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OPTIMIZATION OF DRYING AND BREWING CONDITIONS OF CASCARA FOR KOMBUCHA PRODUCTION BASED ON SENSORY CHARACTERISTICS

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ABSTRACT

Indonesia is among the largest global coffee producers, with an output of 786.19 thousand tons in 2021, largely contributed by smallholder coffee plantations. Coffee fruit is composed of approximately 40% beans and 45% cascara, the latter of which is often discarded and underutilized despite its high polyphenol content. Improper disposal of cascara may cause environmental problems because of its acidity and antinutritional compounds. Cascara represents a promising raw material for functional beverages, such as kombucha, to increase its antioxidant potential. This study focused on developing cascara kombucha from coffee harvested in Magelang, Central Java, a region with distinct geographical characteristics that influence coffee quality. The cascara was dried at different temperatures (35, 40, and 45 °C for 24 h), brewed for 5 and 10 min, and subsequently fermented with a 10% (w/v) kombucha SCOBY for 8 d before pasteurization and storage. Sensory evaluation was performed by trained panelists using Quantitative Descriptive Analysis, followed by a hedonic acceptance test with 26 untrained panelists. The results demonstrated that drying at 45 °C combined with 5 min brewing yielded the highest hedonic score (4.88), while drying at 35 °C with 5 min brewing provided a comparable result (4.73) without significant difference. A longer brewing time (10 min) increased the turbidity. Optimization using DX13 analysis indicated that drying at 35 °C for 24 h and brewing for 5 min achieved the highest desirability for more effective production. These findings suggest that cascara kombucha has potential as a novel functional beverage, although further optimization is required to maximize its antioxidant and phenolic retention.

Keywords: brewing, cascara, drying, kombucha, optimization

INTRODUCTION

Coffee production in Indonesia has shown an increasing trend annually. In 2021, production reached 786.19 thousand tons, representing a 3.12% increase compared to the previous year, with the majority originating from smallholder plantations that account for 99.32% of the total coffee cultivation area in the country (Badan Pusat Statistik, 2022). Domestic coffee consumption has also experienced positive growth, with the highest annual growth rate of 1.7% during 2017–2021, surpassing the global coffee consumption growth rate of only 1.0% (International Coffee Organization, 2021). This condition reflects the growing interest of Indonesian society in coffee consumption, in line with the increase in its production.

Coffee fruit consists of approximately 45% peel (cascara), 10% mucilage, 5% parchment skin, and 40% coffee beans (Nurhayati et al., 2020). Despite being the largest component, the peel or cascara is often discarded during commercial coffee processing, as only the beans are used. Cascara has mainly been used as a compost, bioethanol, and animal feed. Nevertheless, this waste can cause considerable environmental problems. Compounds such as caffeine, polyphenols, and tannins in cascara contribute to environmental pollution in coffee-producing countries (Anal, 2017). The acidic nature of coffee peels and mucilage may also cause equipment corrosion and complicate disposal processes. If released into aquatic environments, waste can lower water pH and endanger fish and other aquatic organisms (Riandani et al., 2022). Furthermore, the utilization of cascara as animal feed is limited because of the presence of caffeine and tannins, which act as antinutritional factors (Esquivel and Jimenez, 2012).

Although cascara has several negative effects, it contains high levels of polyphenols that are beneficial as antioxidant compounds for humans. Antioxidants play a role in scavenging free radicals that accumulate in the body, thereby helping to prevent degenerative diseases, such as cancer and diabetes (Laila et al., 2024). Recently, the use of cascara as a functional beverage ingredient has gained increasing attention, for instance, in the form of cascara tea prepared similarly to conventional tea. This beverage has gained popularity in several coffee-producing countries. Cascara infusion produces a reddish-brown color similar to that of tea (Judkis, 2017), with a fruity aroma described as a combination of blackcurrant and watermelon (Pabari, 2014). Other studies have reported cascara aromas resembling rose, cherry, mango, and tobacco (Muzaifa et al., 2019).

The antioxidant capacity of cascara is influenced by its phenolic content, including protocatechuic acid, chlorogenic acid (Heeger et al., 2017), and hydroxycinnamic acids (Cubero-Castillo et al., 2017). To date, cascara has been processed using brewing methods. One alternative approach is to ferment cascara into kombucha tea. Kombucha is a fermented beverage prepared from brewed leaves or fruits with added sugar, followed by fermentation with a starter culture known as the Symbiotic Culture of Bacteria and Yeasts (SCOBY) (Nurhayati et al., 2020).

