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Mangrove-Based Kombucha as a Functional Beverage: A Literature Review

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ABSTRACT

Mangrove plants are potential alternative substrates for functional kombucha because they contain bioactive compounds and are widely available in coastal ecosystems. This review aims to examine mangrove-based kombucha based on substrate types, fermentation conditions, bioactive components, and biological activities. A narrative literature review was conducted using articles obtained from Google Scholar, ScienceDirect and Consensus, with priority given to publications from 2020 to 2026. The reviewed studies showed that Rhizophora mucronata, Sonneratia caseolaris, Sonneratia ovata, and Rhizophora apiculata have been explored as substrates or complementary ingredients in kombucha production. Fermentation factors, including sugar concentration, starter concentration, and fermentation time, influence acidity, microbial growth, secondary metabolites, and functional properties. The reported bioactive components include phenolics, flavonoids, tannins, saponins, alkaloids, triterpenoids, and organic acids. The main biological activities are antidiabetic, antioxidant, and antibacterial effects. Overall, mangrove-based kombucha is promising as a functional beverage innovation derived from coastal biological resources. Further studies are needed to validate its safety, bioactivity, formulation, and consumer acceptance.

Keywords: *Bioactive compounds, fermentation, functional beverage, kombucha, mangrove*

1. INTRODUCTION

Kombucha is widely recognized as a fermented beverage produced through the metabolic activity of a microbial consortium known as the Symbiotic Culture of Bacteria and Yeast (SCOBY). During fermentation, sugar serves as the primary energy source for microorganisms, particularly yeasts and acetic acid bacteria. The metabolic interactions within this consortium lead to the production of various compounds, including organic acids, soluble polyphenols, vitamins, enzymes, and other metabolites that contribute to the taste, aroma, acidity, and functional value of kombucha (de Oliveira et al., 2023; Fabricio et al., 2023). Traditionally, kombucha is prepared using black or green tea as the main substrate. However, recent studies have demonstrated that various plant-based materials can also be used as fermentation substrates, especially those rich in bioactive compounds and with potential applications in functional food development (de Oliveira et al., 2023).

The use of alternative substrates has become an important aspect in kombucha development. The type of raw material used can influence the chemical characteristics, microbial composition, metabolite profile, and biological activity of the final product. In addition, processing factors such as sugar concentration, starter amount, fermentation temperature, and fermentation duration also affect kombucha quality (de Oliveira et al., 2023). Insufficient fermentation time may result in incomplete metabolite formation, whereas excessive fermentation can increase acidity and reduce sensory acceptance. Therefore, appropriate substrate selection and controlled fermentation formulation are essential to produce kombucha that is safe, stable, and potentially beneficial to health.

Mangroves are coastal biological resources with considerable potential as raw materials for functional beverages. Beyond their ecological role in maintaining the stability of coastal ecosystems, several mangrove species are known to contain nutrients and biologically active secondary metabolites. Compounds such as phenolics, flavonoids, tannins, saponins, alkaloids, and triterpenoids have been reported in various mangrove plant parts, including leaves, fruits, flowers, and bark. These compounds are associated with several biological activities, including antioxidant, antimicrobial, antidiabetic, anti-inflammatory, and other health-related effects (Basyuni et al., 2025; Hardiningtyas et al., 2024). Therefore, mangroves should not only be viewed as ecologically important plants, but also as promising natural resources for the development of bioactive food and beverage products.

A number of mangrove species have recently been explored as primary substrates or supplementary ingredients in kombucha production. Among them, *Rhizophora mucronata* has received considerable attention because of its potential use in herbal tea and kombucha formulations. Kombucha prepared from *R. mucronata* fruit has been evaluated using different sugar concentrations and fermentation periods to assess its physicochemical characteristics, phenolic content, total acidity, sensory acceptance, and α-glucosidase inhibitory activity. The findings indicate that specific fermentation formulations can produce strong antidiabetic potential, mainly through the inhibition of α-glucosidase activity (Hardoko et al., 2020). In addition to the fruit, *R. mucronata* leaves have also been investigated as raw material for tea and kombucha, showing α-glucosidase inhibitory activity and the presence of flavonoid glycosides (Puspitasari et al., 2024).

