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Fortification of Yogurt with Arabica Coffee Cascara Extract: The Effects of Concentration and Fermentation Duration on Acidity and Sensory Characteristics

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ABSTRACT*: Coffee cascara, a by-product of coffee processing, is a potential source of bioactive compounds such as polyphenols and chlorogenic acids. However, its application in yogurt fermentation systems remains limited. Therefore, this study aimed to evaluate the effect of cascara extract concentration and fermentation time on the physicochemical and sensory properties of yogurt. This study aimed to evaluate the effect of Arabica coffee cascara extract concentration (water-based) and fermentation duration on the acidity characteristics and sensory acceptance of yogurt. The experiment was conducted using a factorial completely randomized design with two factors: cascara extract concentration (1.5%, 2%, and 2.5% w/v) and fermentation duration (3 and 6 hours). The evaluated parameters included pH, titratable acidity (TA), and sensory attributes (color, aroma, taste, and overall acceptance) assessed using a hedonic test with untrained panellists The results demonstrated that fermentation duration significantly influenced yogurt acidification, resulting in lower pH values and higher titratable acidity as fermentation duration increased. The pH values ranged from 4.63 to 4.92, while titratable acidity ranged from 0.58% to 0.75% lactic acid. The addition of cascara extracts up to 2.5% did not inhibit the metabolic activity of lactic acid bacteria during fermentation. Sensory evaluation indicated that yogurt containing 2% cascara extract fermented for 6 hours obtained the highest overall acceptance score, indicating an optimal balance between acidity and sensory characteristics. These findings demonstrated that Arabica coffee cascara extract has potential as a functional ingredient in yogurt production while supporting the valorization of coffee processing by-products into value-added fermented dairy products.*

Keywords: *Acidification; Cascara Coffee; Fermentation Duration; Sensory Acceptance; Yogurt*

1. INTRODUCTION

Yogurt is a fermented dairy product produced by lactic acid bacteria (LAB) through a fermentation process, primarily *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. LAB play a role in converting lactose into lactic acid. The metabolic activity of these two microorganisms result a decrease in milk pH to near the isoelectric point of casein (around pH 4.6), thereby triggering protein coagulation and the formation of a semi-solid gel structure, which is one of the main characteristics of yogurt (Aryana & Olson, 2017; Ayivi & Ibrahim, 2022). In addition to creating the characteristic texture and flavor, the fermentation process also contributes to improved microbiological stability and the functional value of fermented dairy products (Elkot & Ismail, 2025). As public awareness of healthy food increases, yogurt development has shifted toward functional products enriched with plant-based bioactive compounds. The incorporation of ingredients rich in phenolics, dietary fiber, and natural antioxidants can enhance antioxidant activity, improve color, and modify texture (Elkot & Ismail, 2025; Granato et al., 2010). However, these additions also introduce potential interactions with milk proteins that may affect the stability of the yogurt matrix. Phenolic compounds can form complexes with casein through hydrophobic interactions and hydrogen bonding, which may induce protein aggregation or alter gel structure. As public awareness of healthy food grows, current yogurt development focuses not only on basic nutritional quality but also on the creation of functional food products with added bioactive value. One widely adopted approach involves fortifying yogurt with plant-based ingredients rich in phenolic compounds, dietary fiber, or natural antioxidant components. The addition of plant extracts, fruits, or agro-industrial waste-based materials is known to enhance antioxidant activity, improve natural color characteristics, and modulate the texture and viscosity of yogurt (Elkot & Ismail, 2025; Granato et al., 2010). Recent studies report that fortifying yogurt with plant extracts such as berries, tea, rosella, or herbal ingredients can enhance antioxidant capacity and provide unique sensory characteristics, although excessively high concentrations may potentially cause an astringent taste due to polyphenol content (Ahmad et al., 2026; Hartati et al., 2025; Maharani et al., 2021; Supriyanti et al., 2022).

In the context of food system sustainability, the utilization of agro-industrial waste as a raw material for functional foods has garnered increasing attention in recent years. The concepts of food waste valorization and the circular economy promote the reuse of agricultural or agroindustrial waste into value-added products, thereby reducing environmental impacts while improving resource utilization efficiency (Râpă et al., 2024; Sarker et al., 2023). One type of agroindustrial waste with significant potential is cascara, the coffee fruit peel produced during coffee processing. This waste can account for approximately 40–50% of the total weight of fresh coffee fruit, making it a substantial volume, particularly in coffee-producing countries like Indonesia (Putri et al., 2025; Wijayanti et al., 2025).

