched with various herbal additives maintained higher polyphenol levels and antioxidant capacity throughout fermentation, confirming the stabilizing effect of medicinal plants on both chemical composition and functional properties of enriched kombucha [17].

Collectively, these studies illustrate that medicinal and herbal plant enrichment have pronounced positive effects on beverage chemical composition, increasing their functional content, as well as the biological activities. Additionally, some herbs might be used for their health-related benefits to stabilize the physicochemical properties of unpasteurized kombucha and to flavor the beverages.

2.2. Characteristics and Health Benefits of Fruit and Vegetable Bioactive Molecules Enrichment of Kombucha

Across all studies related to the plant-enriched kombucha, SCOBY consortium evolution is closely linked to enrichment type (e.g., fruits, vegetables, food waste) and concentration, while the production of organic acids, phenolic metabolites, and other secondary compounds is enhanced when the microbial consortia metabolize substrates rich in polyphenols, sugars, and vitamins. These changes directly correlate with observed TPC and health-related activities, including antioxidant effect, antimicrobial properties, and other functional bioactivities [9,20,24,26].

Fruit-enriched kombucha typically introduces high levels of anthocyanins, flavonols, vitamin C, and natural sugars that stimulate yeast metabolism, leading to vigorous fermentation, enhanced ester formation, and elevated antioxidant capacity. Thus, in a recent study [24] three kombucha formulations were prepared using green tea and nectars of Amazonian fruits—taperebá (*Spondias lutea*), cupuaçu (*Theobroma grandiflorum* L.), and bacuri (*Platonia insignis*)—and the content of total phenolic compounds (TPC), vitamin C and antioxidant capacity ($\mu\text{mol TE/mL}$) were determined before and after addition of the nectars. The baseline fermentation shown TPC of 30.60 ± 0.93 mg GAE/L and antioxidant capacity of 295.02 ± 5.59 $\mu\text{mol TE/mL}$. All three fruit-enriched kombuchas demonstrated that the microbial consortia efficiently metabolize sugars while simultaneously extracting and transforming fruit polyphenols, resulting in increased TPC and ethanol. The taperebá formulation recorded higher values for TPC (34.92 ± 12.25 mg GAE/L), antioxidant capacity (320.57 ± 9.53 $\mu\text{mol TE/mL}$) and vitamin C (198.25 mg/100 g) among the tested fruits. Acetic acid was the most prevalent organic compound in enriched kombucha, while ethanol content was higher than in non-enriched kombucha as fruit pulps allowed the addition of sugars capable of promoting chemical transformation [24]. Kombucha's ethanol content generally ranges from 3.6 to 10 g/L, with cupuaçu kombucha being the most alcoholic. Moreover, this research demonstrated that enrichment with Amazonian fruit nectars can effectively raise both phenolic-based and ascorbate-based antioxidative metrics in kombucha formulations [24]. Microbiological assessment concluded that mesophilic bacteria, molds and yeast populations are similar in these three enriched kombuchas. Meanwhile, in enriched green tea kombucha with fruit pulps from Cerrado biome species (guavira and seriguela), fermented for 14 days, it was found that in all formulations the counts of yeasts and LAB ranged from 10^6 to 10^7 CFU/ mL and were higher than those of AAB [28]. Surprisingly, the total phenolic content was highest in the green kombucha control than in enriched kombucha, while the guavira kombucha exhibited superior antioxidant capacity relative to both seriguela and control [28]. Both Cerrado fruits enhanced ABTS and DPPH radical scavenging activity, despite modest increases in TPC, indicating that both fermentation-mediated metabolite transformation and the intrinsic bioactivity of the enrichment contribute to the antioxidant profile [28]. The guavira kombucha had volatile acidity within the legal standards. A recent study systematically investigated six kombucha beverages prepared from green tea, flavored with grape, cashew apple, passion fruit, caja, genipap, and tamarind [26]. The tamarind-flavored kombucha presented the highest flavonoid content (156.77 mg EQ/g) followed by the flavorings of passion fruit (150.57 mg EQ/g) and cashew (136.05 mg EQ/g). In the green kombucha and in the six flavored kombucha beverages, a total of twenty-six compounds were identified, including essential polyphenols, such as epicatechin, gallic acid, epicatechin gallate, and epigallocatechin. Similar, pitanga-flavored kombucha (PFK) and umbu-cajá-flavored kombucha (UCFK) have different metabolite profile with citric, succinic, acetic, butyric, and malic acids, except for the malic acid in PFK [29]. The main volatile compounds, terpenes, improved the sensorial profile of PFK and UCFK, as they contributed to the

