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Transformation of Bioactive Compounds in Coffee Ground Kombucha: The Effect of Sugar Sources on Chemical and Sensory Properties

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ABSTRACT

Spent coffee grounds still contain valuable bioactive compounds that can be valorized through kombucha fermentation to develop functional beverages and support the sustainable utilization of coffee processing by-products. This study aimed to evaluate the effect of different sugar sources on the transformation of bioactive compounds and the chemical and sensory properties of coffee ground kombucha. Kombucha was prepared using spent coffee grounds as the fermentation substrate with three sugar sources (sucrose, glucose, and fructose) and fermented for 15 days at 28 °C using a standard SCOBY culture. Microbial growth, reducing sugar, total acidity, and pH were monitored, while total phenolic content, antioxidant activity, and sensory properties were analyzed. The results showed that the sugar source significantly influenced fermentation and product characteristics. Glucose promoted the most intensive fermentation, resulting in the highest acidity (13.94 g/L) and lowest pH (2.20). In contrast, fructose produced the highest total phenolic content (1341.81 µg/mL) and antioxidant activity (83.22%). Sensory evaluation indicated that fructose-based kombucha was the most preferred due to its balanced aroma, flavor, sweetness, and acidity. Overall, fructose was identified as the most suitable sugar source for producing coffee ground kombucha with enhanced bioactive and sensory qualities.

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1. INTRODUCTION

In Indonesia, according to the Indonesian Coffee and Cocoa Entrepreneurs Association (Asosiasi Pengusaha Kopi dan Cokelat Indonesia/APKCI), coffee grounds are estimated to reach 15.59 tons per day due to the threefold annual growth of coffee shops [1]. Improperly utilized coffee grounds can cause unpleasant odors and waste accumulation [2, 3]. Nevertheless, from a chemical composition perspective, coffee grounds still contain essential nutrients such as polysaccharides (including cellulose, hemicellulose, and mannan), as well as proteins, lipids, and bioactive compounds such as chlorogenic acid, caffeine, melanoidins, and other polyphenols [4, 5]. The presence of these bioactive compounds makes coffee grounds a potential substrate for fermentation, particularly in the diversification of functional foods and beverages.

Kombucha is created through a symbiotic fermentation model involving a cooperative community of acetic acid bacteria and yeasts, known as the SCOBY. This symbiotic culture can take sugar-rich liquids and turn them into various beneficial compounds, such as organic acids, conjugated polyphenols, and highly bioactive antioxidant compounds [6]. Using coffee grounds as a fermentation medium is promising because it can help release and transform bioactive compounds—specifically the phenolic compounds naturally bound within the coffee matrix. Past research has already shown that fermenting with coffee grounds can boost both the total phenolic content and the antioxidant activity of the finished drink [7].

The sugar type chosen for fermentation heavily influences the final characteristics and metabolite composition of kombucha. Sucrose is a popular choice because it hydrolyzes into glucose and fructose for the SCOBY to metabolize [8, 9]. However, using glucose or fructose directly yields different results: glucose stimulates gluconic acid production by acetic acid bacteria, while fructose is favored by yeasts for ethanol creation [10]. Because each sugar creates a unique metabolic environment [11], analyzing the optimal sugar source is a crucial step toward improving the quality of coffee ground kombucha.

Based on the discussion above, the main objective of this study is to determine the potential use of coffee grounds in kombucha fermentation with variations in sugar sources—sucrose, glucose, and fructose. This main objective is elaborated into four specific research goals: (1) to observe the dynamics of microbial cell growth; (2) to analyze the changes in reducing sugar, total acidity, and pH; (3) to examine the variation in total phenolic content and antioxidant activity during the fermentation of coffee ground kombucha; and (4) to evaluate the organoleptic properties of the final kombucha products as assessed by eight panelists.

This research is expected to offer fresh insights on the development of functional beverages from coffee grounds while supporting circular economy principles through the valorization of coffee waste into sustainable products with enhanced bioactive properties. The remainder of this paper is organized as follows. Section 2 describes the materials and methods used in this study, including the fermentation process of coffee ground kombucha with different sugar sources and the analytical procedures applied. Section 3 presents and discusses the results related to microbial growth, physicochemical characteristics, bioactive compounds, and sensory properties of the kombucha. Finally, Section 4 provides the conclusions of the study.