Various studies indicate that cascara, a byproduct of the coffee agroindustry, is rich in bioactive compounds such as polyphenols, flavonoids, chlorogenic acid, dietary fiber, and small amounts of caffeine, which contribute to antioxidant activity and potential health benefits (Lachenmeier et al., 2022; Lestari et al., 2022; Muzaifa et al., 2021). Phenolic compounds in cascara can interact with milk proteins through hydrophobic and hydrogen bonding, affecting gel stability and texture in fermented dairy products (Nemli et al., 2024; Tosif et al., 2021), while certain LAB are able to metabolize these compounds during fermentation, potentially modulating the fermentation environment and generating additional bioactive metabolites (De Montijo-Prieto et al., 2023; Li et al., 2021). In practice, cascara has been applied in various food and beverage products, including cascara tea, fermented drinks, gluten-free bread, and as a natural colorant, contributing to both functional and sensory enhancement (Arpi et al., 2021; DePaula et al., 2022; Guglielmetti et al., 2019; Rios et al., 2020; Pramono et al., 2021).

Nevertheless, studies on the utilization of cascara in yogurt fermentation systems remain relatively limited. Most previous research has focused on the application of cascara in non-dairy beverages or functional extracts, while studies evaluating the interaction of cascara with yogurt starter cultures are still rarely reported. Furthermore, few studies have systematically examined the relationship between cascara concentration and fermentation duration on acid formation dynamics during yogurt fermentation, particularly in thermophilic fermentation systems involving *L. bulgaricus* and *S thermophilus*. However, the interaction between phenolic compounds and fermentation microorganisms has the potential to influence fermentation kinetics, lactic acid formation, and the sensory characteristics of the final product (De Montijo-Prieto et al., 2023; Li et al., 2021).

Based on the above discussion, there are several scientific gaps that still require further investigation. First, there is a limited body of research on the effects of cascara extract on acidification dynamics in yogurt fermentation systems. Second, few studies have comprehensively analyzed the interaction between cascara concentration and fermentation duration on the physicochemical characteristics and sensory acceptance of yogurt. Third, research on the utilization of local Arabica coffee cascara as a yogurt fortifier remains very limited, particularly regarding Hargo Kiloso Ponorogo Arabica coffee cascara, which holds potential as a source of local agro-industrial raw materials. Therefore, this study aimed to analyze the effects of Arabica coffee cascara extract concentration and fermentation duration on changes in acidity (pH and total titratable acidity) and on the sensory acceptance of yogurt. This study is expected to provide scientific contributions to the development of fortified yogurt products based on coffee agro-industrial waste and to support the utilization of coffee husks as value-added functional food ingredients within the framework of sustainable agro-industrial development.

2. MATERIALS AND METHODS

Research Design

This study employed a two-factor completely randomized design (CRD). The first factor was the concentration of cascara extract (A), consisting of three levels: 1.5% (A1), 2% (A2), and 2.5% (A3) (w/v). The second factor was fermentation duration (B), consisting of two levels: 3 hours (B1) and 6 hours (B2). The treatment combinations resulted in six experimental units (table 1), each replicated three times. Data were analyzed using two-way Analysis of Variance (ANOVA) at a 5% significance level. If significant differences were found, a Tukey post-hoc test was conducted to determine differences between treatments.

Table 1. Treatment Combinations

Cascara Concentration (%)	3 Hour	6 Hour
1.5	A1B1	A1B2
2	A2B1	A2B2
2.5	A3B1	A3B2

Notes: Factor A represented the cascara extract concentration, consisting of A1 = 1.5%, A2 = 2%, and A3 = 2.5%, while Factor B represented the fermentation duration, consisting of B1 = 3 hours and B2 = 6 hours.

Materials

The main materials in this study included commercially sourced fresh milk, Hargo Kiloso Arabica coffee cascara extract (Ponorogo), white granulated sugar (5% w/v), and a commercial yogurt starter containing *L. delbrueckii* subsp. *bulgaricus* and *S. thermophilus.*

Preparation of Cascara Extract

Cascara was obtained from the dried husks of Hargo Kiloso Arabica coffee. Extraction was carried out using a hot infusion method with a cascara-to-water ratio of 1:4 (w/v) at a temperature 100°C for 5 minutes, followed by filtration to obtain the filtrate.

