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Research Article

Utilizing Strong-Alkalized Cocoa Bean Shell Powder as a Functional Cocoa Substitute in Chocolate Cupcakes

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ABSTRACT.

Cocoa bean shell (CBS) is a major byproduct of cocoa processing which is typically discarded. This study explored the potential of strong-alkalized CBS powder (SA-CBS) as a sustainable, functional substitute for cocoa powder in chocolate cupcake formulations. Cupcakes were prepared with varying levels of SA-CBS substitution (0, 25, 50, 75, 100%) and evaluated for physicochemical and sensory properties. Physical properties such as height, weight, diameter, texture, and color were measured, and consumer acceptability assessed through sensory evaluation. Proximate analysis was performed on the most preferred formulation to determine nutritional composition. Results showed that SA-CBS powder substitution had no significant effect on cupcake weight and lower diameter ($p<0.05$), but significantly influenced other properties, including upper diameter, height, specific volume, texture, and color. Consumer acceptability tests showed that the 50% SA-CBS formulation was most preferred, particularly for its dark appearance, moist texture, and chocolate flavor. Proximate analysis of this formulation revealed 39.5% moisture, 2.58% ash, 24.75% fat, 0.24% fiber, 20.65% protein, 250.55 mg/g total sugars, and 12.27% nitrogen-free extracts. These findings demonstrate that SA-CBS powder is a promising cocoa powder alternative in baked goods. Its favorable sensory attributes, along with high protein and fat content, highlight its functional, nutritional, and sustainable value for food applications.

Keywords: Cupcake Quality, Cocoa powder substitution, Strong-alkalized cocoa bean shell, Consumer acceptability test, Cocoa bean shell cupcakes

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INTRODUCTION

Cocoa (*Theobroma cacao* L.), a key Philippine agricultural product, is essential for chocolate production, yielding high-value products, including cocoa nibs, liquor, butter, powder, and confectionery blocks. Known for its antioxidant and vitamin content, cocoa thrives in the country's favorable climate, providing a competitive advantage in Asia [1]. However, the increasing demand for cocoa has also resulted in increased processing by-products, posing economic and environmental challenges. One major by-product, cocoa bean shells (CBS), is often discarded, although their high fiber and antioxidant content suggests potential for food industry applications [2]. Therefore, repurposing CBS can enhance sustainability by maximizing its nutritional potential and adding value to cocoa production.

Several studies have explored CBS as a food ingredient, including its use as an alternative to wheat flour [3], incorporation in cereal bars [4], and application as a source of dietary fiber [5]. However, CBS may contain mycotoxins, heavy metals, polycyclic aromatic hydrocarbons (PAHs), and microorganisms, which may pose health risks [6,5]. Despite its nutritional potential, the incorporation of CBS into food products remains limited due to undesirable sensory attributes, variable composition, and potential safety concerns. Thus, processing strategies that enhance its functionality and consumer acceptability are necessary to enable its wider application as a sustainable food ingredient. These risks can be mitigated through processing approaches such as alkalization, which may improve the safety and functional properties of CBS while preserving its beneficial compounds, making it more suitable for food product development.

In cocoa powder production, alkalization using sodium hydroxide or potassium carbonate enhances solubility, reduces acidity, and decreases bitterness and astringency [7]. This process elevates the pH of natural CBS powder from 6 to 8 [8], improving color and flavor through reactions between cocoa pigments and the alkalizing agent [9]. Alkalization can be categorized into light, medium, and strong levels, wherein stronger alkalization produces a deeper color and more pronounced flavor, making alkalized cocoa ingredients suitable for various dairy and bakery applications [9]. Previous studies have explored the potential of alkalized CBS as a food ingredient; however, its application in formulated bakery products remains limited. In particular, the incorporation of strongly alkalized CBS (SA-CBS) as a partial substitute for cocoa powder in chocolate cupcakes has not been extensively investigated. Since cocoa powder significantly contributes to the color, flavor, and overall acceptability of chocolate bakery products, evaluating the effects of SA-CBS incorporation is necessary to determine its feasibility as a sustainable cocoa-derived ingredient.