2. METHODS

The research started by preparing a liquid base for the kombucha, which involved extracting the coffee grounds according to the study's flowchart. As the fermentation

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progressed, the team monitored key changes by counting microbial cells with a hemocytometer and measuring reducing sugar, pH, and titratable acidity. Once the batches were ready, the beneficial compounds were analyzed: total phenolic content and antioxidant activity were quantified using the DPPH assay. Finally, a team of trained panelists conducted a sensory evaluation. All this data—chemical, bioactive, and sensory—was then put through a Pearson correlation analysis to understand how the different factors influenced each other.

2.1. Sample Preparation

We extracted the coffee grounds to get the liquid base, then added the SCOBY to start the kombucha fermentation, followed by controlled incubation.

2.1.1. Coffee grounds liquid

After the coffee ground kombucha was ready, we collected samples based on the different treatment groups. To prepare them for testing, the samples were extracted using distilled water at 60°C for an hour, then filtered. The final liquid was immediately frozen at −20°C until it was required for testing. For the phenolic and antioxidant assays, we had to dilute the samples with distilled water; this crucial step ensured that the absorbance values were accurate and landed within the established calibration curve range [12, 13].

2.1.2. Flowchart of kombucha fermentation research

To begin the fermentation, we used rejuvenated, seven-day-old SCOBY cultures. These starters were combined with the liquid obtained from the coffee grounds extraction. We tested three different sugar sources at specific concentrations: sucrose (10%), glucose (18%), and fructose (18%) (all w/v). Each 200 mL vessel was set up with a 10% kombucha solution, a single SCOBY, and the appropriate sugar ratio (10% sucrose, 18% glucose, or 18% fructose). All tests were run in triplicate for reliability. The fermentation took place in an incubator strictly maintained at 28°C. Key parameters—reducing sugar, acidity, pH, total phenol, and TA—were measured frequently across the 15-day period, specifically on days 0, 2, 4, 5, 6, 7, 9, 11, 13, and 15, following the workflow and schedule shown in **Figures 1** and **2**.

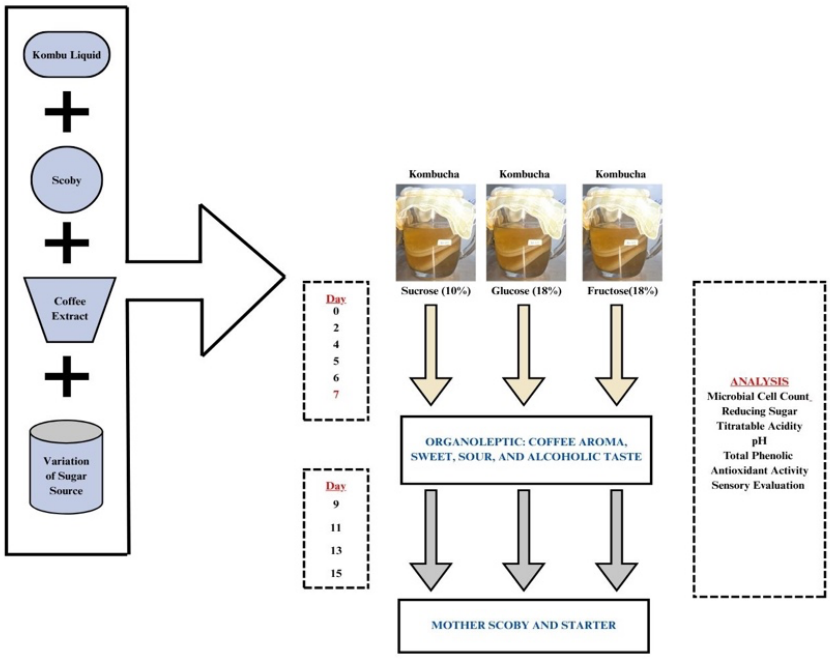

Figure 1. Flowchart of kombucha fermentation research.

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(a) (b)

Figure 2. Kombucha fermentation with sucrose, glucose, and fructose (a) day 4 (b) day 5.