The hot water extraction method was chosen because it was effective in dissolving hydrophilic phenolic compounds and antioxidants in Coffe cascara (Heeger et al., 2017; Iriondo-Dehond et al., 2020). The extract filtrate was then cooled to room temperature before being added to the milk.

Yogurt Production Process

150 mL of fresh milk was pasteurized at a temperature 80°C for 15 minutes to inactivate contaminating microorganisms and spoilage enzymes (Dwiki Ramadhan et al., 2024). Afterward, the milk was cooled from 42°C to 45°C before inoculation a liquid starter culture commercial at 0.5% (w/v).

Cascara extract was added according to the treatment (1.5%; 2%; and 2.5%) before the fermentation process. Fermentation was carried out at 45°C for 3 and 6 hours according to the treatment. This temperature was the optimum for yogurt culture growth and lactic acid production (Aryana & Olson, 2017).

During fermentation, LAB converted lactose into lactic acid, causing a decrease in pH and coagulation of milk proteins, particularly casein (Tamime & Robinson, 2007). Variations in fermentation duration were used to evaluate the effect of time on acid formation and the sensory characteristics of the product.

Physicochemical Analysis

pH Measurement

pH values were measured using a digital pH meter calibrated with pH 4.00 and 7.00 buffers prior to use. Measurements were conducted at room temperature.

The decrease in pH during fermentation reflects the metabolic activity of LAB in producing lactic acid (Dwiki Ramadhan et al., 2024).

Total titratable acidity

Total titratable acidity (TA) was determined using a titration method with 0.1 N NaOH solution using phenolphthalein as an indicator. Results were expressed as percent lactic acid (% w/v) according to the standard method for yogurt analysis (AOAC, 1995).

TA serves as a quantitative indicator of acid formation during fermentation and correlates with LAB activity (Aryana & Olson, 2017).

Organoleptic Test

The sensory test was conducted using a hedonic rating method to assess the attributes of color, aroma, taste, and overall acceptability. A 1–5 scale was used (1 = strongly dislike, 5 = strongly like). The Panel consisted of 30 untrained panelists. Panelists were selected from university students and staff and were familiar with yogurt products, although they had no formal training in sensory evaluation.

Sensory evaluation was conducted to assess the effect of the interaction between cascara phenolic compounds and acid formation on consumer acceptance, given that phenolic compounds can influence the taste and aroma of fermented products (Filannino et al., 2015).

3. RESULTS AND DISCUSSION

3.1. pH Value

The pH value is an important parameter in evaluating the yogurt fermentation process because it reflects the metabolic activity of LAB during the conversion of lactose into lactic acid. The decrease in pH during fermentation plays a role in the coagulation of milk proteins, particularly casein, which occurs when the pH approaches the isoelectric point around 4.6, thereby forming the characteristic gel structure of yogurt (Aryana & Olson, 2017).

Table 2. pH Values of Yogurt Under Various Conditions

Cascara Concentration (%)	3 Hour	6 Hour
1.5	4.92 ± 0.03^{a}	4.63 ± 0.02^{c}
2%	4.88 ± 0.04^{a}	4.67 ± 0.03^{c}
2.5%	4.85 ± 0.05^{b}	4.70 ± 0.04^{c}

Notes:
Values are expressed as mean ± standard deviation (n = 3). Different superscript letters within the same column indicate a significant difference ($p < 0.05$) based on Tukey's test.

Table 2 indicates that the pH of the yogurt ranged from 4.63 to 4.92 across various combinations of cascara extract concentration and fermentation duration. The results of the ANOVA analysis indicate that fermentation duration had a significant effect ($p < 0.05$) on the pH of the yogurt, whereas the effect of cascara concentration was relatively smaller and did not indicate a significant interaction with fermentation duration.

Fermentation for 3 hours resulted in pH values ranging from 4.85 to 4.92, indicating that the acidification process had not yet reached the optimal conditions for yogurt gel formation. Conversely, fermentation for 6 hours produced lower pH values, namely 4.63–4.70, which approached the isoelectric point of casein. These conditions indicate that the metabolic activity of the bacteria has occurred more intensively, leading to a significant increase in lactic acid accumulation.