Given its fiber content and improved sensory characteristics after alkalization [7], CBS powder has potential as a cocoa powder substitute in baked goods. Chocolate cupcakes represent a suitable food system, specifically for high-moisture, leavened baked goods, for evaluating SA-CBS incorporation because cocoa powder contributes significantly to the color, texture, and sensory attributes of chocolate-based bakery products. Therefore, assessing the effects of SA-CBS substitution on physicochemical properties and consumer acceptability is essential in determining its potential as a sustainable cocoa-derived ingredient. Additionally, the utilization of CBS offers environmental and economic benefits due to the increasing generation of cocoa processing waste. Globally, an estimated 700,000 tons of cocoa bean shell (CBS) waste are generated annually [10,11], highlighting the need for sustainable valorization strategies.

Given the aforementioned research gaps, this study evaluates the potential of SA-CBS powder as a sustainable cocoa-derived ingredient in chocolate cupcakes formulated with varying levels of SA-CBS substitution, thereby addressing an important gap in the literature. The effects of SA-CBS incorporation on the physicochemical, physical, and sensory properties of the cupcakes were assessed to determine its feasibility as a cocoa powder substitute. By evaluating the influence of substitution level on product quality, this study is expected to provide insights into the development of sustainable cocoa-based ingredients and value-added applications for cocoa processing by-products. The findings from this study are expected to contribute to the growing body of research on food by-product valorization by providing practical insights into the application of CBS as a sustainable and functional ingredient in bakery products.

METHODOLOGY

2.1 Materials

The CBS were sourced from Malagos Agri-Ventures Corporation in Davao City, Philippines, collected after the winnowing process during chocolate production. The CBS was ground, vacuum-sealed in PE bags, and stored at -20 °C until use. Other chocolate cupcake ingredients, including all-purpose flour, wheat gluten, cocoa powder, sugar, baking

powder, modified starch, iodized salt, vegetable oil, vanilla extract, butter, eggs, and water, were purchased from a supermarket locally found in Los Baños, Laguna, Philippines.

2.2 Chemical Preparation

All solvents and reagents used were analytical grade.

2.3 Alkalization of Cocoa Bean Shell powder

The alkalization of CBS was carried out using NaOH as the alkalizing agent. Thirty grams of CBS powder was added to 150 mL of 2.53% NaOH (w/w) solution. The mixture was then stirred until a homogeneous slurry was formed. The slurry was then heated in a water bath (50 °C) for 30 minutes with constant stirring at 1150 rpm. Afterwards, it was dried in an oven dryer at 75 °C for 17 hours. The dried sample was ground, sieved through a 20-mesh sieve, and stored at -20 °C. The resulting SA-CBS powder had a pH of 7.64 ± 0.036, while the commercial cocoa powder had a pH of 8.02 ± 0.021. Both values fall within the optimal pH range for SA-CBS powder (7.6–8.2 or higher) [12]. In addition to its suitable pH, the SA-CBS powder contained 4.56% moisture, 12.72% ash, 7.43% fat, 8.71% fiber, and 19.68% protein, indicating its potential as a nutrient-rich ingredient.

2.4 Chocolate cupcake production

Chocolate cupcakes were prepared following the method of Souza et al. [3], with modifications. The chocolate cupcake formulations were based on a total flour basis of 56 g, composed of 28 g all-purpose flour and 28 g wheat gluten. All ingredients were expressed in baker's percentages relative to this flour basis. The fixed ingredients across all formulations included 71.43% sugar, 10.71% baking powder, 5.36% modified starch, 1.79% iodized salt, 32.14% vegetable oil, 10.71% vanilla extract, 25% butter, 71.43% egg, and 89.29% water. Commercial cocoa powder and SA-CBS powder were substituted at levels of 0%, 25%, 50%, 75%, and 100% of a total 14 g, corresponding to 25% of the flour basis. The substitutions were as follows: 0% SA-CBS (14 g cocoa powder), 25% SA-CBS (10.5 g cocoa powder, 3.5 g SA-CBS), 50% SA-CBS (7 g cocoa powder, 7 g SA-CBS), 75% SA-CBS (3.5 g cocoa powder, 10.5 g SA-CBS), and 100% SA-CBS (14 g SA-CBS). All dry ingredients were weighed using a digital scale (Reznor SF-400, Philippines), mixed thoroughly, and combined with wet ingredients using a wire whisk until homogeneous. The batter was poured into cupcake molds and baked at 180 °C for 10 minutes. Doneness was confirmed through internal temperature measurements (93–98 °C) and texture evaluations. Afterward, the cupcakes were cooled to room temperature prior to profile, color, sensory, and proximate analyses.