The fermentation process, which typically lasts 1–2 weeks, can influence the sugar content, alcohol content, pH, and antioxidant capacity. During fermentation, *Saccharomyces cerevisiae* breaks down glucose into ethanol, whereas *Acetobacter xylinum* oxidizes ethanol into acetic acid. Microbial enzymatic activity during fermentation may also enhance the levels of free polyphenols, as enzymes release bound polyphenols, making them more detectable (Zubaidah et al., 2012). However, only a small fraction (5–10%) of dietary polyphenols is absorbed by the human body. Unabsorbed polyphenols reach the large intestine, where they interact with the gut microbiota. Rodríguez-Daza et al. (2021) highlighted the dual action of polyphenols, which can stimulate probiotic bacterial growth while suppressing pathogenic bacterial populations.

The physical and chemical characteristics of coffee fruits vary across regions owing to geographical differences. According to Hu et al. (2024), higher elevations tend to produce coffee with chemical compositions that are associated with more complex flavors. Magelang Regency is characterized by a basin landscape surrounded by five mountains, including Mount Sumbing. Coffee in this region is cultivated at altitudes ranging from 900 to 2,000 m above sea level (Direktorat Jenderal Kekayaan Intelektual, 2023). Since 2016, the Ministry of Agriculture has designated Magelang as a national priority area for coffee plantation development (Kementerian Hukum dan Hak Asasi Manusia Republik Indonesia, 2022). With these distinctive geographical conditions, coffee from Magelang is assumed to have unique flavor profiles and physicochemical properties.

In kombucha preparation, cascara must be dried to facilitate the brewing process. Proper control of temperature and time during brewing is essential to ensure the safety of the product. However, heat application during drying and brewing may affect polyphenol content, as these compounds possess chemical structures that are highly susceptible to thermal degradation, which can reduce antioxidant activity (Kurniati et al., 2019; Dewi et al., 2022). Furthermore, the drying temperature significantly influences the aroma and color quality of cascara tea infusions (Tampubolon et al., 2024), which subsequently undergo fermentation.

To date, studies specifically investigating the effects of drying temperature and pasteurization on the sensory characteristics of cascara kombucha, particularly from Magelang coffee, are limited. The present study builds upon a previous study that compared Arabica coffee cherries with and without sorting. The

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findings indicated that the sensory attributes of the two products did not differ significantly from those of commercial kombucha. However, heating and drying processes have been shown to reduce the antioxidant and phenolic contents of kombucha (Gunawan et al., 2025). Therefore, determining the appropriate drying and pasteurization temperatures is necessary to obtain cascara kombucha with optimal antioxidant activity.

MATERIALS AND METHODE

Material

The materials used in this study included cascara, SCOBY (Symbiotic Culture of Bacteria and Yeast), and granulated sugar. Cascara was obtained from coffee harvested by farmers in the Windusari District, Magelang Regency. The cascara used consisted of sorted peels from ripe coffee cherries, whereas cascara from unripe green cherries was discarded. Prior to use, the cascara was thoroughly washed, packed in ziplock plastic bags, stored in a freezer, and subsequently dried using a dehydrator at the designated treatment temperature. SCOBY was purchased online from a local kombucha culture supplier and used as a fermentation starter. Granulated sugar was sourced from a local market in Magelang and served as the sucrose source during the kombucha fermentation process.

Experiment Design and Analysis

This study employed a 3×2 factorial experimental design with two treatment factors: cascara drying temperature (35, 40, and 45 °C) and brewing time (5 and 10 min), resulting in six treatment combinations (35-5, 35-10, 40-5, 40-10, 45-5, and 45-10). Each treatment combination was replicated twice, yielding 12 samples. The observed variables included pH, total soluble solids (°Brix), and sensory characteristics assessed through Quantitative Descriptive Analysis (QDA) and an overall hedonic test. This design was used to evaluate the effects of drying temperature and brewing time on the physicochemical and sensory qualities of cascara kombucha. Data optimization analysis was performed using Design Expert 13 software with the Response Surface Method, while sensory test data were analyzed using ANOVA followed by Duncan's and Dunnett's post-hoc tests at a significance level of 0.05.

Research Prosedure

Postharvest Handling of Coffee Cherries

Coffee cherries were first sorted based on quality and ripeness, with unripe green cherries being discarded. Cascara from ripe cherries was then washed and stored in ziplock plastic bags in a freezer to prevent the loss and evaporation of the bioactive compounds. Subsequently, the cascara was dried using a dehydrator at 35, 40, and 45 °C for 24 h. The dried cascara was then repackaged in zip-lock plastic bags with silica gel and stored at room temperature.