The decrease in pH during fermentation is closely related to the growth kinetics of the yogurt starter culture. In thermophilic yogurt fermentation systems, *S. thermophilus* typically plays a role in the early stages of fermentation by rapidly producing lactic acid and lowering the environmental pH. This pH decrease then stimulates the growth of *L. delbrueckii* subsp. *bulgaricus*, which contributes to increased acid production and the formation of volatile compounds such as acetaldehyde that influence the sensory characteristics of yogurt (Champagne et al., 2018; Tamime & Robinson, 2007).

When compared to the yogurt quality standards according to SNI 2981:2009, which specify a pH range of approximately 4.0–4.5, the 6-hour fermentation treatment performed a pH value approaching this range, whereas the 3-hour fermentation remained relatively higher. These results align with the study by Nguyen et al. (2020), which reported that the acidification rate in yogurt fermentation increased significantly after the initial adaptation phase (lag phase) and reached stability during the late exponential phase of fermentation.

The addition of cascara extract at concentrations of 1.5–2.5% did not exhibit an inhibitory effect on starter culture activity. This indicates that the phenolic compound content in cascara within that concentration range remains within the tolerance limits of LAB. Several studies suggest that phenolic compounds can interact with milk proteins or microbial cell membranes, potentially influencing fermentation activity depending on their concentration (Filannino et al., 2018; Li et al., 2021).

Nevertheless, at higher cascara concentrations (2.5%), the pH decrease was not significantly greater than that observed at the 2% treatment. This suggests the possibility of a threshold effect of phenolic compounds on the metabolic metabolic activity of LAB. Interactions between polyphenols and milk proteins or bacterial cell membrane components can affect membrane permeability and microbial enzymatic activity, thereby reducing the efficiency of fermentative metabolism at certain concentrations (Kamiloglu et al., 2021; Zhang et al., 2022).

These findings were also consistent with the study by Öztürk et al. (2018), which reported that fortifying yogurt with plant extracts at moderate concentrations does not inhibit the acidification process, but at higher concentrations may affect fermentation kinetics. Thus, cascara concentrations in the range of 1.5–2.5% are still acceptable to the yogurt fermentation system without causing significant inhibition of starter culture activity.

3.2. Total titratable acidity (TA)

Total titratable acidity is a quantitative parameter used to measure the total accumulation of organic acids formed during yogurt fermentation. Unlike pH, which indicates the concentration of free hydrogen ions, the total titratable aciditys value reflects the total amount of acid formed during the fermentation process (Aryana & Olson, 2017). The results demonstrated that the total titratable acidity content of yogurt ranged from 0.58–0.75% lactic acid across various treatment combinations (Table 3). ANOVA analysis indicated that both cascara concentration and fermentation duration had a significant effect ($p < 0.05$) on the total titratable acidity content of yogurt.

The increase in total titratable acidity was primarily influenced by fermentation duration; a 6 hour fermentation resulted in higher total titratable acidity compared to a 3-hour fermentation. This behaviour was consistent with the metabolic activity of the starter culture, which continuously hydrolyse lactose into lactic acid throughout the fermentation process. The relationship between the decrease in pH and the increase in total titratable acidity indicated that these two parameters were interrelated in describing the dynamics of acid formation during yogurt fermentation.

Table 3. Total titratable acidity

Cascara Concen tration (%)	3 Hour	6 Hour
1.5	0.58 ± 0.02[a]	0.67 ± 0.03[b]
2	0.60 ± 0.03[a]	0.1 ± 0.02[c]
2.5	0.62 ± 0.02[a]	0.75 ± 0.03[c]

Notes:
Values are expressed as mean ± standard deviation (n = 3). Different letters indicate significant differences at the 5% level.

The highest total titratable acidity value was obtained in the treatment with a 2.5% cascara concentration and 6 hour fermentation, amounting to 0.75% lactic acid. This value remained within the quality standards for yogurt according to SNI 2981:2009, which requires a minimum total titratable acidity of approximately 0.5% lactic acid. These results indicated that the fermentation process conducted in this study produces yogurt with acidity characteristics that meet quality standards.

