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REVIEW ARTICLE

A Review of Upcycle Coffee Cherry Husk (Cascara) in Kombucha Fermentation: Enhancing Bioactive Compound Potential

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ABSTRACT

The growing concern about managing diabetes and adhering to dietary restrictions has led to the development of low-sugar, nutritious products. Kombucha, a fermented tea produced with a symbiotic culture of bacteria and yeast (SCOBY), provides essential probiotics and enzymes that aid digestion and boost the immune system. Cascara, or the dried husk of the coffee cherry, contains bioactive compounds such as quercetin, chlorogenic acid, and ferulic acid, making it valuable for managing oxidative stress, diabetes, and regulating enzymes. Combining cascara with kombucha presents an opportunity to enhance the beverage's health benefits. Generally, fermentation for 10–14 days with 100 g/L sucrose produced an optimal balance in pH, total phenolic content (TPC), flavonoid content (TFC), and antioxidant activity. Cascara kombucha also demonstrated antibacterial effects against *Staphylococcus aureus*, *Escherichia coli*, and *Salmonella enterica*. This review highlights that cascara kombucha is not only a promising functional beverage but also a sustainable strategy for reducing coffee waste and improving post-harvest economic value.

KEYWORDS: *Antioxidant activity, Bioactive compounds, Cascara, Fermentation, Kombucha*

Introduction

Coffee is widely favored and consumed by the public due to its distinctive taste, aroma, and health benefits (Nieber, 2017, cited in Abduh *et al.*, 2023). In coffee fruit, there is a content of about 30% coffee grounds from the dry matter of coffee fruit (Braham, 1978, in Abduh *et al.*, 2023). Therefore, processing coffee fruit into coffee beans produces considerable waste, especially in coffee grounds (Abduh *et al.*, 2023). Coffee fruit skin contains 13-27% cellulose, 2-17% lipid, 9-11% protein, 4.5% tannin, 6.5% pectin, 12.4% reducing sugar, and 57-63% non-nitrogen. Coffee fruit skin can be processed into value-added products, one of which is cascara. Cascara, or the dried husk of the coffee cherry, contains bioactive compounds such as quercetin, chlorogenic acid, and ferulic acid, making it valuable for managing oxidative stress, diabetes, and enzyme regulation. Based on the assessment by the EFSA Panel on Nutrition, Novel Foods, and Allergens, cascara is considered safe for consumption when used for its intended use (Turck *et al.*, 2022; Abduh *et al.*, 2023). According to the research results by Abduh *et al.* (2023), the total phenolic content of cascara was higher when using the hot brewing method; however, the antioxidant activity was lower than that of the cold brewing method. The optimal cascara brewing method was performed at 77°C for 8 minutes without propolis, yielding an IC50 value of 432.87 ppm and a total phenolic content of 2.07%.

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Kombucha is a fermented tea produced with a symbiotic culture of bacteria and yeast (SCOBY), which provides essential probiotics and enzymes that aid digestion and boost the immune system (Van *et al.*, 2023). Kombucha is a low-alcohol fermented beverage that is experiencing rapid growth in the functional beverage market and is one of the most in-demand fermented food products. Naturally, this fermented drink contains between 0 and 3% alcohol by volume (ABV) (Jang *et al.*, 2021). The increasing interest in kombucha drinks has led to the exploration of new raw materials, the use of different strains of microorganisms, and variations in fermentation conditions. This has led to changes in the chemical composition of kombucha, which in turn may affect its health benefits. Such dynamic developments run the risk of producing products that no longer align with the fundamental concept of functional beverages. Therefore, it is important to understand the key factors that influence the biological activity of kombucha, as well as how changes in each element can impact the fermentation process and the health benefits of the final product (Antolak *et al.*, 2021). The use of cascara as the main ingredient for making kombucha can enhance its distinctive flavor while potentially increasing bioactive compounds (Thongbai *et al.*, 2025). Cascara kombucha is classified as an upcycling product. Upcycling is the process of converting waste materials into valuable and functional products while preserving the original form of the materials (Nutrizio *et al.*, 2024). The effectiveness of this process is greatly influenced by fermentation conditions such as sugar content, particle size, and fermentation time. Therefore, this review aims to comprehensively examine the biotransformation mechanisms, quality determinants, and sustainability potential of cascara-based kombucha as a natural, environmentally friendly functional beverage. The purpose of writing this paper is to review the current literature on kombucha fermentation using by-products like coffee cascara. Different studies were included in the discussion to compare each method and its potential for fermentation beverages. Through this research, it is expected that the resulting product will not only offer good functional benefits for health but also serve as a form of upcycling coffee by-product waste into high-value, environmentally friendly products with economic potential.

