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Physical and sensory quality of jongkong layer cake with coconut shell and bamboo charcoal

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ABSTRACT

The limited availability of rice straw ash as a traditional natural black colorant has encouraged the exploration of alternative materials for jongkong layer cake. This study aimed to evaluate the effects of coconut shell charcoal powder and bamboo charcoal powder on the physical and sensory quality of jongkong layer cake. An experimental method was employed. Physical quality was evaluated based on grayscale intensity and layer uniformity using ImageJ and analyzed by analysis of variance (ANOVA), while sensory quality was assessed using the duo-trio test and analyzed using the binomial test. Sensory quality was evaluated using a duo-trio discrimination test involving 40 moderately trained panelists, with 20 panelists evaluating each charcoal treatment against the control. The sensory data were analyzed using the binomial test. Sensory evaluation revealed differences only in specific attributes, with coconut shell charcoal differing from the control only in texture, whereas bamboo charcoal differed in black-layer color and aroma. Overall, coconut shell charcoal powder showed greater sensory similarity to the control and may serve as a promising substitute for rice straw ash in jongkong layer cake.

Keywords: bamboo charcoal; coconut shell charcoal; duo-trio test; jongkong layer cake; rice straw ash substitute

INTRODUCTION

Jongkong layer cake is a traditional Indonesian cake characterized by repeated black and white layers and a chewy texture derived from a combination of rice flour, tapioca flour, coconut milk, and sugar (Nimpuno, 2016). Its uniqueness lies in the use of rice straw ash as a natural colorant that produces an intense black color while also contributing distinctive sensory characteristics. In addition to functioning as a colorant, rice straw ash has long been used in various traditional food products because it can produce a relatively stable color during heating (Kusumastuti & Hidayati, 2022).

As attention to the use of natural ingredients in food products increases, the use of natural colorants has become an important aspect in developing safe and sustainable traditional products (Zacharias, 2019). However, the availability of rice straw ash has become increasingly limited because rice straw is now widely utilized for compost, livestock feed, agricultural mulch, and biomass energy production (Singh et al., 2023). In addition, fluctuations in national rice production affect the availability of rice straw as an agricultural by-product, further reducing the availability of rice straw ash for traditional food processing (Akshaya et al., 2023).

These conditions have encouraged the exploration of alternative natural black colorants that are readily available, safe, and capable of maintaining the characteristic appearance of traditional jongkong layer cake. Among the potential alternatives, food-grade coconut shell charcoal and bamboo charcoal have attracted increasing attention because they provide an intense black color and remain stable during food processing (Natarajan et al., 2023). These characteristics suggest that both materials have the potential to replace rice straw ash as natural colorants in traditional food products (Manurung et al., 2024).

Coconut shell charcoal is considered a promising natural colorant because it produces a deep black color and remains stable during food processing. As an abundant agricultural by-product in Indonesia, coconut shell charcoal is also readily available and supports the utilization of agricultural waste. The advantages of coconut shell charcoal include its wide availability, relatively low ash content, stable carbon structure, and ability to produce a uniform black color during heating. However, its porous structure and solid carbon particles may alter water distribution, batter flow, and starch gelatinization. At relatively high concentrations, these characteristics may increase product firmness or produce textural differences compared with rice straw ash.

Ahmad Khorairi et al., (2023) reported that the incorporation of activated charcoal powder derived from coconut shell into banana ice cream successfully produced an attractive black appearance without adversely affecting its physical quality, while the optimum formulation containing 0.3% activated charcoal achieved the best overall treatment. These findings indicate that coconut shell charcoal has considerable potential for application as a natural black colorant in food products. Bamboo charcoal has also been increasingly applied as a food-grade natural colorant because it provides an intense black appearance and remains visually stable during food processing. Previous studies demonstrated that bamboo charcoal has been successfully incorporated into various food products, while maintaining acceptable product quality.

Bamboo charcoal offers several advantages, including high porosity, an intense black appearance, and the use of rapidly renewable biomass. Its strong coloring capacity may allow the desired black appearance to be achieved at a lower concentration. Nevertheless, inadequate grinding, sieving, or dispersion may leave fine particles in the product, resulting in a slightly gritty mouthfeel. Differences in raw material composition and carbonization conditions may also affect color intensity and aroma, causing greater sensory differences from the traditional rice straw ash product.