Preparation of Cascara Kombucha

Cascara tea was prepared by mixing 1% (w/v) dried cascara and 10% (w/v) sucrose in 3 liters of water, following the method described by Nurhayati et al. (2020). The solution was boiled and maintained for 5 and 10 min according to the treatment variation. The cascara infusion was subsequently transferred into glass jars and allowed to cool overnight at room temperature. Thereafter, the infusion was inoculated with 10% (w/v) kombucha SCOBY and fermented for 9 days, with pH measurements taken every 3 days. The fermented cascara solution was then separated from the culture, pasteurized at 72 °C for 15 s, and bottled in tightly sealed 250 mL plastic containers for further analysis.

Analytical Procedures

Physicochemical Analysis

pH testing was conducted to determine the acidity level of kombucha throughout fermentation and in the final product, as pH is a key indicator of the safety and stability of fermented beverages. Measurements were performed using a calibrated pH meter with pH 7 and pH 4 buffer solutions, following Puspaningrum et al. (2022). Total soluble solids were measured to determine the concentrations of dissolved compounds, such as sugars, organic acids, and bioactive fermentation products. The analysis was carried out using a manual refractometer, expressed in °Brix, by placing a drop of sample on the prism and reading the value from the optical scale.

Sensory Evaluation

Sensory evaluation of cascara kombucha was conducted using the QDA method, with parameters including aroma, texture, color, and taste, to assess descriptive sensory characteristics. The evaluation involved six trained panelists and 26 untrained panelists recruited from students of the Department of Food Technology. Additionally, a hedonic test was conducted to assess consumer acceptance of the product, involving the same 26 untrained panelists. A seven-point overall hedonic scale was employed, ranging from “Dislike Extremely” to “Like Extremely.” The panelists completed the evaluation forms based on their individual responses. Water was provided between the samples to neutralize taste perception.

RESULTS AND DISCUSSION

Physicochemical Analysis

The results of the total soluble solids (°Brix) test under the different drying and brewing treatments are presented in Figure 1.

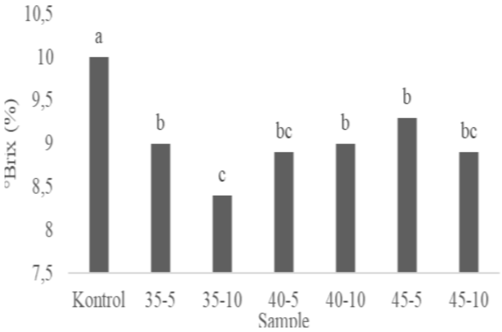

Figure 1. Effect of drying and brewing on total soluble solids (°Brix) of cascara kombucha. Bars followed by the same letters indicate no significant difference (DMRT, α = 5%). Cascara drying temperature was 35, 40 and 45 ºC, while the brewing time were 5 and 10 min.

The control sample recorded a total soluble solids value of 10.0%, whereas cascara kombucha after fermentation showed reduced values ranging from 8.4% to 9.3%. This reduction indicates that fermentation by the microbial consortium of kombucha (SCOBY) utilized simple sugars as the main substrate, thereby decreasing the total soluble sugar concentration in the medium. These findings are consistent with Shafira et al. (2022), who reported that cascara kombucha fermentation consistently decreases °Brix with increasing fermentation time.

Analysis of variance (ANOVA), followed by Duncan’s test (α = 0.05), revealed three homogenous groups of °Brix values. The 35–10 treatment (8.4%) formed a distinct group with the lowest value, which was significantly different from that of the control (10.0%). Treatments 40–5 (8.9%) and 45–10 (8.9%) overlapped with the intermediate group (9.0–9.3%), showing no significant difference from treatments 35–5 (9.0%), 40–10 (9.0%), and 45–5 (9.3%). The control (10.0%) was classified into a separate subset with the highest value. Accordingly, only the 45–5 treatment (9.3%) approached the control, although it remained significantly different from it.

The lowest °Brix value (8.4%) in the 35–10 treatment can be attributed to prolonged brewing at a lower drying temperature, which likely extracted more sugars and bioactive compounds, enriching the initial substrate and enabling more intensive fermentation. Conversely, the 45–5 treatment, with a higher drying temperature and shorter brewing time, yielded a higher post-fermentation °Brix value (9.3%) because fewer soluble sugars were initially extracted, thereby limiting the microbial sugar consumption. Higher drying temperatures (40 °C and 45 °C) consistently produced higher °Brix values (8.9–9.3%) than the 35–10 treatment, suggesting that the availability of soluble sugars in the substrate was limited from the outset. This may be due to the degradation of simple sugars during the high-temperature drying process. Another plausible explanation is that high-temperature drying reduced the cascara moisture content, causing sugars initially bound to water to revert to the solid phase. These sugars require a longer time to dissolve during brewing, thereby restricting fermentation intensity and preventing drastic °Brix reductions compared to low-temperature drying.