2.5 Chocolate cupcake properties

2.5.1 Physical profile of chocolate cupcakes

Cupcake diameter and height were measured using a digital caliper (Ingco, Philippines), while weight was determined using an analytical balance (OHAUS corporation, USA).

Volume was measured using the rice grain displacement method, based on AACC Method 10-05.01:1998 with minor modifications [13-16]. A container of known dimensions was initially filled with rice grains to determine its baseline volume. Each cupcake was then placed on a thin layer of rice at the bottom of the container, which was refilled with rice grains until level. The volume of displaced rice, corresponding to the cupcake volume, was measured using a graduated cylinder. Cupcake volume per unit weight was calculated using the formula:

$$\text{Volume per unit weight for cupcake} = \frac{\text{Volume of excess seeds (mL)}}{\text{Weight of the cupcake (g)}} \quad (1)$$

2.5.2 Texture profile analysis of cupcakes

The texture of each cupcake was analyzed using an EZ-SX texture analyzer (Shimadzu Corp., Japan), following Olaerts et al. [17]. After cooling at room temperature for 30 minutes, 25 mm-high and 30 mm-diameter crumb cylinders were extracted from the center and compressed twice to 30% of their original height at 100 mm/min using a 75 mm cylindrical probe, with a 3-second rest between compressions. Hardness was determined as the maximum peak force (N) from the force-time graph [18].

2.5.3 Color analysis of cupcakes

The color of each cupcake was analyzed using a chromameter (Konica Minolta, Japan), measuring L* (black to white), a* (greenness to redness), and b* (blueness to yellowness) values, following the methods described by Tinchan et al. [16] with minor modifications.

The color of each formulation was determined by comparing it to the other formulations to assess variations in color attributes. In this analysis, each formulation served as

both a sample and a reference point. The reference point in each calculation corresponded to the formulation against which another formulation's color attributes were compared. The color differences between samples were calculated using the equation:

$$\text{Color Difference: } \Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

$$= \sqrt{(L^*_1 - L^*_2)^2 + (a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2} \quad (2)$$

Where:

L* indicates lightness, a* represents the red-green axis, and b* denotes the yellow-blue axis. Values with subscript $_1$ represent components of the first sample, while values with subscript $_2$ correspond to the second sample.

For the total color difference between formulations, the following criteria were applied: $\Delta E^* < 1$, color differences are not evident to the naked human eye; $1 < \Delta E^* < 3$, color differences are not noticeable to the naked eye; and $\Delta E^* > 3$, differences are noticeable to the naked eye [19].

2.5.4 Sensory analysis of cupcakes

A consumer acceptability test was done to evaluate the sensory attributes of chocolate cupcakes and determine the most desirable formulation. Forty-five untrained panelists (aged 18 to 59 years old) assessed the appearance, texture, taste, and overall quality of the cupcakes using a 9-point hedonic scale.

2.6 Proximate analysis of the desired cupcake formulation

The most preferred chocolate cupcake formulation was analyzed for proximate composition to determine moisture, fat, fiber, ash, protein, and nitrogen-free extracts, following AOAC [20] with slight modifications. A nitrogen-to-protein conversion factor of 6.25 was used to calculate crude protein. The total sugar content was determined using the phenol sulfuric acid method from Tamboli et al. [21], with minor modifications.