In addition, Gonzalez et al., (2020) reported that the incorporation of food-grade charcoal into bread produced a distinctive black appearance while maintaining acceptable physicochemical properties and consumer acceptance, although some changes in dough rheology and texture were observed. These findings demonstrate the feasibility of using food-grade charcoal as a natural black colorant in food applications.

The different material characteristics of coconut shell charcoal and bamboo charcoal may explain the sensory differences observed in this study. Coconut shell charcoal has a relatively compact structure and may disperse more uniformly in the batter, resulting in color and aroma characteristics that are closer to those of the control product. However, its interaction with the starch matrix may alter texture. In contrast, bamboo charcoal has high porosity and stronger coloring capacity, but variations in particle size, dispersion, and residual compounds may produce more noticeable differences in black-layer color, aroma, and mouthfeel. Therefore, the suitability of each charcoal material depends not only on its ability to produce a black color but also on its effects on the structural and sensory characteristics of jongkong layer cake.

METHODOLOGY

Materials

The materials used in this study were rice flour, tapioca flour, granulated sugar, salt, coconut milk, suji leaves, pandan leaves, water, rice straw ash, coconut shell charcoal powder (P-IRT No. 2103216430115-27), and bamboo charcoal powder (P-IRT No. 8133216010099-26). Rice straw ash was used as the control, while coconut shell charcoal powder and bamboo charcoal powder were used as alternative natural colorants for the black layer of jongkong layer cake.

Research Stages

The study was conducted at the Food Processing Laboratory, Culinary Arts Education Study Program, Faculty of Engineering, Universitas Negeri Jakarta, from August 2025 to July 2026.

Prior to the main experiment, preliminary formulation selection was conducted through expert judgment involving five expert panelists to determine the optimum concentrations of coconut shell charcoal powder and bamboo charcoal powder. Based on the results of this evaluation, 40% coconut shell charcoal powder and 30% bamboo charcoal powder were selected for the main experiment.

The expert panelists were lecturers from the Culinary Arts Education Study Program who were selected based on their academic competence in culinary product assessment and their familiarity with traditional food products. They evaluated the formulations based on black-layer color, color consistency between layers, charcoal aroma, chewiness, charcoal residue, charcoal taste, sweetness balance, and overall product preference. Based on the results of this evaluation, coconut shell charcoal powder at a charcoal-to-water ratio of 40:100 (w/w) and bamboo charcoal powder at a charcoal-to-water ratio of 30:100 (w/w) were selected for the main experiment. These concentrations, hereafter referred to as 40% and 30%, respectively, were calculated based on the weight of charcoal powder relative to 100 g of water, rather than on the total weight of the colorant solution or the total cake formulation. Thus, the 40% coconut shell charcoal formulation consisted of 40 g of coconut shell charcoal powder mixed with 100 g of water, whereas the 30% bamboo charcoal formulation consisted of 30 g of bamboo charcoal powder mixed with 100 g of water.

The main experiment consisted of three treatments with three replications, resulting in nine experimental units: jongkong layer cake prepared using rice straw ash as the control (L), 40% coconut shell charcoal powder (AK), and 30% bamboo charcoal powder (AB). The resulting samples were then analyzed for physical and sensory quality.

The resulting samples were then analyzed for physical quality and sensory quality. Physical quality was measured using digital image analysis with ImageJ software to objectively evaluate grayscale intensity and layer uniformity (Martínez-Lara et al., 2025). Sensory quality was analyzed using the duo-trio test, a discriminative test used to determine sensory differences between treatment samples and the control sample (Setyaningsih et al., 2018). The colorant solution formulations for each treatment are presented in Table 1.

Table 1.
Colorant formulation for the black layer of jongkong layer cake

Treatment	Charcoal powder (g)	Water (g)
L	30	100
AK	40	100
AB	30	100

Note: L = control; AK = coconut shell charcoal; AB = bamboo charcoal.