appearance of/increase in new terpenoids (e.g., curzerene and β -caryophyllene). The most predominant phenolics in all beverages was epigallocatechin gallate (above 63%), and their presence increased antioxidant activity. Supplementing black tea kombucha with the Indian gooseberry (*Phyllanthus emblica* L.) fruit homogenate increased TPC and antioxidant activity, which might be correlated with high vitamin C content [30]. A reduction in sugar concentration was observed during the fermentation process, while the TFC and total acidity of the fermented beverages increased. Moreover, the antimicrobial activities of enriched kombucha beverages, specifically those produced from a high proportion of homogenates, were significantly greater. The high antimicrobial efficacy of kombucha supplemented with the Indian gooseberry against pathogenic microorganisms may be attributed to organic acid (e.g., acetic acid), polyphenol contents, high levels of vitamin C and several volatile compounds from the kombucha products [30]. Although the kombucha prepared by fusion black tea with low homogenate concentration (10–20% (v/v)) showed no antimicrobial activity against any of the tested microbes, the product demonstrated notable nutritional and health benefits.

A new strategy involving agro-food by-products highlights the potential of circular economy approaches in kombucha production. It has been shown that sugar substrate in black tea kombucha replaced with pineapple peels and cores (PPC) can be a sustainable utilization of food industry residues to enrich the beverage with additional nutrients [25]. A higher rate of sugar consumption in the PPC-enriched kombucha enhanced the growth and metabolic activities of the microbial community SCOBY. As results, the products had higher amounts of functional metabolites than the control kombucha, including volatile compounds that contributed to the flavor and had strong health benefits. Also, other beneficial compounds (e.g., sugars, organic acids, vitamins, polyphenols, minerals) were enhanced that could be related to the higher TPC and antioxidant activity of the PPC-enriched beverages [25]. Moreover, molecular biology analysis of SCOBY by next-generation sequencing demonstrated an increase in AAB species *Acetobacter* and *Komagataeibacter*, bacteria *Bacillus* spp. and yeast *Dekkera* spp. The enriched beverage variants exhibited vigorous antimicrobial activity against all tested pathogens, including Gram-negative bacteria (*A. hydrophila*, *E. coli*, *P. aeruginosa*, and *S. typhi*) and Gram-positive bacteria (*B. cereus*), compared to control kombucha. These findings underscore the dual role of such by-products in both functional enhancement and environmental sustainability.

In terms of vegetable enrichment, black carrot and garlic were shown to increase polyphenol content and antioxidant capacity. Recent reports have proven in that kombucha beverages containing black carrot juice (20%) from two varieties (Hatay, Konya), the vegetables increased the anthocyanin content, TPC, antioxidant capacity (ABTS, CUPRAC) and had more bioaccessible phenolics [27]. However, kombucha with fermented garlic had a lower TPC than the garlic bulbs but a higher antioxidant activity and strong antibacterial activity against *S. aureus* [32]. Moreover, both vegetables changed the color of the kombucha.

Overall, the studies demonstrate that kombucha enrichment with fruits and vegetables bioactives influences microbial dynamics, both by providing additional nutrients and by altering the chemical environment through bioactive compounds. By incorporating nutrient- and polyphenol-rich fruits, the functional profile of the beverage can be enhanced, increasing both antioxidant potential and bioactive compounds content beyond what is achieved with standard black tea kombucha.