The relationship between the increase in total titratable acidity and fermentation duration can be explained through the metabolic kinetics of LAB. During fermentation, the starter culture gradually utilized lactose as an energy source via the glycolysis pathway, producing lactic acid as the primary metabolic product. This accumulation of lactic acid leads to an increase in total titratable acidity over time (Soni et al., 2020).

In addition to fermentation duration, the addition of cascara extract also tends to increase total titratable acidity. This is because it contains phenolic compounds that may influence the metabolism of LAB. Several studies report that phenolic compounds at moderate concentrations can act as stimulatory factors for the growth of certain fermentation microorganisms through co-metabolic or enzymatic transformation mechanisms (De Montijo-Prieto et al., 2023; Filannino et al., 2015).

However, the contribution of cascara to the increase in total titratable acidity value in this study was relatively smaller compared to the effect of fermentation duration. This indicates that the dynamics of acid formation in the yogurt system were more largely determined by the activity of the starter culture than by the additional bioactive components from cascara.

This finding were consistent with previous studies reporting that fermentation duration is the dominant factor determining the intensity of acidification in yogurt. Previous studied by (Dabija et al., 2018) also reported that the increase in total titratable acidity value during yogurt fermentation is closely correlated with the metabolic activity of the starter culture and fermentation duration.

The results of this study indicate that the addition of cascara extract at concentrations up to 2.5% (table 3) does not inhibit the yogurt fermentation process and still allows for optimal acid formation. The combination of cascara concentration and fermentation duration produces acidity characteristics that meet yogurt quality standards and have the potential to enhance the product's functional value through the addition of bioactive compounds from cascara.

3.3. Organoleptic Test

Color

Color is one of the sensory attributes first observed by consumers and plays a crucial role in shaping initial perceptions of the quality and freshness of yogurt products. Color changes in yogurt fortified with plant-based ingredients are generally caused by the presence of natural pigments and phenolic compounds that dissolve during the fermentation process. The addition of cascara extract in this study resulted in a color change in the yogurt ranging from light brown to reddish-brown, originating from the polyphenol content and natural pigments in the coffee fruit peel.

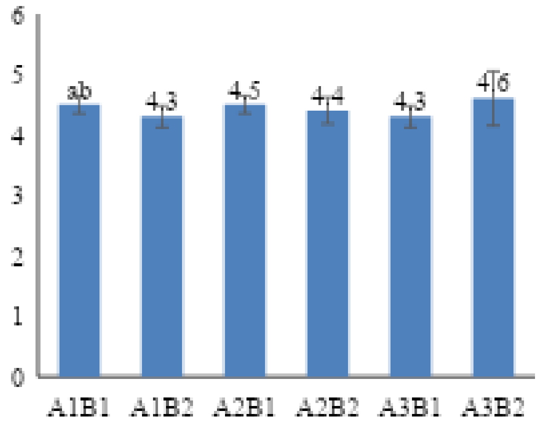

Figure 1. The Effect of Cascara Extract Concentration and Fermentation duration on the Sensory Color Attributes of Yogurt

The hedonic test results demonstrated that treatment A3B2 (2.5% cascara and 6-hour fermentation) received the highest color score compared to the other treatments. The increase in color intensity at higher cascara concentrations indicates that the phenolic pigments in cascara were evenly dispersed throughout the yogurt matrix during fermentation. Phenolic compounds and natural pigments in cascara are known to have a reddish-brown color that can influence the visual characteristics of food products (Heeger et al., 2017; Iriondo-Dehond et al., 2020).

Previous studies have also reported that fortifying yogurt with plant extracts can enhance the product's visual appeal by creating natural color distinct from conventional yogurt. Barukčić et al., (2022) reported that adding plant extracts to yogurt can improve the perception of natural color and provide visual differentiation in fermented dairy products. Another study by Mohamed Ahmed et al., (2021) also demonstrated that the addition of plant extracts can improve the sensory color value of yogurt as long as the concentration of the additives remains within limits acceptable to consumers.

Thus, the addition of cascara not only enhances the visual characteristics of yogurt but also introduces a non-traditional color that may affect consumer perception. The reddish-brown hue derived from cascara differs from the typical white appearance of yogurt, which may lead some consumers to associate the product with deterioration or artificial alteration if not properly informed. Therefore, appropriate labeling and communication strategies are essential to ensure that the color change is interpreted as a natural and desirable attribute rather than a quality defect.