In addition to the genus *Rhizophora*, some species of *Sonneratia* also show potential for development as kombucha substrates. *Sonneratia caseolaris* has been reported as a suitable fermentation substrate for kombucha and can support the growth of fermentative bacterial communities. Another species, *Sonneratia ovata*, locally known as kedabu, has also been used as a supplementary ingredient in kombucha. The addition of kedabu fruit juice at different concentrations was reported to affect physicochemical characteristics, lactic acid bacteria count, yeast counts, alcohol content, and antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* (Nasution et al., 2025). Fitriyani et al. (2024) reported that kombucha formulated with pedada (*Sonneratia caseolaris*) fruit juice showed antioxidant activity and antibacterial effects against *Escherichia coli* and *Salmonella typhi*, indicating its potential as a functional fermented beverage.

Previous studies also indicate that mangroves can support the development of kombucha with diverse biological activities. Pedada leaves have been investigated as a raw material for kombucha tea, mainly in relation to physicochemical properties and antioxidant activity. In another study, kombucha made from a combination of clove leaves and *Rhizophora apiculata* mangrove leaves showed antioxidant activity and contained several phytochemical groups, including alkaloids, saponins, tannins, and phenols (Pasassa et al., 2025; Putra et al., n.d.). These findings suggest that the potential of mangrove-based kombucha is not limited to antidiabetic activity, but also includes antibacterial, antioxidant, and other possible bioactivities

Recent studies on mangrove-based kombucha have begun to develop, but the available evidence is still fragmented across various species, plant parts, fermentation conditions, and biological activities. Variations in substrate type, sugar concentration, starter level, incubation time, metabolite analysis, and bioactivity assays make direct comparison among studies challenging. In addition, few reviews have specifically synthesized the relationship between mangrove substrates, fermentation formulation, bioactive compounds, and the functional potential of kombucha. Therefore, this review is needed to provide an integrated overview of current findings and to support the future development of mangrove-based kombucha as a functional beverage.

Based on this background, this review aims to examine the potential of mangrove-based kombucha as a functional beverage by analyzing the reported substrates, fermentation methods, sugar concentrations, starter levels, incubation periods, bioactive compounds, and biological activities. This review is expected to provide a scientific overview of current research on mangrove kombucha, highlight existing opportunities and limitations, and offer insights for future studies and product innovation using coastal biological resources.

2. MATERIALS AND METHODS

The Methods section should describe the research design, materials or samples, study location and time, procedures, data collection, and data analysis clearly enough to allow replication. Previously published methods should be cited, and only relevant modifications need to be explained. Ethical approval must be stated when the study involves humans, animals, or biological materials requiring permission. For Review Articles, this section may be written as Review Method and should include the literature search strategy, databases, keywords, inclusion and exclusion criteria, review period, and method of analysis or synthesis. For Short Communications, the methods should be concise but sufficiently clear. This study employed a narrative literature review approach to examine the development of mangrove-based kombucha as a functional beverage. The review focused on studies related to mangrove substrates, kombucha fermentation, fermentation formulation, bioactive compounds, and reported biological activities. Literature was collected through Google Scholar, ScienceDirect, and Consensus using keywords in English and Indonesian, including "kombucha," "mangrove kombucha," "kombucha mangrove," "*Rhizophora mucronata* kombucha," "*Sonneratia caseolaris* kombucha," "*Sonneratia ovata* kombucha," "mangrove functional beverage," "kombucha fermentation," "bioactive compounds," "antioxidant activity," "antibacterial activity," and "antidiabetic activity." The search prioritized publications from 2020 to 2026 to reflect recent research trends, although older sources were also considered when they provided important theoretical or comparative information.