2.2. Microbial Cell Count Using a Hemocytometer

The microbial cell count was performed using a direct counting technique with a hemocytometer [14]. Each sample was homogenized prior to slide preparation. A drop of the sample was placed on the observation plate, and the number of visible microbial cells was counted. Subsequently, the bacterial and yeast cells observed were recorded separately. The total counts of bacterial and yeast cells were determined at the Biochemistry Laboratory, Department of Chemistry, Faculty of Science and Mathematics, Satya Wacana Christian University (UKSW).

2.3. Reducing Sugar Content

The DNS method was used to determine the amount of reducing sugar. The core method involved reacting the samples with the DNS reagent, boiling them briefly at 95°C, cooling them down, and finally measuring the resulting color change at 540 nm. The final concentrations were determined using a glucose standard curve, with results expressed as mg glucose equivalents per mL [13, 15].

2.4. pH Measurement

The pH meter was calibrated using three buffer solutions prior to its use (pH 4.01, 7.00, and 10.00). To take a reading, the electrode was immersed in the room-temperature sample (20–25 °C) and waited for the reading to stabilize. All measurements were performed in triplicate for reliable results [16].

2.5. Titratable Acidity

Titratable acidity (TA) was determined by titrating 10 mL of the sample with 0.1 M NaOH to pH 8.2 (using phenolphthalein indicator or pH meter). Results were expressed as grams of acetic acid per liter (g/L) according to the following Eq. (1).

$$\text{TA (g/L)} = \frac{V_{NaOH} \times M_{NaOH} \times 60.05}{V_{sample}} \quad (1)$$

where 60.05 is the molecular weight of acetic acid [17,18].

2.6. Total Phenolic Content

The Folin–Ciocalteu method was used to measure Total Phenolic Content. We started by combining 0.5 mL of sample with 2.5 mL of the 10% Folin–Ciocalteu reagent and incubating for five minutes. Then, we introduced 2 mL of 7.5% Na_2CO_3. The final color reaction developed over 30 minutes at room temperature in the dark, and the absorbance was read at 765 nm.

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Concentration was reported in mg GAE/L (gallic acid equivalents per liter), calculated against a gallic acid standard curve [12, 13, 19].

2.7. Antioxidant Activity (DPPH Assay)

The treatment in this station goes through several phases shown schematically in **Figure 1**. As illustrated schematically, this stage involved several sequential phases, encompassing an antioxidant activity test, preparation of a stock solution, determination of the maximum wavelength of DPPH, and an antioxidant activity test using the DPPH method.

2.7.1. Antioxidant activity test [20]

The analytical instruments used included a UV-Visible Spectrophotometer (Shimadzu 00787) and a pH meter (Elmetron CP-505). Additional laboratory equipment used in this study included Petri dishes, measuring cylinders, drop pipettes, micropipettes, aluminum foil, stainless steel electric kettles, clean cloths, and rubber bands. The materials used consisted of fermented coffee ground kombucha, 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution, methanol (p.a.), and distilled water (aquadest).

2.7.2. Preparation of stock solution

An amount of 0.5 mg of DPPH was weighed and dissolved in 50 mL of methanol p.a to obtain a concentration of 10 mg/L. The preparation of the control solution began with making a 10 mg/L DPPH stock solution, which was stirred until homogeneous. The solution was then incubated for 30 minutes at a temperature of 37ºC. The pH measurement of the kombucha tea sample was carried out by taking about 100 mL of kombucha tea solution, placing it into a beaker glass, and then measuring the pH of the kombucha tea solution using a pH meter.

2.7.3. Determination of the maximum wavelength of DPPH

To find the maximum absorption wavelength for DPPH, we first prepared a 10 mg/L stock solution. This solution was then incubated at 37°C for 30 minutes. Finally, we measured its absorbance across the spectrum, specifically from 400 to 800 nm.