2.3. Characteristics and Health Benefits of Plant-Enriched Honey Kombucha

Honey consists of simple sugars or monosaccharides (up about 75% of the sugars in honey), 10–15% disaccharides, pollen, polyphenols, flavonoids, vitamins, enzymes and

minerals [33–38]. The main sugars from honey, fructose (~38%) and glucose (~31%), serve as primary carbon sources during kombucha fermentation [33]. Honey also contains trace oligosaccharides, which may act as prebiotic substrates for certain microbial strains in kombucha [37,38]. Enzymes such as glucose oxidase, invertase, and diastase regulate oxidation–reduction reactions, generating gluconic acid and hydrogen peroxide, both of which contribute to honey’s antimicrobial capacity [37,38]. Phenolic compounds—including quercetin, pinocembrin, and caffeic acid—impart significant antioxidant effects, while organic acids (gluconic, citric, acetic) modulate pH and fermentation dynamics [33,37,38]. Honey has good potential as a natural ingredient for kombucha fermentation, which may show antimicrobial effects on the SCOBY microbiota. Honey’s antibacterial peptides, such as bee defensin-1, reinforce microbial stability and enhance antimicrobial potential [39]. It is important to mention that honey composition varies by floral and geographical origin, influencing its polyphenolic and enzymatic content [34–37,40]. Monofloral honeys (e.g., manuka, acacia, or chestnut) contain distinct phenolic fingerprints and exhibit stronger antimicrobial activity, while multifloral honeys display a broader polyphenolic spectrum and synergistic antioxidant potential [34,37,38]. This variability directly impacts kombucha microbial metabolism and metabolite formation, especially in terms of organic acid balance and phenolic bioavailability [40,41].

Honey serves as an efficient alternative carbon source to refined sucrose in kombucha fermentation [33,37]. Its monosaccharide composition allows for faster microbial adaptation, bypassing the invertase-mediated hydrolysis step required for sucrose metabolism. Sucrose-based kombucha typically yields gluconic, glucuronic, and acetic acids as dominant metabolites [42]. When honey replaces sucrose, fermentation produces a richer SCOBY matrix and various bioactive compounds, including phenolic derivatives and organic acids, enhancing antioxidant activity, and microbial diversity [43]. Empirical research demonstrates that honey-based kombucha significantly boosts beverages antioxidant, antimicrobial, and anti-inflammatory activities [7,44–48].

Several studies used honey as a substrate and co-enrichment with plant extracts or herb infusion [22,23], which further enhances the beverage’s functional potential. A new report studied formulated acacia honey kombucha (primary fermentation for 7 days), then added adjuncts such as brown seaweed (*Laminaria digitata*), powder of dry ginger, lavender flowers, and cinnamon for the secondary fermentation (4 days) and compared the results with the same beverages obtained with sucrose substrate [22]. As expected, honey kombucha samples (HK) showed higher titratable acidity value compared to sugar kombucha (SK), as a result of the rapid conversion of sugars from honey to acetic acid, while a slightly higher alcohol concentration was reported for SK samples [22]. At the end of primary fermentation, the honey kombucha variant showed considerably higher SCOBY weight (126.67 g) compared to SK (103.64 g). Their findings revealed that HK variants showed a notable increase in antioxidant capacity compared to SK, based on the DPPH and FRAP readouts from days 3–7 (e.g., reported DPPH inhibition values ~164.4–164.8% and FRAP $\approx 155 \mu\text{g TE/mL}$). Additionally, the authors suggested that seaweed-derived flavonoids may interact with honey-derived antioxidants and microbial metabolites to produce a highly potent antioxidant matrix [22]. Shelf-life studies and sensory acceptability varied, but SK samples with seaweed and cinnamon (SKC) received the highest acceptability scores and ginger HK the lower acceptance rate [22]. Another study [23] developed a kombucha beverage using dried olive leaf (0–5%) and honey (20 °Brix) or beet sugar 20% as substrates [23]. Over 12 days of fermentation, both total phenolic content and antioxidant activity increased in sugar- and honey-based kombucha variants. The authors attributed these effects to the high concentration of phenolic compounds naturally present in olive leaves and honey. At the end of the fermentation, the TPC for kombucha formulations

with sweetened beet sugar were higher than for honey-derived samples; the highest value of TPC and antioxidant activity (ABTS assay) was recorded for sugar supplemented with olive leaf 5%, 21.03 ± 0.22 mg/100 mg GAE) and $6.63 \mu\text{mol trolox/g}$, respectively [23]. This was not a surprise, as honey is known to have an antimicrobial effect on the SCOBY microbiota. The study's strength is the fractionation (extractable vs. hydrolysable) and simulated gastrointestinal bioaccessibility measurement, showing that fermentation with honey and plant adjuncts can increase the fraction of phenolics available for absorption [23].