Aroma

Aroma is an important sensory attribute in the evaluation of fermented products because it is directly related to the volatile compounds formed during the metabolic activity of LAB. The characteristic aroma of yogurt is primarily attributed to volatile compounds such as acetaldehyde, diacetyl, and acetoin, which are produced by starter cultures during fermentation (Aryana & Olson, 2017).

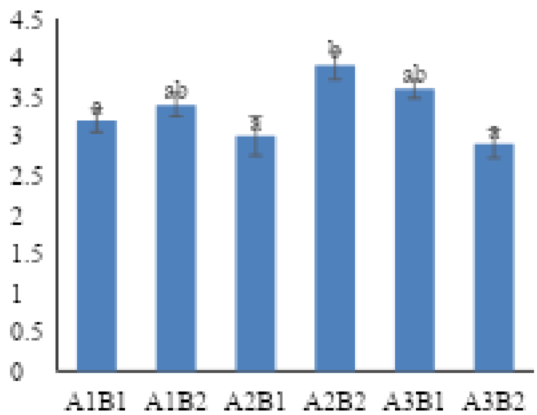

Figure 2. The Effect of Cascara Extract Concentration and Fermentation duration on the Sensory Aroma Attributes of Yogurt

The results of the study demonstrated that treatment A2B2 (2% cascara and 6 hours of fermentation) produced the highest aroma score compared to the other treatments (figure 2). This indicates that a combination of moderate cascara concentration and sufficient fermentation duration yields an optimal balance between the characteristic aroma of yogurt and the additional aroma from cascara.

Cascara extract is known to contain various natural volatile compounds that can impart herbal and fruity aroma characteristics to food products (Heeger et al., 2017). When added to the yogurt fermentation system, these volatile compounds can interact with aroma compounds produced by lactic acid bacteria, thereby resulting in greater aroma complexity.

However, at higher cascara concentrations (2.5%), aroma scores tended to decrease. This may be associated with the increased presence of phenolic compounds, which can produce herbal notes that may be perceived as earthy or medicinal by some panellists. Such attributes may be perceived as less acceptable by consumers, particularly when the aroma deviates from the typical profile of yogurt. Previous studies have reported that while increasing plant extract concentration can enhance aroma intensity, excessive concentrations may lead to overly strong or less desirable sensory attributes. Several studies have reported that increasing the concentration of plant extracts in yogurt can enhance aroma intensity; however, at excessively high concentrations, this can result in an overly strong aroma, thereby reducing consumer acceptance (Li et al., 2021; Mohamed Ahmed et al., 2021).

Taste

Taste is the primary sensory parameter that determines the success of a yogurt formulation because it reflects the balance between acidity levels, cascara-derived phenolic compounds, and the panelis sensory perception of the product. In yogurt, taste is influenced by a combination of lactic acid, volatile fermentation compounds, and interactions between milk components and the added ingredients used (Walstra et al., 2005).

Sensory test results demonstrated that treatments A3B1 and A2B2 obtained the highest taste scores compared to the other treatments (figure 3). This indicates that the balance between cascara concentration and fermentation level plays a crucial role in determining the taste characteristics of yogurt.

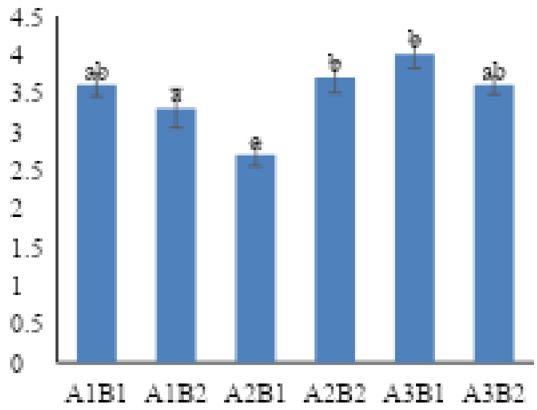

Figure 3. The Effect of Cascara Extract Concentration and Fermentation duration on the Sensory Taste Attributes of Yogurt

The phenolic compounds found in cascara are known to influence taste perception through the formation of complexes between polyphenols and milk proteins. This interaction can produce protein–polyphenol complexes that affect the sensory properties of the product, including flavour intensity and mouthfeel (Ahmad et al., 2026; Han et al., 2019). Importantly, this effect is influenced by fermentation duration. At shorter fermentation times (3 hour), lower acid production allows higher cascara concentrations to be tolerated without disrupting sensory balance. In contrast, longer fermentation (6 hour) increases acidification, which, combined with high polyphenol levels, may lead to excessive sourness and astringency.