2.7.4. Antioxidant activity test using the DPPH method

To measure the antioxidant activity, we combined 1 mL of the DPPH solution (10 mg/L) with 50 µL of the sample. This mixture was then brought up to a total volume of 5 mL using methanol (p.a.). After incubating for 30 minutes at 37°C, the absorbance was read at 513 nm. The final antioxidant activity was determined by seeing how much the sample inhibited the absorption of the DPPH radical, calculated using the following percentage in Eq. (2).

$$\%\ inhibition = \frac{(absorbance\ of\ \text{DPPH} - absorbance\ of\ sample)}{absorbance\ of\ DPPH} \times 10 \quad (2)$$

Description:

Abs DPPH (control) : Absorbance of DPPH radical (10 mg/L) at a wavelength of 513 nm

Abs Sample : Absorbance of the sample in DPPH radical solution (10 mg/mL) at a wavelength of 513 nm

2.8. Sensory Evaluation

The study included a sensory evaluation and received approval from the institution, namely the Directorate of Research and Community Service (DRPM) of Satya Wacana Christian

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University. Prior to participation, all panelists were provided with a clear explanation regarding the purpose of the study, the procedures involved, the expected benefits, potential risks, and their rights as research participants. Participation was voluntary, and informed consent was obtained from each panelist before the sensory evaluation was conducted. They judged the samples based on six criteria: aroma, color, coffee flavor, sweetness, sourness, and alcoholic taste. The scores were assigned using the following scale:

9 = Extreme liking
8 = Great liking
7 = Moderate liking
6 = Slight liking
5 = Neither liking nor disliking
5 = Neither liking nor disliking
4 = Slight disliking
3 = Moderate disliking
2 = Great disliking
1 = Extreme disliking

The data obtained were presented in the form of a radar chart (spider diagram) [21].

2.9. Pearson Correlation

This study included a Pearson correlation analysis to describe the relationships among biochemical variables for each sugar source (glucose, sucrose, fructose) during fermentation, as this approach is widely applied in the analysis of functional food fermentations (Barakat et al., 2024; Muflihah et al., 2021). The correlation coefficient (r) represents a measure of covariance-based correlation that eliminates the issue of scale. The formula for the correlation is presented as follows Eq. (3) [22].

$$r_{XY} = \frac{Cov_{XY}}{S_X S_Y} = \frac{\sum(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{(X_i-\bar{X})^2}\sqrt{(Y_i-\bar{Y})^2}} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1. Dynamics of Microbial Cell Growth During Coffee Ground Kombucha Fermentation with Different Sugar Sources

The microbial growth patterns during fermentation (see **Figure 3**) showed that sucrose and fructose followed a similar trajectory up until day 9. In contrast, glucose maintained a lower, steadier population. However, after day 9, fructose saw a dramatic spike in bacterial count, while the levels for sucrose and glucose began to drop. A Pearson correlation analysis (**Table 1**) linked microbial growth to sugar consumption, and the fructose treatment showed the strongest relationship (-0.454). Sucrose (-0.357) and glucose (-0.253) followed. Since all these values are negative, it confirms that as the sugar concentration decreased, the bacterial cell count increased. This growth profile strongly suggests that fructose is the most effective sugar for driving coffee ground kombucha fermentation.

Considering the fructolysis pathway, where fructose is chemically converted into glucose (a process called isomerization, according to [23], it seems likely that the necessary enzymes become much more active around day nine of the fermentation. Overall, the patterns of bacterial growth shown in **Figure 3** are fascinating, suggesting that the bacteria are switching the type of carbon source they utilize as the fermentation progresses.

The dominant bacteria in kombucha are typically Acetic Acid Bacteria (AAB), mainly belonging to the *Komagataeibacter* genus [24-26]. Specific, common species include *K. intermedius, K. xylinus, K. rhaeticus, K. saccharivorans*, and *K. kombuchae* [27-29]. Beyond the acetic acid bacteria, kombucha also contains species of Lactic Acid Bacteria (LAB), including the genera *Lactobacillus*, *Leuconostoc*, and *Bifidobacterium* [10]. As for yeast, the main players come from many genera, with dominant species often found in *Zygosaccharomyces* (*Z. bailii*), *Saccharomycodes* (*S. ludwigii*), *Candida*, *Torulaspora*, *Pichia*,

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Brettanomyces/Dekkera (*B. bruxellensis*), *Schizosaccharomyces* (*S. pombe*), and *Saccharomyces* (*S. cerevisiae*) [6, 25, 28, 30, 31].