Material and Method

This study adopted a laboratory-based experimental design enhanced by a comprehensive review. The main objectives of this experimental approach were to evaluate the impact of cascara particle size variation and kombucha fermentation duration on the antioxidant activity and bioactive compound composition in cascara-based functional beverages. The levels of functional substances produced will provide beneficial effects that support health and reduce the risk of chronic diseases. The effects produced are cardioprotective, anti-inflammatory, and anticarcinogenic, as well as several other components that support these benefits.

The material used in this study is dried Cascara derived from Arabica coffee (local coffee) (*Coffea arabica* L.), which is obtained from Chiang Mai, Thailand. Then, the material will be milled to obtain fine particles using a blender. The milled particles will be sieved into two sizes: a fine size of 0.5-1.0 mm and a coarse size of 4-6 mm. Particle size adjustment is based on previous findings, which indicate that the surface area of smaller materials is necessary to enhance the efficiency of extracting bioactive compounds (Thongbai *et al.*, 2025).

In this study, cascara was prepared in different particle sizes, with varying starter compositions, and in various forms. For each cascara sample, boil it with water for different time parameters. Then, sucrose was added and stirred thoroughly until dissolved. After the solution cooled, the starter (SCOBY, kombucha sour broth, and BAL) was added to initiate the fermentation process. The fermentation process lasted for the shortest at 10 days and the longest at 18 days at room temperature. After the fermentation was complete, the cascara kombucha was stored at 5°C for further physicochemical analysis.

Based on this review, several chemical reagents are used to help measure the content of flavonoid compounds, antioxidant activity, and phenolic compounds. The main reagents include gallic acid as a calibration standard, aluminum chloride ($AlCl_3$) for flavonoid testing, 2,2-diphenyl-1-picrylhydrazyl (DPPH), and ascorbic acid for evaluating antioxidant activity, as well as Folin-Ciocalteu for total phenolic analysis. The combination of coffee ingredients and chemical reagents allowed for comprehensive testing of the bioactive characteristics of cascara, both before and after kombucha fermentation (Thongbai *et al.*, 2025).

Various parameters were analyzed to evaluate the quality of cascara kombucha. In the testing stage, total soluble solids (TSS) and pH values were measured using a pH meter and digital refractometer (ATAGO). In the next stage, total phenolic content (TPC) was analyzed using the Folin–Ciocalteu method and expressed in µg GAE/mL. In contrast, total flavonoid content (TFC) was measured using the $AlCl_3$ colorimetric method and expressed in µg QE/mL. Antioxidant activity was evaluated using the DPPH method, measured at a wavelength of 517 nm, with results presented in µg $FeSO_4$/mL. Further analysis using HPLC was conducted to determine the results of phenolic acid and flavonoid compounds, using a C18 column and detected at 280, 320, and 370 nm.

Results and Discussion

The physicochemical characteristics of cascara kombucha are presented in Table 1 and the comparison between cascara kombuchas is presented in Table 2.