The inclusion criteria were articles that discussed kombucha using mangrove or relevant plant-based substrates, reported fermentation conditions, described physicochemical or bioactive characteristics, or evaluated biological activities such as antioxidant, antibacterial, and antidiabetic effects. Articles were excluded when they were unrelated to kombucha, mangrove, or functional beverages, lacked clear publication information, had incomplete data, or came from non-academic sources. The selected literature was analyzed descriptively and thematically by extracting information on substrate type, fermentation method, sugar concentration, starter concentration, incubation time, bioactive compounds, biological activity, and authorship. The findings were then synthesized into major themes, including mangrove substrates, fermentation formulation, bioactive compounds, biological activities, and future development opportunities.

3. RESULTS AND DISCUSSION

The reviewed literature indicates that research on mangrove-based kombucha remains limited, although interest in this topic has begun to grow, particularly for several species such as *Rhizophora mucronata*, *Sonneratia caseolaris*, *Sonneratia ovata*, and *Rhizophora apiculata*. These species have been utilized in various forms, including fruits, leaves, fruit juice, or in combination with other plant materials. In general, the use of mangroves as kombucha substrates is supported by their secondary metabolite content, such as phenolics, flavonoids, tannins, saponins, alkaloids, and triterpenoids, which may contribute to the biological activity of the fermented product. A review on the edible and medicinal uses of mangroves also reported that several mangrove species have potential as sources of food, beverages, and natural bioactive materials with antioxidant, antidiabetic, antimicrobial, and other health-promoting properties (Basyuni et al., 2025)

3.1 Potential of Mangroves as Alternative Kombucha Substrates

The reviewed studies show that mangrove substrates used in kombucha research are derived from different plant parts, mainly fruits, leaves, and fruit juices. The fruit of *R. mucronata* has been utilized as a herbal tea base for kombucha, while its leaves have been explored as raw materials for tea and kombucha, particularly in relation to α-glucosidase inhibitory activity. In the genus *Sonneratia*, substrate utilization is more commonly focused on fruit juice, such as those from *S. caseolaris* and *S. ovata*. This is likely due to the naturally acidic taste and nutritional composition of *Sonneratia* fruits, which make them suitable for the development of fermented beverages (**Table 1**).

The use of different plant parts may influence the characteristics of mangrove-based kombucha. Leaves are commonly associated with phenolic compounds, flavonoids, and tannins, whereas fruits may contribute natural sugars, organic acids, vitamins, and flavor-related components. Basyuni et al. (2025) reported that mangroves are not only used as food resources but also have medicinal value due to their bioactive constituents. This supports the scientific basis for using mangroves as kombucha substrates to produce functional beverages, rather than merely as a coastal food innovation.

Table 1. Fermentation formulation and biological activity of mangrove-based kombucha

No	Substrate	Bioactive compounds	Sugar concentration	Substrate formulation	Incubation time	Main potential	References
1	Herbal tea from *Rhizophora mucronata* fruit	Phenolic compounds, flavonoids, organic acids	10%, 20%, 30%	*R. mucronata* fruit tea; 10% kombucha starter.	7, 14, 21 days	Antidiabetic; α-glucosidase inhibition; IC50 33.95 ppm.	Hardoko et al. (2020)
2	*Rhizophora mucronata* leaf	Flavonoid glycosides	10% sucrose	9.36 g *R. mucronata* tea powder suspended in 3.6 L boiling water;	0, 7, 14 days	Antidiabetic; IC50 0.09 ± 0.04 mg/mL.	Puspitasari et al. (2024)
3	*Sonneratia caseolaris* fruit juice	Flavonoids, steroids, triterpenoids, and other phytochemical compounds	10% sucrose	Mangrove apple pulp 1:1; 10% starter; SCOBY cellulose.	12 days; optimal bacterial density on day 8	Supports fermentative bacteria; dominated by acetic acid bacteria.	Visakhadevi et al. (2024)
4	*Sonneratia ovata* fruit juice	Phenolics, flavonoids, saponins, terpenoids, and organic acids	10%	Black tea with *S. ovata* fruit juice; 10% starter.	14 days	Antibacterial against *E. coli* and *S. aureus*.	Nasution et al. (2025)
5	Pedada (*Sonneratia caseolaris*)	Phenolic compounds, flavonoids, organic acids, and antioxidant-related compounds	-	Pedada fruit juice variants: 0–40%.	Primary fermentation for 12 days and secondary fermentation for 4 days	Antioxidant and antibacterial activities.	Fitriyani et al. (2024)
6	Kombucha from clove leaves and *Rhizophora apiculata* mangrove leaves	Alkaloids, saponins, tannins, and phenols	10%	Clove leaves and *R. apiculata* leaves; 10% starter and SCOBY.	0, 7, 14 days	Antioxidant; strongest activity on day 7; IC50 4.748 ppm.	Pasassa et al. (2025)