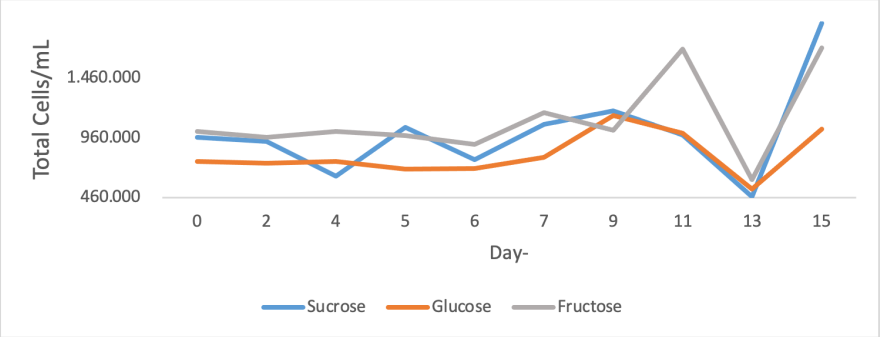

Figure 3. Dynamics of microbial cell growth during coffee ground kombucha fermentation with different sugar sources.

Table 1. Results of Pearson correlation analysis.

Pearson Correlation	Sucrose	Glucose	Fructose
Reducing Sugar and Microbial Cell Count	-0.357	-0.253	-0.454
Total Acidity (TA) and pH	-0.180	-0.761	-0.591
Reducing Sugar and Total Acidity (TA)	0.203	-0.945	-0.610
Total Phenolic Content and Antioxidant Activity	0.015	0.745	0.729

The unique nature of kombucha stems from its bacteria and yeasts existing in a state of both cooperation and competition. This dynamic relationship triggers a series of biochemical reactions that produce the drink's key components, such as acetic acid, gluconic acid, glucuronic acid, and ethanol [32]. These resulting substances constantly shape both the flavor profile and the microbial composition of the kombucha culture [6, 25, 28, 31]. Although we have a good understanding of the microbes and chemistry in commercial kombucha, there is still a shortage of thorough studies dedicated specifically to its sensory characteristics [33].

3.2. Dynamics of Reducing Sugar, Total Acidity, and pH During Coffee Ground Kombucha Fermentation with Different Sugar Sources

After 15 days, the coffee ground kombucha fermentation results clearly showed that the type of sugar used—sucrose, glucose, or fructose—had a unique impact on the final chemical makeup. This intense fermentation process was defined by three linked changes: sugar concentration dropped, total acidity rose, and the pH decreased. **Figure 4** provides a visual representation of these three dynamic trends.

Figure 4 clearly shows that reducing sugar content dropped significantly in every batch, proving the SCOBY culture was actively consuming the sugar. This decrease is a direct sign of microbial activity; for the sucrose batch, the enzyme invertase first broke it down into glucose and fructose. Glucose showed the fastest and largest decrease, plunging from 237.98 to 111.76 mg/mL (a 53% reduction). This suggests that glucose is the microbes' preferred food source. Since glucose is rapidly broken down through glycolysis to produce ethanol and organic acids, it enters the fermentation pathway quickly. Fructose, conversely, is utilized more slowly, causing its levels to decrease more gradually. This difference in consumption speed is clearly visible in **Figure 4**, where the glucose curve falls much faster than the fructose curve [24].

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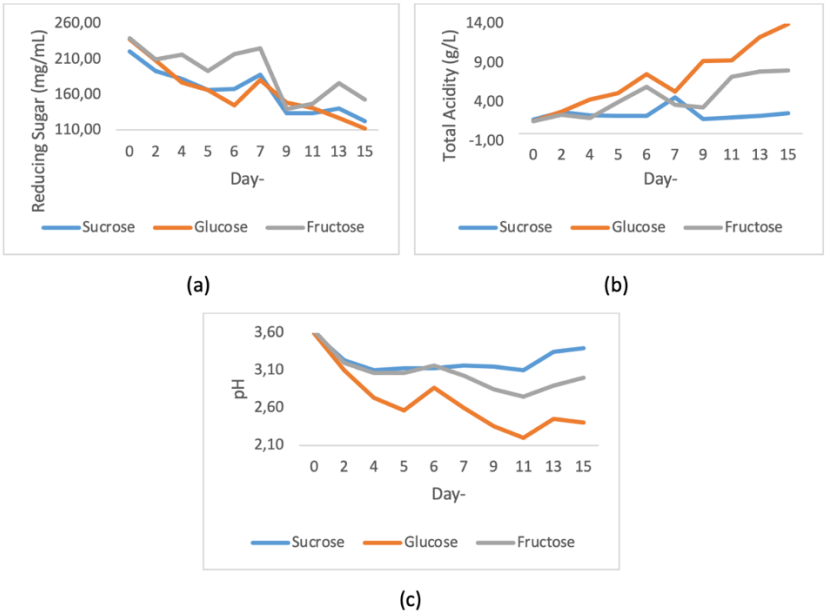