Procedure for Making Jongkong Layer Cake

Jongkong layer cake preparation began with preparing and weighing all ingredients according to the formulation. Suji leaves and pandan leaves were extracted with the addition of water and then filtered to obtain a green colorant solution. Rice flour, tapioca flour, granulated sugar, salt, and coconut milk were mixed until homogeneous using a balloon whisk. The batter was then divided into two portions: green-layer batter and black-layer batter.

The suji and pandan leaf extract was added to the green-layer batter, while rice straw ash, coconut shell charcoal powder, or bamboo charcoal powder was added to the black-layer batter according to the treatment. The batter was poured alternately into a pan in the order of green layer and black layer and steamed for 5 minutes after each layer was added. This process was repeated until all layers were formed. After all layers had been poured, final steaming was carried out for 30 minutes at a process temperature of approximately 70°C. The temperature referred to the steaming process rather than the internal temperature of the product. The cooked product was cooled at room temperature, cut into serving-size pieces, and packaged for testing. The overall research procedure is presented in Figure 1.

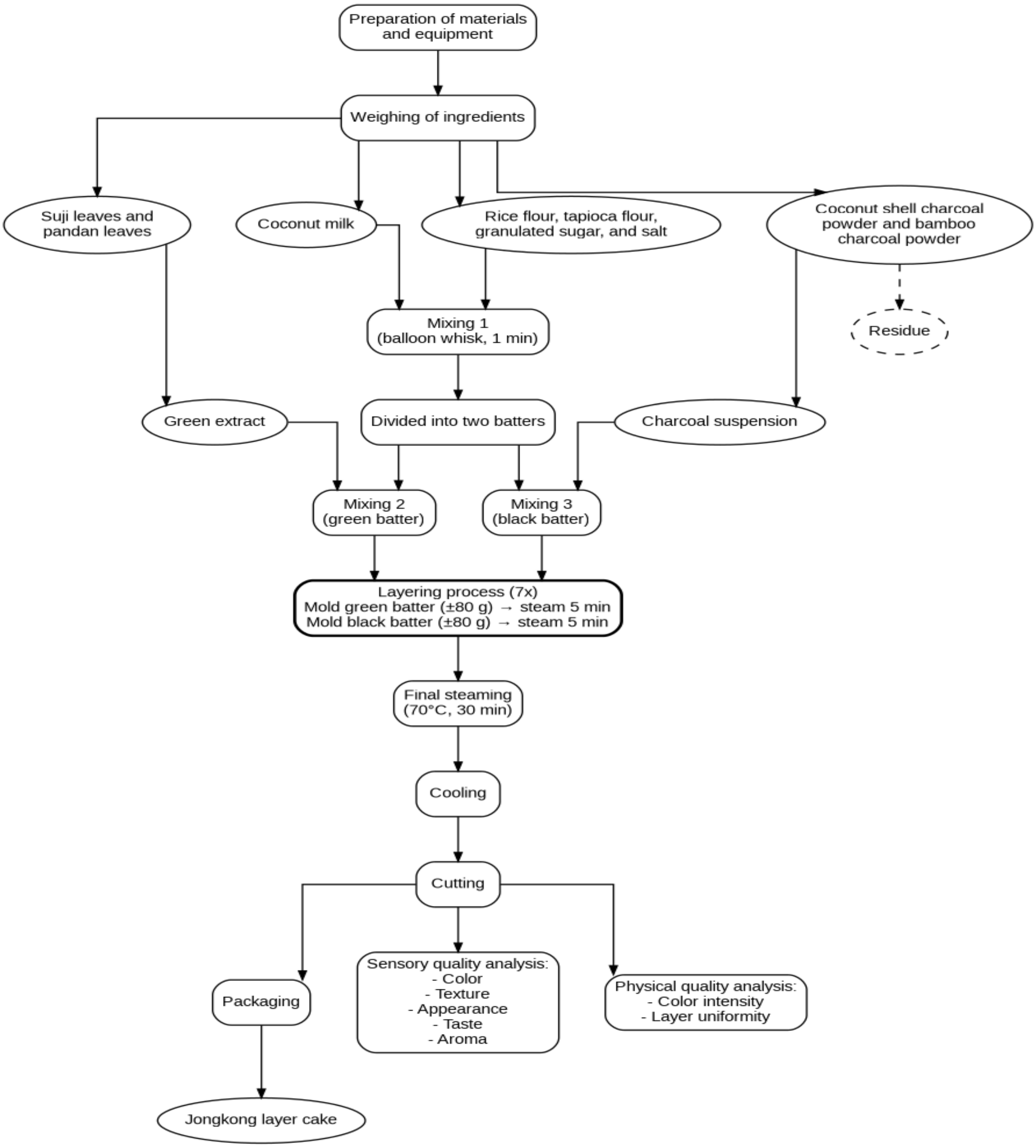

Figure 1. Flowchart of the research stages for jongkong layer cake using coconut shell charcoal powder and bamboo charcoal powder

RESULTS PROCEDURES

Physical Quality Analysis

Physical quality analysis was conducted by evaluating grayscale intensity and layer uniformity using Image software. Sample photographs were captured under standardized lighting conditions and at a fixed shooting distance to minimize measurement variability. The grayscale intensity of the black layer was determined using the mean gray value obtained from grayscale image analysis, where lower mean gray values indicate a darker black appearance. Layer uniformity was assessed by measuring the thickness of each black layer at multiple observation points, after which the coefficient of variation (CV) was calculated to evaluate the consistency of layer thickness. Lower CV values indicate more uniform and neater layers (Martínez-Lara et al., 2025).

Sensory Quality Analysis

Sensory quality analysis was conducted using the duo-trio test with 40 semi-trained panelists. Each panelist received one reference sample (control) and two randomly coded samples consisting of one sample identical to the reference and one different sample. Panelists were asked to identify the sample with characteristics most similar to the reference sample based on the observed attributes. The assessed attributes included black-layer color, aroma, texture, chewiness, layer separation, sweetness, aftertaste, and overall impression. The duo-trio method was used to determine the panelists' ability to distinguish sensory characteristics between treatment samples and the reference sample (Setyaningsih et al., 2018).