Astringency is a dry and rough sensation in the oral cavity caused by the interaction between polyphenols and salivary proteins. Polyphenolic compounds can precipitate salivary proteins, thereby reducing oral lubrication and producing a characteristic dry sensation. In yogurt systems, this phenomenon may occur if the polyphenol concentration from the added ingredients is too high. Previous studies have also reported that fortifying yogurt with plant extracts rich in polyphenols can enhance flavor complexity; however, excessive increases in concentration can induce an astringent sensation that reduces panelists' acceptability (Li et al., 2021; Salehi et al., 2021).

Overall Acceptance

Overall acceptance is a sensory parameter obtained directly through a hedonic assessment, in which panelists evaluate their overall liking of the product based on the combined perception of color, aroma, and taste. This parameter represents an integrated consumer response rather than a calculated average of individual sensory attributes.

This parameter is often used to determine the most optimal product formulation from the consumer's perspective. The results of the study indicate that treatment A2B2 (2% cascara and 6-hour fermentation) yielded the highest overall acceptability score (figure 4). This indicates that a 2% concentration of cascara provides the best balance between the sensory characteristics of the yogurt and the contribution of bioactive compounds from cascara.

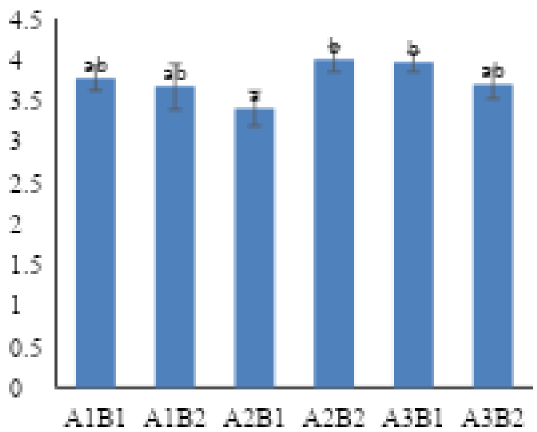

Figure 4. The Effect of Cascara Extract Concentration and Fermentation duration on the Overall Sensory Acceptance of Yogurt

The overall acceptability of yogurt is not influenced by a single sensory attribute, but rather results from a complex interaction between acid formation during fermentation, the contribution of volatile compounds, and the presence of bioactive compounds from fortifying ingredients. 2% concentration of cascara demonstrated a balance between acidity levels and sensory profile that remained within a range acceptable to the panelists, resulting in higher likability scores compared to both lower and higher concentrations. Excessively high concentrations have the potential to increase the intensity of sourness and astringency due to phenolic compound content, which can reduce the product's sensory acceptance. Additionally, fermentation duration plays a crucial role in shaping sensory characteristics through increased production of lactic acid and flavor compounds resulting from lactic acid bacteria metabolism, which directly influence the taste and aroma of yogurt (Barukčić et al., 2022; Iriondo-Dehond et al., 2020). These findings aligned with previous research indicating that the addition of bioactive ingredients in moderate amounts can improve yogurt's sensory quality; however, at excessively high concentrations, they may reduce consumer acceptability due to changes in flavor profile and texture (Purbowati et al., 2023). Thus, optimizing the concentration of fortifying ingredients and fermentation duration are key factors in the development of functional yogurt that not only offers health benefits but also remains sensorially acceptable to consumers.

3.4. Integrative Analysis of Yogurt Acidity and Sensory Properties

The yogurt fermentation process is a complex biochemical system involving interactions between the metabolic activity of LAB, the composition of the milk substrate, and the additional components used in the product formulation. The pH, total titratable acidity (TA), and sensory characteristics are interrelated and collectively reflect the dynamics of fermentation as well as the final quality of the yogurt product (Aryana & Olson, 2017).