Figure 4. Fermentation dynamics of coffee ground kombucha with different sugar sources on (a) reducing sugar concentration, (b) total acidity, and (c) pH.

Glucose generally serves as the primary source of carbon and energy for both the yeast and bacteria within the SCOBY. Yeast first must break down sucrose into its simpler parts: glucose and fructose. Then, both the yeast and bacteria use these simple sugars in a process called glycolysis to generate the energy (ATP) needed for them to grow and reproduce. As these sugars are metabolized, they create various organic acids as by-products. These different sugar consumption rates ultimately dictate the final chemical makeup, including the production of acetic acid and other bioactive compounds that give kombucha its functional benefits [6].

As the sugar is used up, we see a sharp jump in Total Acidity (TA), especially after the seventh day. The glucose treatment led to the highest acid buildup, both mid-fermentation (3.31 g/L on day seven) and at the end (13.94 g/L). This result shows that microbes not only consume glucose faster but also convert it into organic acids more efficiently. Different bacteria contribute to this acidity: Acetic Acid Bacteria change the ethanol (produced by the yeast) into acetic acid [34]. Lactic Acid Bacteria transform sugars into lactic acid [35]. Additionally, other bacteria in the kombucha convert glucose into gluconic acid [35].

The buildup of organic acids increases the Total Acidity [36], and these acids then release hydrogen ions (H^+) into the liquid. This rise in H^+ concentration is what directly lowers the pH, making the kombucha more acidic [37]. Notably, the glucose batch achieved the lowest pH (2.20), creating an environment harsh enough to inhibit pathogenic microorganisms. Taken together, these results demonstrate a classic, efficient fermentation process where microbes consume different sugars at varying speeds and yield unique results.

The rise in Total Acidity (TA) across all three sugar groups perfectly mirrors the observed pH dynamics. This correlation is confirmed by the Pearson analysis (**Table 1**), which showed negative coefficients between TA and pH: sucrose at -0.180, glucose at -0.761, and fructose at -0.591. Once again, glucose proved to be the strongest driver, exhibiting the most intense correlation in both the reducing sugar/TA relationship and the TA/pH relationship. Finally, remember that in this aerobic kombucha brewing, the acetic acid bacteria utilize oxygen to oxidize the ethanol, producing the main product, acetate [38].

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According to the Pearson correlation results in **Table 1**, the link between reducing sugar and Total Acidity (TA) was strongly negative for glucose (-0.945) and fructose (-0.610). Sucrose, however, showed a weak positive correlation (0.203). The exceptionally strong negative correlation for glucose (r = -0.945) clearly demonstrates that as glucose is consumed, organic acid production spikes. This supports the idea that glucose is the preferred food source for kombucha microorganisms, accelerating the creation of fermentation acids and the resulting pH drop [10]. Furthermore, this strong negative relationship indicates that the glucose is being actively used up to create acids. Research also suggests glucose can specifically boost the production of organic acids like gluconic acid [39].

The negative correlation for fructose (r = -0.610) shows that as fructose levels drop, acid production goes up. For sucrose, its primary role in acid formation comes from its enzymatic breakdown—the enzyme invertase hydrolyzes it into glucose and fructose [40]. Importantly, both glucose and fructose are closely linked metabolically, as most fructose can be converted into glucose thanks to the enzyme isomerase [41].

The weak correlation observed for sucrose can be explained by how its breakdown is tied to H^+ concentration [42]. When the pH rises, sucrose hydrolysis speeds up (breaking it into glucose and fructose), but when pH drops, the hydrolysis rate slows. Therefore, as sucrose is consumed, we see a decrease in Total Acidity (TA) and an increase in pH—a pattern also seen with fructose. Based on all these results, fructose appears to be the most suitable sugar. It produces moderate TA levels, offering a balance compared to the aggressive acid production seen with the glucose treatment, which clearly drove a much greater increase in TA (as shown in **Figure 3**).