Statistical Analysis

Grayscale intensity and layer uniformity data were analyzed using analysis of variance (ANOVA) under a completely randomized design (CRD) consisting of three treatments and three replications at a 5% significance level (Febrianti & Hardianti, 2024). Sensory data obtained from the duo-trio test were analyzed using the binomial test to determine whether significant sensory differences existed between each treatment and the control. Decisions were based on probability values (p-values), where $p \leq 0.05$ indicated a significant difference, whereas $p > 0.05$ indicated no significant difference between the samples (Setyaningsih et al., 2018).

RESULT AND DISCUSSION

Physical Quality Analysis

Physical quality analysis was performed by evaluating the grayscale intensity and layer uniformity of jongkong layer cake for each treatment, namely the control (rice straw ash), coconut shell charcoal powder, and bamboo charcoal powder. Grayscale intensity was measured using the mean gray value obtained from grayscale image analysis with ImageJ, whereas layer uniformity was determined based on the coefficient of variation (CV%) of layer thickness. The mean values and the results of the analysis of variance (ANOVA) are presented in Table 2.

Table 2.
Mean grayscale intensity and layer uniformity of jongkong layer cake

Treatment	Mean Gray Value	Layer uniformity (CV%)
L	56.75 ± 5.26	12.80 ± 0.97
AK	53.33 ± 7.67	10.67 ± 0.87
AB	51.86 ± 7.67	10.87 ± 2.35
Fcalculated	0.391	2.75
Fcritical (α = 0.05)	5.14	5.14
Decision	Not significantly different	Not significantly different

Note: Values are means ± standard deviations from three replications. L = control; AK = coconut shell charcoal; AB = bamboo charcoal.

The ANOVA results showed that the use of coconut shell charcoal powder and bamboo charcoal powder as substitutes for rice straw ash did not have a significant effect on the grayscale intensity or layer uniformity of jongkong layer cake. The calculated F values for mean gray value (0.391) and layer uniformity (2.75) were lower than the Fcritical value (5.14), so failed to reject H0. Nevertheless, descriptively, the mean gray value decreased from the control (56.75) to the coconut shell charcoal treatment (53.33) and the bamboo charcoal treatment (51.86), indicating a darker black layer. A lower mean gray value indicates a darker grayscale appearance because less reflected light is detected from the sample surface during image analysis.