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3.2 Fermentation Formulation of Mangrove-Based Kombucha

Fermentation formulation is a key factor in the development of mangrove-based kombucha. Hardoko et al. (2020) evaluated *R. mucronata* fruit kombucha using different sugar concentrations of 10%, 20%, and 30%, along with fermentation periods of 7, 14, and 21 days. The study found that the combination of 10% sugar and 14 days of fermentation produced the strongest α-glucosidase inhibitory activity, with an IC50 value of 33.95 ppm. This finding indicates that a higher sugar concentration does not necessarily improve biological activity, as metabolite formation during fermentation is influenced by the interaction among the substrate, microbial consortium, and fermentation time (Hardoko et al., 2020).

Puspitasari et al. (2024) prepared *R. mucronata* leaf kombucha using 10% sucrose and fermentation periods of 0, 7, and 14 days. The results showed that kombucha fermented for 7 days had stronger α-glucosidase inhibitory activity than the unfermented tea. This finding suggests that fermentation may enhance or modify the biological activity of mangrove-derived materials, although the optimal fermentation period can differ depending on the substrate used. In *S. caseolaris* fruit juice kombucha, fermentation was conducted for 12 days, with the highest bacterial density reported on day 8. This indicates that microbial growth patterns should also be considered when determining the optimal harvest time for kombucha (Visakhadevi et al., 2024).

Overall, most reviewed studies used approximately 10% sugar and 10% kombucha starter, especially in *Sonneratia*-based formulations. However, differences in starter form, substrate preparation, and incubation time indicate that mangrove-based kombucha has not yet had a standardized fermentation formulation. Further optimization of sugar concentration, starter-to-substrate ratio, temperature, and fermentation duration is therefore required to ensure consistent physicochemical quality, safety, and bioactivity.

3.3 Profile of Bioactive Compounds in Mangrove-Based Kombucha

Bioactive compounds reported in mangrove-based kombucha are generally associated with phenolic compounds, flavonoids, tannins, saponins, alkaloids, triterpenoids, and fermentation-derived organic acids. In *R. mucronata* fruit kombucha, total phenolic content is an important parameter related to antidiabetic activity. Hardoko et al. (2020) reported that *R. mucronata* fruit kombucha contained high total phenolic content and showed strong α-glucosidase inhibitory activity. In another study, Puspitasari et al. (2024) identified flavonoid glycosides in *R. mucronata* tea, kombucha, and methanolic leaf extract, supporting the potential of this species as a source of α-glucosidase inhibitory compounds.

The addition of kedabu (*Sonneratia ovata*) fruit juice to kombucha contributes to the presence of secondary metabolites, including phenolics, flavonoids, saponins, and terpenoids. These compounds may enhance antibacterial activity, particularly when they interact with organic acids formed during fermentation. Likewise, kombucha prepared from a combination of clove leaves and *Rhizophora apiculata* leaves has been reported to contain alkaloids, saponins, tannins, and phenols after fermentation. The combined presence of plant-derived bioactive compounds and fermentation metabolites provides a scientific basis for explaining the biological activity of mangrove-based kombucha as a functional beverage.