During the fermentation stage, the optimal duration will help in the production process of cascara kombucha. This is supported by research results, which found that fermentation for 7 to 14 days is the ideal duration for determining the desired sensory characteristics, namely aroma, sweetness, and acidity. Reducing the fermentation time to 7 days will impact antioxidant activity and the levels of polyphenols and flavonoids, which become lower. Therefore, a more extended fermentation period of 14 days will enhance the health benefits and overall quality of the cascara kombucha (Van *et al.*, 2023). The result from Thongbai *et al.* (2025) showed that the pH value of Cascara Kombucha is around 3.22-3.34. The fermentation process produces organic acids that increase the acidity level. Another experiment states that the pH of cascara from different coffee varieties is around 2.69-5.3 from 10–14-day fermentation. Processing methods and differences in coffee cultivars may influence the variety. Simajuntak *et al.* (2024) experiment results showed that the pH value decreased along with the fermentation time, from 3.66 to 3.58 within 8 days. This indicates that the accumulation of lactic acid and organic acids during fermentation reduced kombucha's acidity. According to FDA standards (Coton *et al.*, 2017), kombucha pH should not be lower than 3.0 to be considered acceptable. The standard pH level for food safety to help inhibit the growth of bacteria is 4,6. The lower pH in this study is in the safety range of the microbiological factor. The decrease in pH occurs due to the influence of changes in sugar substrates, which are converted into organic acids and alcohol. This can be caused by the amount of acetic acid bacteria in all kombucha samples increasing over a period of fermentation time and reaching a maximum. After reaching the maximum fermentation level, it will stop due to the pH being unsuitable (Tanticharakunsir *et al.*, 2020). During fermentation, the reduction in pH supports the growth of *Acetobacter xylinum* bacteria contained in the kombucha starter, allowing them to carry out their metabolic activities. During the fermentation process, bacteria break down sucrose into alcohol and other organic acids, releasing protons that result in a decrease in pH (Puspaningrum *et al.*, 2022).

Table 1. Physiochemical characteristics of cascara tea kombucha

Substrate	Substrate concentration	Sucrose	Starter	Fermentation time (days)	Temperature	Parameter Objectives					References
						pH	TSS	TPC	TFC	Antioxidant Activity (DPPH)	
Whole cascara	1%	(10% b/b) 100 g/L	5% (b/b) SCOBY	14	30°C	3.29	10.9	(µg GAE/mL) 385.44	(µg QE/mL) 216.57	(µg AE/mL) 228	Thongbai *et al.*, 2025
Coarsely ground cascara	1%	(10% b/b) 100 g/L	5% (b/b) SCOBY	14	30°C	3.34	10.15	(µg GAE/mL) 383.51	(µg QE/mL) 215.33	(µg AE/mL) 220	Thongbai *et al.*, 2025
Finely ground cascara	1%	(10% b/b) 100 g/L	5% (b/b) SCOBY	14	30°C	3.22	10	(µg GAE/mL) 424.04	(µg QE/mL) 240.27	(µg AE/mL) 232	Thongbai *et al.*, 2025
Cascara powder	3%	(10% b/b) 100 g/L	5% (v/v) Lactobacillus plantarum ATCC 8014	10	27°C	3.66	1.29	(mg GAE/g) 12.74	(mg QE/g) 3.4	(IC50 ppm) 215	Simanjuntak *et al.*, 2024
Cascara powder	3%	(10% b/b) 100 g/L	5% (v/v) Lactobacillus plantarum ATCC 8014	14	27°C	3.62	1.08	(mg GAE/g) 8.97	(mg QE/g) 2.91	(IC50 ppm) 300	Simanjuntak *et al.*, 2024
Cascara powder	3%	(10% b/b) 100 g/L	5% (v/v) Lactobacillus plantarum ATCC 8014	18	27°C	3.58	0.88	(mg GAE/g) 7.41	(mg QE/g) 2.67	(IC50 ppm) 368	Simanjuntak *et al.*, 2024
Whole Cascara	1%	(10% b/b) 100 g/L	SCOBY 3% (b/b) + fermented sour broth 10% (b/b)	14	30°C	2.32	-	(mg GAE/L) 275.41	(mg QE/L) 170.44	70.70%	Le BXN *et al.*, 2022