In this study, the decrease in pH observed during fermentation indicates the occurrence of acidification resulting from lactose metabolism by the yogurt starter cultures, namely *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus*. These two microorganisms work synergistically in the yogurt fermentation system. *S. thermophilus* typically plays a role in the early stages of fermentation by producing lactic acid and lowering the pH of the environment, which then stimulates the growth of *L.bulgaricus* to continue acid production and generate volatile compounds that contribute to the yogurt's aroma characteristics (Tamime & Robinson, 2007).

The decrease in pH during fermentation was directly correlated with an increase in total titratable acidity (TA), reflecting the accumulation of organic acids produced during lactic acid bacteria metabolism. The relationship between these two parameters indicates that the dynamics of yogurt fermentation are influenced by the growth kinetics of the microorganisms and the rate of lactose utilization as an energy source. As fermentation proceeds, the accumulation of lactic acid result a decrease in pH until it approaches the isoelectric point of casein (around pH 4.6), which triggers the coagulation of milk proteins and the formation of the characteristic gel structure of yogurt (Walstra et al., 2005).

In the context of this study, increasing the fermentation duration from 3 hours to 6 hours resulted in a greater pH decrease and an increase in TA values. This indicates that fermentation duration is the primary factor determining the intensity of acidification in the yogurt system. These results align with the study by (An et al., 2025), which reported that the acidification rate in yogurt fermentation increases significantly after the microbial adaptation phase and reaches a maximum level during the exponential growth phase of bacteria.

The addition of cascara extract to the yogurt formulation also has the potential to influence fermentation dynamics through the presence of phenolic compounds it contains. Phenolic compounds are known to interact with milk proteins and microbial cell components, thereby modulating the metabolic metabolic activity of lactic acid bacteria. At moderate concentrations, some phenolic compounds can even act as stimulatory factors for fermentation activity through the mechanism of metabolite transformation by microorganisms (Filannino et al., 2015). This may explain why the addition of cascara at concentrations of 1.5–2.5% in this study did not indicate an inhibitory effect on yogurt fermentation activity.

The relationship between physicochemical and sensory parameters in this study indicates that the intensity of acidification does not always correlate directly with consumer acceptance levels. Although the treatment with the highest cascara concentration and the longest fermentation duration yielded the highest TA value, that treatment did not result in the highest sensory score. Conversely, the combination of moderate cascara concentration (2%) and 6-hour fermentation produced the highest overall acceptance score.

This phenomenon indicates that the balance between acidity level and sensory characteristics is a key factor in determining yogurt quality. Excessively high acidity can result in an overly sour taste, thereby reducing consumer preference. Additionally, phenolic compounds in cascara can interact with milk proteins to form protein–polyphenol complexes that influence the product's sensory properties, including yogurt texture and mouthfeel (Balivo et al., 2024).

The findings of this study indicate that the yogurt fermentation system is influenced not only by the activity of starter microorganisms but also by the complex interactions between the bioactive components of the added ingredients and the milk matrix. Therefore, the development of fortified yogurt requires a formulation approach that considers the balance between fermentation dynamics, acid formation, and the sensory characteristics of the final product.

Overall, the results of this study indicate that a 2% concentration of cascara extract with a 6-hour fermentation duration yields the best balance between the physicochemical and sensory characteristics of the yogurt. These conditions allow for optimal acidification without producing excessive acidity and while maintaining sensory characteristics acceptable to consumers.

4. CONCLUSIONS AND RECOMMENDATIONS

The addition of cascara extract and fermentation duration were significantly influenced the physicochemical characteristics of yogurt. Prolonged fermentation (6 h) enhanced lactic acid production, as reflected by lower pH and higher total titratable acidity ($p < 0.05$), without inhibiting lactic acid bacteria activity. The optimal formulation was achieved at 2% cascara concentration with 6-hour fermentation, yielding a pH of 4.63 and total titratable acidity of 0.75% lactic acid.

From a sensory perspective, the formulation with 2% cascara and 6 hour fermentation yielded the highest overall acceptability, indicating an optimal balance between acidity characteristics and the contribution of cascara's bioactive compounds. These findings underscore the potential of Hargo Kiloso Arabica coffee cascara as a yogurt additive in supporting the conversion of agro-industrial waste into value-added food products.

Future research should include additional analytical parameters, such as total LAB and antioxidant activity, and conduct storage stability tests to support product development.

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