For layer uniformity, all treatments showed relatively similar coefficient of variation (CV) values: 12.80% for the control, 10.67% for coconut shell charcoal, and 10.87% for bamboo charcoal. These results indicate that the addition of charcoal powder did not significantly affect layer formation during the steaming process. The comparable CV values suggest that both charcoal powders were incorporated into the batter without adversely affecting the regularity of the cake layers. This finding is consistent with Amani et al., (2022), who reported that layer quality is influenced primarily by batter homogeneity, molding accuracy, and steaming conditions rather than by the type of colorant used. Similarly, Shao et al., (2024) emphasized that maintaining the stability of the starch gel network during heating is important for preserving layer shape and regularity. Overall, both coconut shell charcoal powder and bamboo charcoal powder maintained the physical quality of jongkong layer cake at a level comparable to that of the rice straw ash control. However, these findings also indicate that instrumental physical measurements alone are insufficient for selecting an appropriate rice straw ash substitute.

Although the treatments showed similar grayscale intensity and layer uniformity, the subsequent duo-trio test revealed differences in sensory similarity between the two charcoal sources. Therefore, sensory evaluation should be considered together with physical quality when assessing alternative natural colorants for jongkong layer cake.

Sensory Quality Analysis

Sensory quality analysis was conducted on jongkong layer cake for each treatment, namely the control using rice straw ash, coconut shell charcoal powder, and bamboo charcoal powder. The test used the duo-trio method to evaluate the panelists' ability to distinguish the sensory characteristics of treatment samples from the control sample based on black-layer color, aroma, texture, chewiness, layer separation, sweetness, aftertaste, and overall impression. The test results were analyzed using the binomial test and are presented as p-values in Table 3.

Table 3.
Duo-trio test results for the sensory quality of jongkong layer cake

Attribute	AK p-value	AB p-value
Black-layer color	0.503	0.041
Aroma	1.176	0.041
Texture	0.012	1.176
Chewiness	0.263	0.503
Layer separation	0.115	0.115
Sweetness	0.824	0.115
Aftertaste	0.503	0.263
Overall impression	0.824	0.115
Decision	significantly different attribute	significantly different attributes

Note: Values are p-values from the binomial test. A p-value ≤ 0.05 indicates a significant difference from the control sample. AK = coconut shell charcoal; AB = bamboo charcoal.

Black-Layer Color

Based on the duo-trio test, the p-value of 0.503 for the coconut shell charcoal treatment indicated that panelists were unable to distinguish the black-layer color from the control product, whereas the p-value of 0.041 for the bamboo charcoal treatment indicated a significant difference. These findings suggest that the black-layer color produced by bamboo charcoal was more readily distinguished by the panelists than that produced by coconut shell charcoal. This result is consistent with the grayscale intensity analysis, in which the bamboo charcoal treatment showed the lowest mean gray value, indicating the darkest black appearance among the treatments. Although ANOVA showed no significant differences in grayscale intensity, the darker appearance produced by bamboo charcoal was still sufficiently noticeable to be recognized during sensory evaluation. Domian et al., (2021) explained that even subtle visual differences in food color can influence consumers' ability to distinguish products despite only small differences in instrumental measurements.