3.3. Dynamics of Total Phenolic Content and Antioxidant Activity During Coffee Ground Kombucha Fermentation with Different Sugar Sources

Kombucha fermentation with different types of sugars showed variations in total phenolic formation and antioxidant activity (**Figures 5a** and **5b**). The total phenolic content in the three sugar source variations showed the same trend. However, fructose had the highest and most stable phenolic content compared to the other sugar sources. On day 7, which is the optimal day for functional beverages, fructose had a total phenolic content of 1309.16 µg/mL, while sucrose and glucose had 1203.90 µg/mL and 1133.72 µg/mL, respectively. By the last day of the study (day 15), fructose still exhibited the highest phenolic content at 1341.81 µg/mL. This indicates that fructose is more effective in preserving polyphenols, possibly because the microbial metabolic pathways are more compatible with fructose [43].

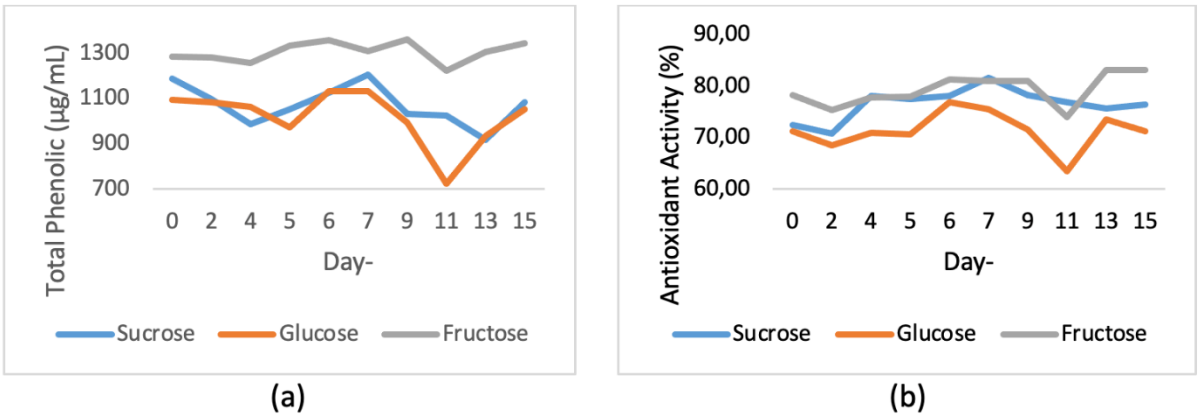

Figure 5. Dynamics of coffee ground kombucha fermentation with different sugar sources on (a) total phenolic content and (b) antioxidant activity.

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The results for antioxidant activity mirrored the phenolic content. By day 15, the fructose batch again stood out with the highest activity at 83.22%, compared to 76.51% for sucrose and 71.22% for glucose. A Pearson correlation (**Table 1**) confirmed a positive relationship between phenolics and antioxidant activity across all three sugar types: 0.015 for sucrose, 0.745 for glucose, and 0.729 for fructose. This clear positive link supports the finding that polyphenols play a key role in neutralizing harmful free radicals by acting as electron donors [44].

The changes observed in total phenolic content and antioxidant activity across the three sugars are linked to the microbes either breaking down or converting the polyphenols to fuel their own growth. This biotransformation is known to happen, with organisms like *Saccharomyces* sp. and acetic acid bacteria capable of turning existing phenolics into different bioactive compounds [45]. Even though the overall phenolic content dropped at certain times, compounds like catechins, phenolic acids, and flavonoids remained important contributors to the final antioxidant capacity [46].

Overall, fructose is the most effective sugar source for making kombucha. It delivers the most stable levels of both phenolic compounds and antioxidant activity, likely because of the natural phenolics already present in the fructose medium. While sucrose remains a viable option, it yields only moderate results. Conversely, glucose causes a sharp drop in these beneficial compounds halfway through fermentation. This confirms that the type of sugar is the most crucial factor in determining the final functional quality of the kombucha.