2.7 Statistical Analysis

The study conducted all experiments and analyses in triplicate, and the results are reported as mean ± standard deviation. All statistical analyses were performed using a significance level of $p<0.05$. Data normality was checked using the Wilk-Shapiro test. One-way ANOVA was used to analyze normally distributed data (95% confidence level), followed by Tukey's test using Minitab® 21 (Minitab, LLC, USA) for post-hoc comparisons. Non-normally distributed data were analyzed using the Kruskal-Wallis test, with Dunn's test performed using IBM® SPSS® (IBM Corp., USA) for post-hoc analysis. Pearson's correlation tests were also conducted using IBM® SPSS® (IBM Corp., USA) to examine relationships between physical and sensory values, while a correlation heatmap was generated using R Studio 4.4.3 (Posit, PBC, USA).

RESULTS AND DISCUSSION

This study evaluated the potential of strong-alkalized cocoa bean shell (SA-CBS) powder as a food ingredient by formulating chocolate cupcakes with varying levels of SA-CBS substitution (0%, 25%, 50%, 75%, and 100%). The effects of SA-CBS incorporation on the cupcakes' physicochemical and sensory properties were assessed. Specifically, physical properties, color, texture profile, sensory acceptability, and proximate composition of the selected formulation were analyzed and evaluated. Figure 1 shows the formulated cupcakes, illustrating the differences in appearance among the various SA-CBS powder concentrations.

3.1 Physical Characteristics of Chocolate Cupcakes with SA-CBS powder

3.1.1 Physical Profile

The weight, height, upper and lower diameters, and specific volumes of the cupcakes in each formulation were measured to evaluate the effect of the SA-CBS powder on its physical and structural characteristics. The results are shown in Table 1. The weight of the cupcakes remained consistent across all substitution levels, indicating that the inclusion of SA-CBS powder did not significantly alter the total mass of the baked products. Both upper and lower diameters were generally comparable across treatments. However, a significant difference in upper diameter was observed between the 25% and 75% SA-CBS samples, with the 25% substitution yielding a smaller upper diameter. This may be attributed to the fibrous nature of SA-CBS powder, which can increase batter density by absorbing moisture, thereby limiting spread during baking and reducing the upper diameter [22]. Interestingly, the 25% substitution sample had a smaller upper diameter than the 75% sample, contrary to expectations based on fiber content. This deviation may be explained by external factors such as uneven oven temperature. Traditional ovens are prone to temperature fluctuations due to inconsistent heat circulation, leading to hot and cold spots that can influence expansion and moisture retention during baking [23,24].

Cupcake height was significantly reduced in the 100% SA-CBS sample compared to the control (0%

substitution), suggesting that full replacement impacts product rise. No significant height differences were observed among the intermediate substitution levels (25% to 75%). Similarly, specific volume was significantly lower in the 100% SA-CBS cupcakes, consistent with their reduced height. This marked reduction in cupcake height likely resulted from the high fiber content, which absorbed more moisture and impaired leavening by disrupting air cell formation, weakening the gluten network, and reducing gas retention [25-27]. In contrast, the height of cupcakes with 25–75% SA-CBS remained relatively stable, suggesting that moderate levels of SA-CBS did not compromise structural integrity. Specific volumes followed a similar pattern, with the 100% SA-CBS cupcake showing the lowest volume, consistent with findings that high fiber levels can impair gluten development and dilute functional proteins.

The relationships among the physical parameters of the chocolate cupcakes were examined using Pearson's correlation tests to assess the strength and direction of linear associations. Pearson correlation analyses showed that there was no significant correlation between weight and specific volume (p = 0.056), indicating that changes in weight did not correspond to changes in volume. On the other hand, there was a moderate negative correlation between cupcake height and weight (r = –0.524, p = 0.046), indicating that taller cupcakes tended to weigh less. This is in line with the findings of Ahmadi et al. [27], who noted that batter with higher fiber content tends to be heavier and denser, which can inhibit air bubble formation, limit expansion, and result in shorter, heavier cupcakes. In contrast, a strong positive correlation was found between height and specific volume (r = 0.725, p = 0.002), confirming the relationship between height and volumetric expansion. A strong positive correlation between height and specific volume highlighted the importance of proper aeration in cupcake structure, consistent with Ahmadi et al. [27] and Neeharika [28], who linked fiber addition to decreased volume in cakes due to impaired gas retention.