These findings are consistent with those of Martínez-Soto et al. (2023), who reported that postharvest treatments, such as size reduction, affect the content of simple sugars and bioactive compounds in cascara. Villarreal-Soto et al. (2018) highlighted that

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the availability of initial substrates is a key determinant of kombucha fermentation intensity. Furthermore, Tampubolon et al. (2024) observed that higher drying temperatures significantly ($p < 0.01$) reduced moisture and polyphenol content, supporting the hypothesis that thermal drying may reduce the amount of extractable solutes in the initial stage.

The results of the pH measurements during fermentation under different drying and brewing treatments are presented in Figure 2.

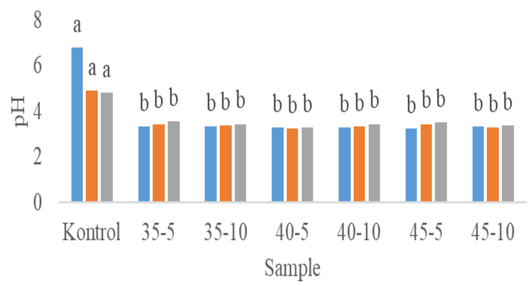

Figure 2. Effect of drying and brewing on the pH of cascara kombucha. Bars followed by the same letters indicate no significant difference (Dunnett's test, α = 5%). Blue, orange, and grey bars represented the 3rd, 6th, and 8th d of brewing. Cascara drying temperature was 35, 40 and 45 ºC, while the brewing time were 5 and 10 min

Dunnett's test confirmed that drying, brewing, and fermentation treatments significantly altered the pH compared to the control (untreated). The pH of the control sample decreased only to 4.8 by day 8, whereas the pH of the fermented treatments rapidly decreased to a range of 3.3–3.6 by day 3. This significant reduction highlights that active microbial fermentation in kombucha was the primary driver of organic acid production (mainly acetic, gluconic, and lactic acids), a process that was absent in the control (Jayabalan et al., 2014; Villarreal-Soto et al., 2018).

These results reinforce the role of cascara fermentation in lowering pH to levels that ensure microbiological stability (<4.0), making the product safer for storage than the control (Marsh et al., 2014). The sharp decrease in pH in fermented cascara kombucha was primarily caused by the production of organic acids, particularly acetic and gluconic acids, by the symbiotic microbial community of acetic acid bacteria and yeasts (Villarreal-Soto et al., 2018). The availability of simple sugars extracted from cascara through drying and brewing supports this fermentation activity. Consequently, all fermentation treatments exhibited consistently low final pH values (3.3–3.6), indicating optimal fermentation. These results are consistent with those of Jayabalan et al. (2014), who reported that kombucha fermentation decreases the pH to 2.5–3.5 within 7–10 days owing to organic acid accumulation.

Although different drying temperatures and brewing times produced variations in the final °Brix values (as previously discussed), the pH values were relatively uniform across the treatments. This suggests that despite differences in initial sugar availability, kombucha microbes consistently reduced pH to similar levels, likely due to the buffering effect of the fermentation system and uniform activity of acetic acid bacteria under the given substrate conditions.

Sensory Evaluation

The results of the sensory analysis are presented in Figure 3.

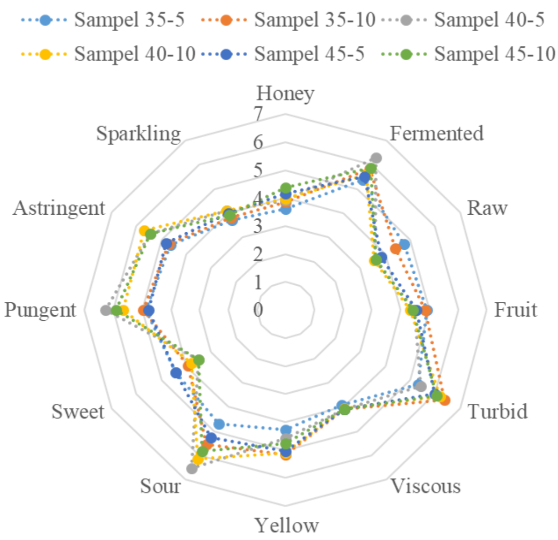

Figure 3. Spider web diagram showing the effects of drying and brewing on the sensory quality of cascara kombucha. Cascara drying temperature was 35, 40 and 45 ºC, while the brewing time were 5 and 10 min.