3.4 Biological Activities and Development Prospects of Mangrove-Based Kombucha

The most frequently reported biological activities of mangrove-based kombucha include antidiabetic, antioxidant, and antibacterial effects. Antidiabetic activity has mainly been evaluated through α-glucosidase inhibition assays, particularly in studies using *R. mucronata* as the substrate. Kombucha prepared from *R. mucronata* fruit showed strong α-glucosidase inhibitory activity and was reported to have a lower IC50 value than acarbose and commercial kombucha in the same study. This finding suggests that mangrove substrates may specifically contribute to the antidiabetic potential of kombucha (Hardoko et al., 2020).

The antidiabetic potential was also observed in *R. mucronata* leaf kombucha. Puspitasari et al. (2024) reported that kombucha prepared from *R. mucronata* leaves and fermented for 7 days exhibited α-glucosidase inhibitory activity, with an IC50 value of 0.09 ± 0.04 mg/mL. This finding indicates that mangrove leaves may serve as promising raw materials for antidiabetic kombucha and offer a more sustainable alternative to bark utilization.

Antibacterial activity has mainly been reported in kombucha supplemented with kedabu (*S. ovata*) fruit juice. Nasution et al. (2025) showed that kedabu kombucha could inhibit *E. coli* and *S. aureus*, although the activity was weak to moderate. This effect may be related to the interaction between fermentation-derived organic acids and secondary metabolites from the fruit. Fitriyani et al. (2024) also reported that pedada (*S. caseolaris*) kombucha exhibited antioxidant and antibacterial activities against *E. coli* and *Salmonella typhi*. Meanwhile, kombucha made from clove leaves and *R. apiculata* showed the strongest antioxidant activity on day 7 (Pasassa et al., 2025). Overall, these findings suggest that both substrate composition and fermentation duration influence the bioactivity of mangrove-based kombucha.

3.5 Research Gaps and Future Prospects

The synthesis of the reviewed literature indicates that research on mangrove-based kombucha is still at an early stage and requires further development. Current studies are mainly concentrated on a few mangrove genera, particularly *Rhizophora* and *Sonneratia*, while other edible or medicinal mangrove species remain less explored. In addition, fermentation conditions differ among studies, including sugar concentration, starter amount, incubation time, and fermentation temperature, making it difficult to establish a standard formulation. Another important gap is the limited reporting of metabolite profiles, which restricts a deeper understanding of how bioactive compounds contribute to the observed biological activities. Most studies also remain focused on in vitro assays or physicochemical evaluation, whereas evidence related to product safety, storage stability, bioavailability, and in vivo or clinical efficacy is still limited.

Future research should move beyond preliminary formulation studies and focus on the systematic optimization of mangrove-based kombucha. Key aspects that need further attention include substrate concentration, sugar level, starter-to-substrate ratio, fermentation temperature, and incubation time to obtain products with consistent quality, safety, and bioactivity. Advanced metabolite characterization using chromatographic or metabolomic approaches is also needed to clarify the relationship between bioactive compounds and biological activities. In addition, underutilized mangrove species such as *Nypa fruticans*, *Bruguiera gymnorrhiza*, and *Sonneratia alba* offer promising opportunities as alternative kombucha substrates because they have been reported as sources of food materials and bioactive compounds. Expanding the diversity of mangrove substrates may strengthen the development of mangrove-based kombucha not only as a functional beverage innovation, but also as a strategy to valorize coastal biological resources with scientific, economic, and sustainability value.

4. CONCLUSION

Mangrove-based kombucha has potential to be developed as a functional beverage because it contains bioactive compounds and exhibits various biological activities, particularly antidiabetic, antioxidant, and antibacterial effects. Mangrove substrates such as *Rhizophora mucronata*, *Sonneratia caseolaris*, *Sonneratia ovata*, and *Rhizophora apiculata* have been used in kombucha formulations with different sugar concentrations, starter levels, and fermentation periods. These fermentation factors influence the physicochemical characteristics, bioactive metabolites, and biological potential of the final product. However, current studies are still limited to a few mangrove species, and most have not comprehensively evaluated product safety, storage stability, and biological efficacy. Therefore, further research is needed to optimize fermentation formulations, characterize metabolite profiles, and assess bioactivity through more comprehensive approaches.

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