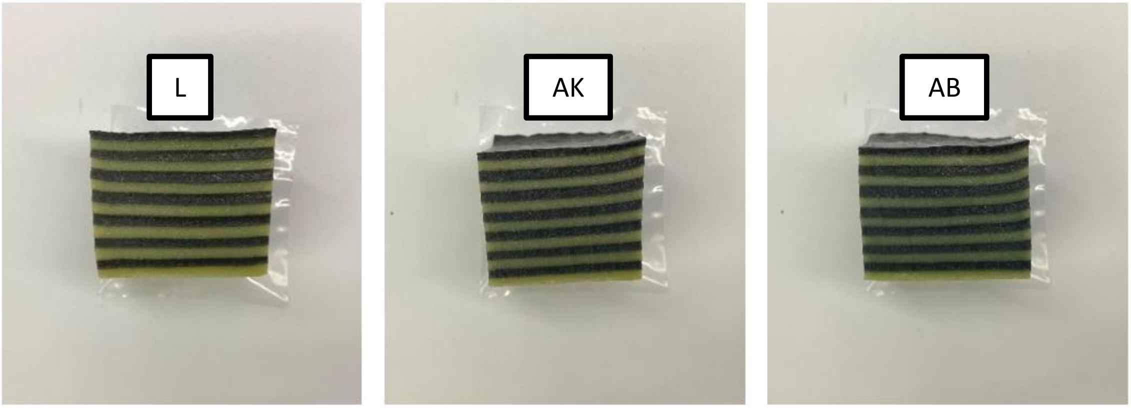

Figure 2. Jongkong layer cake with three types of natural colorant
(L = control; AK = coconut shell charcoal; AB = bamboo charcoal)

Aroma

The aroma data presented in Table 3 were obtained directly from the duo-trio sensory evaluation conducted in this study and were not derived from previous studies. Each treatment was evaluated by 20 moderately trained panelists. In the AK treatment, 10 of the 20 panelists identified the sample as different from the control, resulting in an exact two-sided binomial p-value of 1.000. Therefore, the aroma of the AK treatment was not significantly different from that of the control ($p > 0.05$). In the AB treatment, 15 of the 20 panelists identified the sample as different from the control, resulting in an exact two-sided binomial p-value of 0.041. Thus, the aroma of the AB treatment was significantly different from that of the control ($p < 0.05$). These results suggest that bamboo charcoal slightly influenced the aroma perception of the product compared with coconut shell charcoal. The aroma difference may be associated with differences in the characteristics of the charcoal powder used, which could slightly influence the release of volatile compounds during consumption (Bhatt et al., 2021). Wang et al., (2020) also reported that small changes in ingredient composition may alter the aroma balance of products containing coconut milk and pandan leaves. Therefore, coconut shell charcoal powder maintained the aroma characteristics of jongkong layer cake more closely to the control than bamboo charcoal powder.

Texture

In contrast to the other sensory attributes, texture was the only attribute that differed significantly between the coconut shell charcoal treatment and the control ($p = 0.012$).

During steaming, starch granules in rice flour and tapioca flour absorb water, swell, and partially disintegrate, allowing amylose to leach from the granules and participate in the formation of a continuous gel network. The organization and compactness of this amylose-containing network contribute to the strength and elasticity of rice-flour gels (Tian et al., 2023). Coconut shell charcoal particles do not form part of the gelatinized starch phase but remain dispersed within the continuous starch matrix. Studies on particle-filled food gels have shown that insoluble particles may act as fillers or structural discontinuities within a gel network, thereby modifying its resistance to deformation, hardness, and recovery properties, depending on particle size, concentration, distribution, and particle–matrix interactions (Gravelle et al., (2017).

Moreover, Gonzalez et al., (2020) demonstrated that the addition of activated charcoal modified dough rheology and the textural characteristics of bread, indicating that charcoal particles can affect the mechanical behavior of starch-containing food systems. Accordingly, the significant texture difference observed in the AK treatment may be associated with the relatively high proportion of coconut shell charcoal particles dispersed within the rice–tapioca starch matrix. These particles may have altered the local continuity and deformation behavior of the gel network during steaming, producing a textural difference that could be detected by the panelists. Rustagi (2020) explained that sensory texture perception reflects the mechanical, geometrical, and surface properties detected during oral deformation and mastication. However, because microstructure, rheological properties, water distribution, and instrumental texture were not measured in the present study, the proposed charcoal–starch interaction should be interpreted as a plausible mechanism supported by related literature rather than as a directly demonstrated mechanism.

Chewiness

The test results showed that the p-values of 0.263 for AK and 0.503 for AB were not significantly different from the control. This condition indicates that the use of charcoal powder did not appear to interfere with the formation of the gel structure that produces the elastic texture of jongkong layer cake. Muthu Kumar & Varunkumar (2024) stated that the chewiness of starch-based products is influenced by interactions among starch, water, and the gelatinization process during heating. Liu et al., (2023) also reported that the addition of carbonized material in limited amounts did not significantly change the elasticity of starch-based products. The high number of panelists who perceived no difference shows that charcoal powder addition did not substantially change the chewiness of jongkong layer cake. This is presumed to occur because the chewy texture is more strongly influenced by interactions among rice flour starch, tapioca starch, and coconut milk than by the presence of charcoal powder used in relatively small amounts.