Table 2. Comparison cascara kombucha fermentation

Objective	Fermentation Conditions / Variables	Main Analyses	Key Findings	Highlights / Contribution	References
To evaluate the effect of sucrose concentration on cascara kombucha fermentation and its antioxidant properties.	• Substrate: cascara (coffee husk) extract • Microbial culture: SCOBY • Sucrose concentration: 0, 50, 100, 200 g/L • Temperature: 30°C • Fermentation time: 7–21 days	pH, total sugar, TPC, TFC, antioxidant activity (DPPH), antibacterial test	Optimal sucrose: 100 g/L pH decreased from 5.2 → 2.7 after 14 days TPC increased from 166.69 → 275.41 mg/L TFC increased from 108.53 → 170.44 mg/L DPPH scavenging activity: 70.7% Inhibited E. coli, S. aureus, Salmonella	Demonstrated that moderate sucrose concentration promotes optimal microbial metabolism and antioxidant capacity in cascara kombucha.	Thongbai *et al.*, 2025
To determine the impact of cascara particle size and fermentation on phenolic content and antioxidant potential.	Substrate: cascara (whole, coarse, fine particles) Treatment: cascara tea (CT), cascara tea + sugar (CS), cascara kombucha (CK) Temperature: 25°C Fermentation: 10 days	TPC, TFC, FRAP, DPPH, ABTS, total acid, pH, color, sensory attributes	Fine particle size (0.5–1 mm) gave the highest TPC (424.04 µg/mL) and FRAP (725.29 µg/mL) pH dropped from 4.2 → 3.2 CK showed the strongest antioxidant capacity Improved color and taste due to fermentation	Highlighted that particle size significantly affects extraction efficiency and bioactive enrichment during fermentation.	Le BXN *et al.*, 2022
To evaluate the effect of fermentation duration on the antioxidant and antibacterial activity of cascara kombucha.	Substrate: Arabica cascara extract Microbial starter: Lactiplantibacillus plantarum Fermentation time: 10, 14, 18 days Room temperature (~27°C)	pH, TPC, antioxidant activity (DPPH, FRAP), antibacterial test against H. pylori	pH decreased from 4.47 → 3.66 (day 10) TPC increased from 4.32 → 12.74 mg GAE/g (day 10) Antioxidant activity increased (IC_{50} = 215 ppm) No inhibition against H. pylori	Demonstrated that 10–14 days of fermentation provides the best balance between acidity, antioxidant capacity, and microbial stability.	Simanjuntak *et al.*, 2024

During fermentation, the sugar level decreases due to the addition of sugar, and the higher boiling temperature increases the soluble solid content. The difference in particle size from the cascara significantly affects the TSS concentration. Longer fermentation time will make the microbes metabolize the sugar and convert it into glucose for the microbes nutrients. The kombucha from cascara powder has lower total sugar content than the other type of substrate, the value goes down to 0,88% - 1,29%. The study found that the TSS value ranged from 0.50 to 11.15%, indicating that the highest value was obtained in the presence of dissolved simple sugars. The fermentation factor that occurs over a prolonged 8

period helps facilitate microbial changes that occur during the process of metabolizing the sugar produced into glucose, which serves as a source of nutrients for microbes involved in the fermentation process. The fermentation process that occurs begins with the breakdown of sugar carried out by yeast, which eventually produces alcohol. The production process involves acetic acid bacteria that utilize alcohol, glucuronic acid, and glucose as substrates. The more substrate consumed by microorganisms, the lower the total soluble solids level in kombucha will be (Muzaifa *et al.*, 2022).

The study from each research using different TPC units that reflect different ways of reporting the concentration of phenolic and expressed as Gallic Acid Equivalents (GAE). The study from Simajuntak *et al.* (2024) is normalized content per solid mass (the sample), whereas Thongbai *et al.* (2025) and Le BXN *et al.* (2022) express the concentration in a liquid (the extract). The fermentation of whole cascara kombucha from SCOBY and fermented sour broth shows the lowest concentration; meanwhile, the upper concentration is from the substrate with SCOBY. The TPC value in the Cascara Kombucha sample increased due to microbial activity during the fermentation process. The microbes from kombucha are filled with different strains of bacteria and yeast that can effectively degrade phenolic acid to increase the enzymatic reaction. An acidic environment will promote hydrolysis to break down complex phenol into simpler phenolic acid. The enzymes from kombucha, such as cellulase, pectinase, xylanase, and more. These enzymes will break down a large compound into smaller molecules that increase the TPC.