Therefore, these independent studies corroborate the general trend that honey (type and floral origin matter) and plant bioactives can elevate antioxidant endpoints during kombucha fermentation.

3. Safety, Stability, Bioavailability and Sensory Considerations

As consumer interest in functional beverages expands, researchers are increasingly exploring ways to fortify kombucha with bioactive compounds derived from plant extracts, culinary herbs, and honey [49–53]. These additions can elevate the drink's health-promoting potential, especially antioxidant, antimicrobial, and anti-inflammatory potential, but important considerations should be paid to safety, biochemical stability, and sensory quality [49]. Balancing these factors is essential for ensuring that enriched kombucha delivers genuine benefit without compromising its hallmark characteristics (Figure 1).

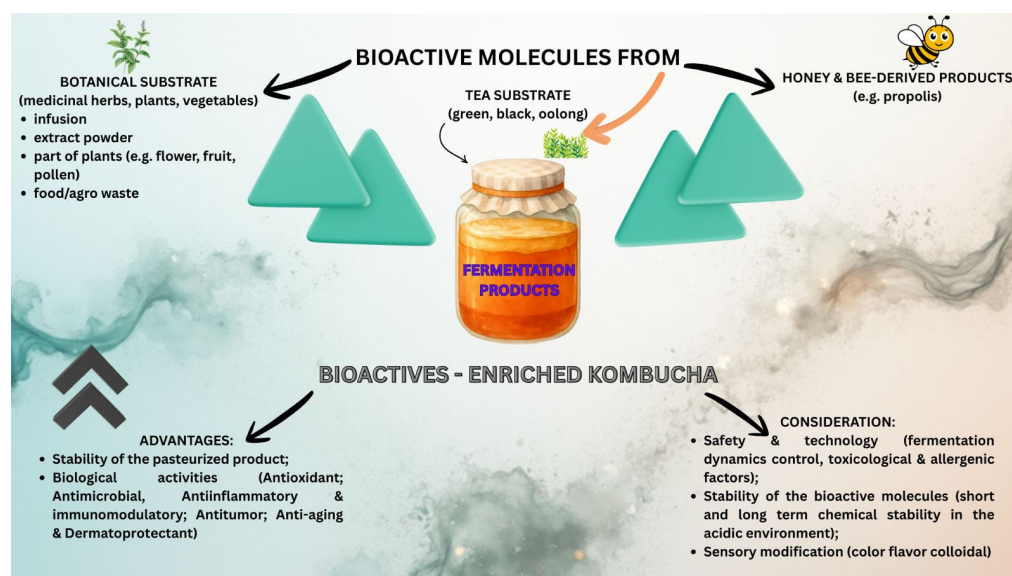


Figure 1. The advantages, safety and technological consideration of plant-enriched traditional and honey kombucha.

Accumulating evidence has proven that kombucha fermentation is dynamic, involving a shifting population of osmophilic yeasts and bacteria (AAB, LAB) within the symbiotic culture SCOBY [33–35]. Enrichment ingredients, such as plant extracts and honey, introduce additional organic substrates, enzymes, micronutrients, and antimicrobial compounds that may alter microbial ecology. Many plant-derived and honey polyphenols have demonstrated antimicrobial activity that can suppress key SCOBY microorganisms, resulting in incomplete fermentation or the emergence of less desirable microbes [16,17,20]. Thus, Gantner et al., 2025 noted that kombucha variants with medicinal plant enrichment hibiscus, spearmint and butterfly pea had lower AAB than the control kombucha but higher probiotic LAB strains in the last two beverages [17]. Also, the type of enrichment was important as hibiscus infusion had the lowest population of AAB, while the highest yeast, molds and LAB populations were in the variant with butterfly pea infusion [17]. On