Layer Separation

The p-value of 0.115 for both treatments showed that coconut shell charcoal powder and bamboo charcoal powder did not have a significant effect on layer separation compared with the control. These results indicate that layer formation during steaming proceeded properly even when charcoal powder was used as a substitute for rice straw ash. This finding is consistent with Csurka et al., (2022),who stated that layer-structure stability is more strongly influenced by batter homogeneity and the steaming process than by added ingredients. Amani et al., (2022) also explained that starch gel stability during heating is a primary factor in the formation of good layers. This result is consistent with the physical quality test, which showed that charcoal powder use did not significantly affect layer uniformity. Thus, charcoal powder addition did not disrupt layer formation during steaming.

Sweetness

Based on the binomial test, the p-values of 0.824 for AK and 0.115 for AB showed that both treatments were not significantly different from the control. These results indicate that charcoal powder did not affect the main taste characteristic of jongkong layer cake. Chochkov & Kirilov, (2023) reported that the use of charcoal powder at low concentrations does not alter the basic taste of food products, while Zhang et al., (2023) explained that sweetness perception is more strongly influenced by sugar concentration than by added ingredients that do not have a dominant taste. These results show that charcoal powder did not contribute enough taste to change the sweetness level of the product. The sweetness characteristic of jongkong layer cake remained dominated by sugar and coconut milk, so the presence of charcoal powder did not significantly affect sweetness perception.

Aftertaste

Sensory testing of aftertaste showed p-values of 0.503 for AK and 0.263 for AB; therefore, both treatments were not significantly different from the control. This result indicates that charcoal powder did not produce a residual taste sensation that panelists could distinguish. According to He et al., (2023), aftertaste is influenced by compounds that remain in the oral cavity after the product is swallowed. Zhang et al., (2023) also reported that additives without a dominant taste generally do not affect the aftertaste of food products. This finding is important because one consideration in using alternative colorants is their ability to maintain product flavor without leaving an undesirable foreign aftertaste.

Overall Impression

In general, the duo-trio test showed that the p-values of 0.824 for AK and 0.115 for AB were not significantly different from the control. This finding indicates that both coconut shell charcoal powder and bamboo charcoal powder were still able to maintain the overall sensory characteristics of jongkong layer cake. According to Maurya, (2024) overall evaluation is the integration of all sensory attributes assessed by panelists. Amani et al., (2022) also stated that changes in one or two sensory attributes do not necessarily affect the overall perception of product quality if the main characteristics of the product can still be maintained. Overall impression represents the final panelist assessment reflecting the combination of all observed sensory attributes. Therefore, coconut shell charcoal powder has greater potential as a substitute for rice straw ash than bamboo charcoal because it maintained most of the product's sensory characteristics.

CONCLUSION

Based on the findings of this study, coconut shell charcoal powder and bamboo charcoal powder can be used as alternative substitutes for rice straw ash without significantly affecting the physical quality of jongkong layer cake. ANOVA showed that the selected formulations (40% coconut shell charcoal powder and 30% bamboo charcoal powder) did not significantly influence grayscale intensity or layer uniformity ($p > 0.05$). The duo-trio test revealed that the coconut shell charcoal treatment differed significantly from the control only in the texture attribute, whereas the bamboo charcoal treatment differed significantly in black-layer color and aroma. No significant differences were observed for the remaining sensory attributes. Overall, coconut shell charcoal powder showed greater sensory similarity to the control than bamboo charcoal powder, indicating its potential as a rice straw ash substitute in jongkong layer cake. Therefore, the 40% coconut shell charcoal formulation can be considered a promising substitute for rice straw ash, although further validation involving broader consumer acceptance and different production conditions is recommended.

Future studies should optimize the particle size and filtration process of bamboo charcoal to reduce residual particles, evaluate consumer acceptance using a larger and more diverse panel, and investigate the stability of color, texture, and sensory quality during storage. Further validation under different processing conditions and at a larger production scale is also required to determine the consistency and practical applicability of the selected formulations.

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