Polyphenols are bioactive compounds composed of more than one phenol group in each molecule. The hydroxyl group in the phenolic compound structure can capture free radicals. Factors influencing the increase in TPC include polyphenolic compounds and microbial activity present in kombucha (Sun *et al.*, 2015; Zubaidah *et al.*, 2019; Muzaifa *et al.*, 2023). The primary microorganisms involved are acetic acid bacteria and yeast, which release various enzymes (cellulase, glucanase, xylanase, pectinase, glucosidase, amylase, and invertase). These enzymes degrade the cell wall structure of cascara in the extract, and the particles pass through the filter cloth, releasing phenolic compounds previously bound in the plant matrix. These enzymes also break down large polyphenols and other compounds into smaller molecules, ultimately increasing the total phenolic content (TPC) in cascara kombucha. This enzymatic activity also promotes the formation of new phenolic compounds as a result of the degradation of complex compounds (Muzaifa *et al.*, 2023). This is further supported by Myo *et al.* (2021), who found that the breakdown of another component, such as tannins, can lead to an increase in phenolic compounds.

Based on the research results, the concentration of polyphenols and flavonoids after 14 days showed a significant increase, consistent with previous research findings that indicate an increase in phytochemical extraction during fermentation (Le BXN *et al.*, 2023). Samples with a fermentation time of 12 days had a more significant effect on TPC, possibly due to changes in the environment during fermentation caused by the accumulation of high levels of organic acids. Similarly, Gaur and Ganzle (2023) stated that during fermentation under acidic conditions, the degradation of condensed tannins occurs, converting them into monomeric phenolic acids, which enhances the antioxidant capacity of the fermented product and increases the overall content of monomeric phenolic acids. The research results show a significant increase, particularly in flavonoid and polyphenol concentrations, after a 14-day fermentation period, consistent with previous studies demonstrating increased phytochemical extraction during the fermentation process (Le BXN *et al*., 2023). During fermentation, the 12-day period had a significantly increasing effect on total phenolic content (TPC), which was associated with changes in the fermentation environment, resulting in a substantial increase in the amount of organic acids. A relatively low pH plays a role in the degradation of bioactive compounds, including antioxidant compounds such as phenolic compounds. Changes in pH, heat, and enzymes facilitate the degradation of phenolic compounds, suggesting that further fermentation processes will likely contribute to the decrease in TPC (Muzaifa *et al*., 2021). The phenolic acid content in cascara kombucha consists of two main groups, namely hydroxycinnamic acid and hydroxybenzoic acid. The hydroxycinnamic acid group includes chlorogenic acid, caffeic acid, p-cumaric acid, cinnamic acid, ferulic acid, and sinapic acid. Meanwhile, the hydroxybenzoic acid group comprises p-hydroxybenzoic acid, gentisic acid, gallic acid, protocatechuic acid, syringic acid, and vanillic acid.

In determining flavonoids, the results found in the Cascara Kombucha from Thongbai *et al.* (2025) were lower, likely due to the transformation or degradation of flavonoids by microbial enzymes released during the fermentation process, which can convert flavonoids into other bioactive compounds that provide health benefits to the human body. This phenomenon is supported by reports on the fermentation of raw tea kombucha, which showed a significant increase in the determination of total flavonoid components and a decrease in total flavonoid content (Zhang *et al*., 2024). According to Aryantini *et al.* (2020), the decrease in flavonoid levels in the samples was influenced by the fermentation process. Enzyme production is influenced by the activity of lactic acid bacteria, which break down complex phenolic compounds, remove them from the substrate, and metabolize sugars. The addition of phenolic groups in flavonoid formation promotes the transformation or synthesis of compounds that produce new flavonoids by releasing free phenolic compounds (Simajuntak *et al*., 2024). The content of flavonoids found includes apigenin, which has anticancer and anti-inflammatory effects, catechins, a component commonly found in tea, kaempferol, which exhibits antimicrobial activity, myricetin, and quercetin. The identified flavonoids are expected to have a positive impact on health and contribute to the functionality of the drink (Wang *et al*., 2022).

The antioxidant capacity is presented by the DPPH radical scavenging assay from different units by expressing the micrograms of antioxidant equivalent per milliliter, inhibitory concentration at 50% in parts per million, and percentage inhibition. Lactiplantibacillus ATCC8014 happens to oxidize, and that's stimulated by the existence of enzymes and non-enzymes. These mechanisms increase the antioxidant capacity; meanwhile, producing organic acids will decrease the antioxidant capacity due to the inhibition produced by bacterial activity. The DPPH inhibition depends on the black tea and kombucha constituents and the components that are produced from the fermentation process. The microbial transformation of the compounds will decrease the antioxidant capacity during the fermentation process, which affects the scavenging rate of kombucha.