Quantitative Descriptive Analysis (QDA) is one of the most widely applied sensory descriptive methods for evaluating the sensory profiles of food products. Trained panelists assess the intensity of predefined sensory attributes, such as aroma, taste, aftertaste, texture, and visual characteristics. Evaluations are performed using numerical intensity scales (e.g., 0–10), allowing for the quantitative measurement of complex sensory perceptions (Stone et al., 2020). This method is regarded as reliable and reproducible because it relies on trained panelists who undergo calibration, thereby minimizing individual biases. QDA has been extensively applied in studies of fermented products, including tea, coffee, and kombucha, to assess the influence of processing on consumer perceptions (Lawless & Heymann, 2010).

QDA results are commonly presented in spider web (radar) diagrams, which depict the intensity of each attribute on a circular coordinate plane. Each axis represents a sensory attribute, and intensity values are plotted by distance from the center, facilitating intuitive visualization of differences among treatments.

Analysis of the spider web diagram using ANOVA followed by Duncan's test revealed that the "Honey" aroma was most prominent in the 45–10 treatment, significantly different from the 35–5 treatment, which, together with 35–10, showed stronger "Raw" aroma. Extended drying and brewing periods tended to increase the intensity of the honey-like aroma while diminishing the raw aroma attributes in cascara kombucha. Samples brewed for 10 min exhibited distinct sensory traits, namely turbidity (opaque texture), enhanced yellow color intensity, and increased astringency. Prolonged brewing has been reported to increase turbidity in tea-based beverages (Wang et al., 2021) and extract polyphenolic compounds that contribute to a pronounced aroma and taste (Su et al., 2025; Guo et al., 2021).

Interestingly, the 40–5 treatment produced the most intense and sharp flavor profile, characterized by a strong fermentative aroma, acidity, and pungency. Samples brewed for 10 min also exhibited high values for these attributes, although the 40–5 treatment remained superior. Conversely, sweetness was more pronounced in the samples brewed for 5 min, except for 40–5. These results were not fully consistent with the °Brix analysis shown in Figure 1. Although the 35–10 treatment had the lowest total soluble solids (suggesting the highest fermentation activity), its sensory fermentation attributes were less intense than those of 40–5. However, the °Brix values of these two treatments after fermentation were not significantly different from each other. Similarly, the lowest sweetness intensity was expected in 35–10, given its lowest °Brix, yet QDA indicated that 40–5 had the lowest perceived sweetness. Based on sensory analysis, the 40–5 treatment exhibited the most intensive fermentation activity. At 40 °C drying and 5 min brewing, it is plausible that soluble solids other than sugars were extracted more effectively, resulting in a higher °Brix than 35–10.

Optimization analysis using Design Expert 13 (DX13) was performed considering temperature and time are within the range (possibility of recreating the production using the tools stated in this study), the highest overall hedonic scores resulting in a cascara kombucha product liked by the consumers, minimum turbidity to produce clarity of the product, and low pH as indicators of food safety (to make cascara kombucha a low-risk product, as pathogenic and spoilage microbes will have difficulty surviving in an acidic pH). The hedonic test results showed that the most preferred sample was produced by drying at 45 °C and brewing for 5 min, although its score was not significantly different from most treatments, except for 40–5, which had the lowest acceptance. The minimum turbidity was recorded for the 35–5 treatment, whereas all treatments yielded comparably low pH values.

Response Surface Methodology (RSM) was employed as a statistical and mathematical approach to model and analyze the effects of multiple independent factors on one or more response variables. The primary aim was to identify the optimal factor combinations that yield the most desirable responses (Montgomery, 2017). The experimental design was set using the custom design option, followed by an analysis to

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determine the solution with the highest desirability value. DX13 suggested drying at 35 °C with 5 min boiling as the optimal condition, predicting an overall hedonic score of 4.4, minimum turbidity of 5.240, and a safe pH of 3.442, with a desirability index of 0.553. However, these predicted values require further validation in future studies.

CONCLUSION

This study confirmed that the drying and brewing methods of cascara significantly influenced the physicochemical and sensory characteristics of the resulting kombucha. Sensory analysis revealed distinct differences in profiles across treatments, and statistical tests confirmed that not all treatment conditions yielded results comparable to those of the control. Furthermore, optimization using Response Surface Methodology (RSM) recommended a drying temperature of 35 °C combined with a brewing time of 5 min as the optimal condition, providing a balance between sensory quality, safety, and consumer preference. These findings highlight the importance of selecting appropriate processing conditions to produce high-quality cascara kombucha with potential for industrial-scale production.

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