the other hand, honey and plant extracts contain fermentable carbohydrates and other bioactive molecules that may accelerate specific fermentation, e.g., driving acetic acid production beyond safe levels or taste. A few studies have demonstrated that enrichment type significantly modulates the microbial composition of enriched kombucha, including SCOBY cellulose production [20,24,28]. Thus, in some cases the total counts or specific populations increased at the end of fermentation, such as AAB and yeast in kitchen mint-enriched kombucha [16,20]. Therefore, selecting concentrations of enrichment that preserve SCOBY viability and functionality is critical, as well as monitoring the fermentation process regarding pH in order to keep the fermentation pH in a safe acidic range. Few studies recorded a brutal reduction in pH and increase in the total titratable acidity after kombucha fermentation with plant or honey enrichment [19,40]. On the other hand, not all plants are suitable for fermentation as some carry allergenic potential or contain high levels of pesticide residues. Plant-enriched kombucha requires rigorous toxicological safety assessment to exclude phytochemical-associated risks such as alkaloid toxicity, excessive bioactive dosing, pesticide residues, or naturally occurring antinutritional factors introduced through medicinal plant fortification. In addition, strict microbial safety control is essential to prevent contamination by pathogenic bacteria, or mycotoxin-producing molds, particularly because added plant substrates may alter fermentation dynamics, pH reduction kinetics, and SCOBY microbial stability. Therefore, most studies used as a substrate or enrichment well-characterized plants with safety and culinary histories, such as ginger, turmeric, hibiscus, chamomile, mint, and carrot [16,17,27,44].

Kombucha's consortium of microorganisms produces enzymes that can modify phytochemicals, as well as honey bioactive compounds, but these enzymatic transformations are not always detrimental, as some can increase bioactivities and bioavailability of beneficial compounds or generated by-products. Thus, black kombucha combined with the medicinal plant extracts of *T. catappa* and *A. marmelos* resulted in the production of bioactive compounds with greater antitumoral properties than traditional kombucha tea [15]. The kombucha of guavira fruit showed the highest antioxidant capacity, compared to the green kombucha and the kombucha made with seriguela fruits [28]. Similar, an interesting investigation concluded that the health benefits of pollen are enhanced by kombucha fermentation, while the content of bioactive compounds (e.g., polyphenols, short chain fatty acids) is higher in the fermented pollen [36]. The soursop leaves (1.5% (*w/v*)) in kombucha enriched with honey demonstrated better antioxidant capacity and antimicrobial activity against two important pathogenic bacteria (*E. coli* and *S. aureus*) than beverages that contain lower amount of plant leaves [42]. Therefore, responsible formulation must prioritize safe ingredients and the right amount of enrichment product that induces health-related effects. Moreover, the understanding of the mechanisms that affect targeted compounds, related to the microorganisms or enzymatic transformations, as well as the bioavailability of obtained beneficial compounds, is important. Despite much information about the compositional and functional gains of honey- and plant-enriched kombucha, studies on bioavailability post-gastrointestinal simulation remain limited. Thus, bioavailability of phenols in the kombucha supplemented with honey and olive leaves was significantly higher than the beverages supplemented with beet sugar only [23]. In the pitanga-flavored and umbu-cajá-flavored kombucha, the most bioaccessible phenolics were caftaric acid (22.38–29.98%), catechin (17.61–23.48%) and hesperidin (22.43–28.47%) [29]. Moreover, after simulated gastrointestinal digestion, the phenolic contents in all kombuchas decreased, showing influence on the significant drop in antioxidant capacity [29]. Another interesting study compared TPC, hydrolysable phenolics and their % bioaccessibilities for beet sugar and honey kombucha samples with olive leaf [23]. Thus, prior investigations demonstrated that enriching traditional black tea Kombucha with olive leaves (1–5%) and honey significantly

increased total phenolic content, antioxidant capacity, and in vitro bioaccessibility [23]. The highest extractable and hydrolysable phenolic values were reported for sugar-based formulations, while the highest bioaccessible phenolic value was in a honey-based sample with supplemented olive leaf of 5.0%. The study highlights that botanical additions rich in polyphenols can act synergistically with fermentation-driven biotransformations, producing beverages with improved functional potential. In these studies, the mechanisms of polyphenols bioavailability were not studied, but it is possible that during fermentation, microbial enzymes (e.g., β -glucosidases, esterases) hydrolyze complex polyphenols into lower-molecular-weight molecules, thereby enhancing their solubility, intestinal permeability, and overall bioaccessibility of the plant-enriched kombucha tea [23,29].