3.4. Results of Organoleptic Evaluation of Coffee Grounds–Based Kombucha Fermentation

Comparing the changes in microbial cell growth, sugar consumption, acidity TA and pH, phenolic content, and antioxidant activity reveals a complex set of biochemical reactions. Although the present study did not quantify specific organic acids such as gluconic acid, glucuronic acid, or acetic acid, previous studies have reported that kombucha fermentation typically produces several key metabolites, including acetic acid, gluconic acid, glucuronic acid, and ethanol [32]. These metabolites have been widely reported to influence the physicochemical characteristics, flavor profile, and microbial dynamics of kombucha during fermentation [6, 25, 28, 31].

Based on **Figure 3**, the most optimal sugar source on day 7 is fructose. This is because fructose exhibits a total acidity range of 2.75–3.63. These results support the study by [47], which found that the best kombucha flavor and aroma are achieved at pH 3. From the pH perspective, both sucrose and fructose are sugar types in coffee grounds kombucha fermentation that are organoleptically acceptable to the panelists. The organoleptic evaluation can be observed in **Table 2** and the Spider Chart in **Figure 6**).

Table 2. Results of organoleptic evaluation of coffee grounds–based kombucha fermentation.

Sugar Type	Aroma	Color	Coffee Flavor	Sweetness	Acidity	Alcohol Flavor	Average
Sucrose	6.9	6.9	5.4	5.1	5.3	5.1	5.8
Glucose	6.9	6.9	5.6	1.1	1.9	2.0	4.1
Fructose	8.0	7.5	8.0	7.5	7.5	7.0	7.6

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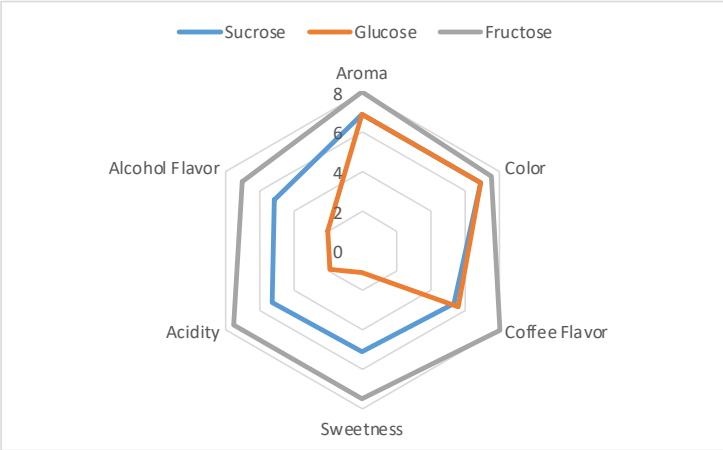

Figure 6. Spider chart of organoleptic evaluation.

Based on evaluations from eight selected panelists, the average sensory scores for the three sugar variations were obtained. The mean scores are visualized in the spider chart (**Figure 6**). As shown in **Figure 6**, the kombucha fermentation using fructose as the sugar source produced the best results in terms of aroma, color, coffee flavor, alcohol note, acidity, and sweetness. In contrast, glucose received the lowest scores across all six sensory evaluation categories. Therefore, fructose is considered the most palatable sugar source variation for consumption. In relation to fermented products as functional beverages, fructose is not only preferred by panelists for its taste but also regarded as the healthiest option due to its antioxidant activity.

4. CONCLUSION

This study demonstrates that the type of sugar significantly influences microbial dynamics and biochemical transformations during the fermentation of coffee-ground-based kombucha. Among the sugars tested, fructose most effectively stimulated microbial activity and metabolite production while promoting a more stable fermentation profile compared with glucose, which led to rapid fermentation, higher acidity, and a greater decline in pH. Fructose also maintained higher levels of total phenolics and antioxidant capacity. Sensory evaluation further confirmed fructose as the most suitable sugar source, yielding balanced acidity, a pleasant flavor profile, and enhanced antioxidant properties. Future research will focus on the supplementation of different nitrogen sources to investigate their potential role in modulating microbial metabolic pathways and enriching flavor compound formation. In addition, further analyses will include the determination of flavonoids and other antioxidant parameters, particularly those associated with the hydrogen atom transfer (HAT) mechanism.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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