Antioxidant activity tests showed a strong correlation between total flavonoid content and DPPH activity. The results of a study by Le BXN *et al.* (2023) indicate that the fermentation process can enhance the antioxidant capacity and reduce the power of kombucha by increasing the content and bioavailability of phenolic compounds. The finely ground cascara yielded the highest antioxidant activity values, indicating that the finer particle size is important to improve the release of bioactive compounds. These values correspond to the highest antioxidant potential among the starter and substrate forms, suggesting that increasing the surface area facilitates a better extraction and microbial interaction during the kombucha fermentation process. Meanwhile, the factor causing reduced antioxidant activity in cascara kombucha is low pH, resulting in a more acidic solution (Shafira *et al*., 2022). Yeast and bacteria compete to produce acids and alcohol by breaking down sugars during fermentation into major components, including ethanol, glucuronic acid, and acetic acid. In the minor component, phenolic acids, enzymes, and lactic acid bacteria are produced. Some well-known countries, such as Russia, Germany, and China, have utilized it as a cancer preventive and immune system builder. (Andini *et al*., 2023).

Sustainability has become one of the most crucial factors influencing consumer choices. With millennials and Gen Z leading the charge, wine drinkers increasingly opt for organic, biodynamic, and sustainably produced fermented drinks. The market potential for kombucha products enhanced with coffee cascara is highly promising, primarily due to its unique characteristics. Only a few kombucha products on the market highlight the natural volatile compounds from this combination as their main appeal, giving them a significant competitive advantage. This combination delivers a distinctive aroma and adds functional value through its believed antioxidant benefits and relaxing effects, setting it apart from conventional kombucha products. With this appeal, the product can target a specific market segment, specifically young consumers who value innovation, uniqueness, and the story behind a product.

As consumers become more informed, engaged, and environmentally conscious, kombucha businesses can adapt and cater to these new preferences. The future of kombucha is not just about selling a product; it's about creating an experience and a lasting connection. By focusing on sustainability, enhancing consumer education, and leveraging technology, the fermented drink industry can look forward to a bright future that blends tradition with innovation. The findings support the process of upcycling coffee cherry husk into kombucha-like beverages, which addresses critical aspects of sustainability for waste reduction and functional innovation. Cascara Kombucha became a pioneer in the healthy beverage category by combining the functional properties of cascara and converting it into functional beverages rich in antioxidants.

Conclusion

Dietary restrictions and diabetes management are driving the development of nutritious low-sugar products. Kombucha is a fermented product based on yeast (SCOBY) and symbiotic cultures of bacteria that help boost the immune system and aid digestion. Cascara is a dried coffee fruit skin that can help manage diabetic oxidative stress and regulate enzymes, making it a potential ingredient for functional beverages. The fermentation process that occurs changes the phenolic profile and increases acidity, while heating and the addition of sugar help accelerate the extraction of bioactive compounds. The best results were obtained through fine particles, which showed high levels of antioxidant activity and bioactive compounds. These findings suggest that optimizing fermentation parameters and particle size will enhance the functional quality of cascara-based kombucha, making it a healthier beverage for disease prevention and health promotion.

Supporting Information

Additional data are available on request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

All authors contributed to the planning, development, and writing of this review article. Lamsihar Alex Siregar: prepared the methodology section, including criteria for literature selection and data organization, and organized and analyzed the key findings from the

selected literature. Clarinda Djuali was responsible for writing the introduction and formulating the background of the review, conducting the literature search, and drafting the initial manuscript. Helga Zefanya Wical contributed to the discussion section by analyzing and interpreting the reviewed literature, critically reviewing, editing, and finalizing the manuscript. All authors discussed the content, approved the final version, and agreed to be accountable for all aspects of the work. Both authors were involved in drafting and revising the manuscript. All authors have read and approved the final version of the manuscript.

Ethical Statement

This study did not involve any human participants or animal subjects; hence, ethical approval was not required. All procedures carried out in this research followed applicable institutional and international guidelines.

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