Enhancing kombucha with plant-derived bioactive compounds is only meaningful if those molecules remain stable throughout fermentation, storage, and consumption. It has to be mentioned that kombucha's fermented environment is chemically complex: acidic pH, active enzymes, fluctuating temperatures, and oxidative processes can degrade sensitive compounds. Polyphenols and certain enzymes are susceptible to hydrolysis or oxidation at low pH, or suffer structural changes that diminish their bioactivity or transform into new metabolites with different health effects [54]. Thus, catechins from tea undergo enzymatic and non-enzymatic oxidation, forming products (e.g., quinones) that are highly reactive and may bind to proteins, amino acids, or microbial enzymes, potentially altering fermentation biochemistry [54]. Therefore, understanding ingredient-specific stability curves allows us to choose the appropriate timing of enrichment and fermentation length as both influence sensory quality. The kombucha beverage with honey and yerba maté infusion, a traditional beverage originating from South America, had a pleasant fruity and sour aftertaste if the fermentation is shorter than 10 days. However, a longer fermentation (15–20 days) increased acidity, and a “vinegar taste” was reported by the subjects, while polyphenolic composition was higher [41]. Similar, Cascade hops addition in the pre-fermentation stage significantly reduced radical formation and enhanced oxidative stability of kombucha [19]. The mechanism is based on the presence of bioactive molecules, such as polyphenols, α -acids, xanthohumol, prenylflavonoids, and essential oils, which stabilize the physicochemical properties of unpasteurized kombucha and increase the content of antioxidant substances with health-related benefits. Therefore, hops were considered a relatively novel additive for kombucha with dual effects. Also, the long-term stability of enriched bioactives is important as storage temperature, light and oxygen exposure influence the activity of bioactive molecules and sensory quality. The important problem of shelf-life stability during storage is essential and relevant in the context of commercial applications. To assess the microbial safety and stability of kombucha, previous reports have indicated that the products were stored in glass bottles and maintained under refrigerated conditions [22]. The fermented beverages obtained using acacia honey and sucrose as substrate and different adjuvants (brown seaweed, ginger, cinnamon, and lavender) maintained their quality, as well as their antioxidant properties, for three months [22].

The sensory profile of kombucha results from interactions between organic acids, fermentation-derived volatiles (ethyl acetate, acetaldehyde, higher alcohols), and tea-derived compounds. Plant extracts and honey enrichments significantly influence kombucha's sensory profile, and careful balancing is essential. Most studies have demonstrated that honey generally harmonizes with kombucha's profile, adding floral notes, and modulates perceived sweetness and softens acidity. However, some compounds can interact with existing volatiles, altering aroma complexity. Thus, sensory evaluation was performed in a study that used brown seaweed *Laminaria digitata* (0.15% w/v), dry ginger (*Zingiber officinale* Roscoe) powder (0.15% w/v), dried lavender flowers (0.5% w/v), and cinnamon powder (0.5% w/v) as adjuncts introduced to both the honey and sugar brew [22]. Although honey

kombucha variants showed a notable increase in antioxidant capacity compared to sugar kombucha, they received lower acceptance ratings. Surprisingly, the honey kombucha with ginger received the lowest acceptability (12.5%), probably due to the biotransformation of volatile compounds from ginger during fermentation that unfavorably altered the flavor of honey-enriched kombucha. This alteration was not observed for ginger sugar-fermented kombucha, with acceptability scores of 75% [22]. Additionally, sensory evaluation indicated that seaweed-containing sugar formulations enhanced consumer acceptability to 87.5%.

Plant polyphenols can increase bitterness and astringency, while certain essential oils may dominate aromatic profiles. Fruit-enriched kombuchas are regarded as healthy substitutes to traditional kombucha and have more appealing sensory characteristics—aroma, flavor, and color. Research findings demonstrated that pitanga and umbu-cajá kombucha is a sweeter beverage because of the pre-existing levels of glucose and fructose in fruits and lower sugar losses, with a tendency for fruity aromas [29].

Medicinal herb infusions significantly enhance the nutritional and sensory properties of herb-enriched kombucha. Thus, traditional kombucha and hawthorn-flavored kombucha (HK) were rated as the tastiest of three herb-flavored kombucha beverages, rated based on the odor, acidity, taste, appearance, and overall quality of beverages at the end of fermentation [20]. Still, this herb-flavored kombucha had the lower antioxidant activity based on the measurement of free radical scavenging activity by DPPH method. In a study comparing different beverages of green kombucha with 30% (*v/v*) infusion of *Mentha spicata*, *Hibiscus sabdariffa*, or *Clitoria ternatea*, the last achieved the highest overall sensory quality due to its fruity aroma and balanced sweet-sour taste, while the mint-enriched kombucha maintained a distinct minty flavor [17]. Another study compared kombucha products enriched with cinnamon, cardamon and thyme, and the highest scores in flavor, odor, pleasantness, acidity, and color were obtained by cinnamon-flavored kombucha [18]. Similarly, Cascade hop-enriched kombucha keeps the medicinal plant fruity and citrusy aromas, with heightened bitterness, as well as a reduction in the intensities of acetic and tea-related flavor aromas [19]. Kombucha enriched with black carrot juice of the Hatay variety had a fresh and pleasant taste, flavor, and nice color due to the presence of anthocyanin and phenolic compounds [27]. Similar, garlic changed the color of kombucha to reddish [32]. Moreover, the bioaccessible phenolics in both carrot-enriched kombuchas were higher than in the control beverage.

4. Conclusions and Future Perspectives

Enriching kombucha with plant-derived biomolecules is a promising approach to creating “next-generation” functional beverages that can expand the range of bioactive metabolites and boost health-promoting activities (e.g., antioxidant, antimicrobial, anti-cancer, and anti-aging) rather than just the flavor or the sensory properties. However, these advantages depend heavily on the tea matrix, the type and amount of enrichment, the timing of addition (before or during fermentation), and processing conditions (e.g., duration, temperature, and pH). These factors influence the SCOBY ecology and the chemical stability and sensory appeal of the final product. Therefore, turning these formulations into commercial or clinical applications involves standardizing raw materials and processes, conducting thorough safety assessments (e.g., covering microbiological control, acidity/ethanol levels, allergens, and contaminants), performing shelf-life studies, and exploring mechanisms to understand how the kombucha microbiome interacts with bioactive substrates. Controlled studies should follow in vitro relevant models to support specific health-related claims. Thus, plant enriched kombucha can become a high-quality functional beverage that meets both scientific and consumer expectations.

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Abbreviations

The following abbreviations are used in this manuscript:

AAB	acetic acid bacteria
LAB	lactic acid bacteria
SCOBY	symbiotic colony of bacteria and yeast
DPPH	2,2-Diphenyl-1-picrylhydrazyl
FRAP	ferric-reducing antioxidant power
ABTS	2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid
CUPRAC	CUPric reducing antioxidant capacity
SOD	superoxide dismutase
CAT	catalase
GPx	glutathione reductase
GAE	gallic acid equivalent
EQ	quercetin equivalent
TE	trolox equivalent
CIN	kombucha enriched with cinnamon
KT	kombucha enriched with <i>Terminalia catappa</i> L.
KA	kombucha enriched with <i>Aegle marmelos</i> (L.)
KC	kombucha enriched with cupuassu <i>Theobroma grandiflorum</i>
KT	kombucha enriched with tapereba <i>Spondias lutea</i> L.
KB	kombucha enriched with bacuri <i>Platonia insignis</i>
PPC	pineapple peels and cores
PFK	kombucha enriched with pitanga <i>Eugenia uniflora</i> L.
UCFK	kombucha enriched with umbu-cajá <i>Spondia tuberosa</i>
KH	kombucha enriched with hop <i>Humulus lupulus</i> L.
KHa	kombucha enriched with hamthorn <i>Polygonum cognatum</i>
KM	kombucha enriched with madinak <i>Crataegus monogyna</i>
K2	kombucha enriched with spearmint <i>Mentha spicata</i>
K3	kombucha enriched with hibiscus <i>Hibiscus sabdariffa</i>
K4	kombucha enriched with butterfly pea <i>Clitoria ternatea</i>
HK	kombucha with Acacia honey
SK	kombucha with sucrose
TPC	total phenolic content
TFC	total flavonoid contents

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