3.1.2 Texture Profile Analysis

Texture is a key quality parameter, influencing consumer acceptance and structural integrity. The effect of CBS concentration on cupcake hardness is presented in Table 1. Texture analysis revealed that hardness increased with higher SA-CBS substitution levels. Hardness rose from 3.65 N at 0% substitution to 5.80 N at 25% (58.90% increase), then to 10.92 N at 50% (88.28% increase from 25%), followed by a smaller increase to 11.21 N at 75% (2.66% increase), and finally to 13.93 N at 100% substitution (24.26% increase from 75%). These findings align with the study conducted by Öztürk and Ova [29], who reported firmer textures in cakes enriched with cocoa hulls. The fibrous composition of SA-CBS absorbs water, competes with other ingredients, and limits the moisture available for gluten development and starch gelatinization, resulting in a denser texture [26].

3.1.3 Color Analysis

Color measurements using CIELAB values showed significant differences, especially at higher substitution levels. Lightness (L*) increased

Figure 1. Chocolate cupcake samples formulated with varying levels of strong-alkalized cocoa bean shell (SA-CBS) powder as a substitute for commercial cocoa powder: (a) 0% SA-CBS, (b) 25% SA-CBS, (c) 50% SA-CBS, (d) 75% SA-CBS, and (e) 100% SA-CBS (no commercial cocoa powder).

Table 1.

Physical characteristics and CIELAB color parameters of chocolate cupcakes formulated with varying levels of strong-alkalized cocoa bean shell (SA-CBS) powder

Parameter	Formulation 1 0% SA-CBS	Formulation 2 25% SA-CBS	Formulation 3 50% SA-CBS	Formulation 4 75% SA-CBS	Formulation 5 100% SA-CBS
Weight (g)	48.53 ± 3.46^{a}	50.95 ± 1.07^{a}	51.95 ± 1.27^{a}	53.38 ± 4.10^{a}	55.15 ± 0.36^{a}
Height (in)	1.50 ± 0.13^{a}	1.40 ± 0.1^{ab}	1.35 ± 0.05^{ab}	1.37 ± 0.06^{ab}	1.23 ± 0.06^{b}
Specific volume (ml/g)	7.37 ± 0.61^{a}	5.11 ± 0.23^{b}	3.40 ± 0.34^{c}	4.88 ± 0.23^{b}	3.20 ± 0.12^{c}
Upper Diameter (in)	2.80 ± 0.01^{ab}	1.82 ± 0.10^{b}	2.67 ± 0.06^{ab}	2.97 ± 0.06^{a}	2.9 ± 0.1^{ab}
Lower Diameter (in)	1.73 ± 0.06^{a}	1.67 ± 0.15^{a}	1.67 ± 0.06^{a}	1.63 ± 0.06^{a}	1.43 ± 0.06^{a}
Hardness (N)	3.65 ± 0.35^{d}	5.80 ± 0.62^{c}	10.92 ± 0.41^{b}	10.73 ± 0.75^{b}	13.93 ± 0.67^{a}
Lightness (L*)	30.12 ± 1.14^{b}	31.73 ± 2.16^{ab}	32.28 ±1.79^{ab}	33.67 ±0.65^{ab}	35.45 ± 1.07^{a}
a-values (a*)	9.21 ± 0.14^{c}	9.32 ± 0.09^{c}	10.56 ± 0.44^{b}	11.73 ± 0.19^{b}	15.10 ± 0.09^{a}
b-values (b*)	8.79 ± 0.10^{c}	8.52 ± 0.04^{c}	9.99 ± 0.10^{b}	10.16 ± 0.10^{b}	15.44 ± 0.33^{a}

Mean values ± SD (n=3). Values with different superscript within the same row indicate a significant difference (p<0.05).

significantly in the 100% SA-CBS samples, indicating a lighter crumb color. Redness (a*) and yellowness (b*) also increased with higher SA-CBS concentrations. Significant differences in a* and b* values were observed between the 0% and 75%–100% groups, as well as between 0–25% and 50–75% substitution levels. Interestingly, cupcakes with 100% SA-CBS were lighter than the control, possibly due to the darker hue and higher pH (8.02) of commercial cocoa powder compared to SA-CBS powder (pH 7.64), as higher pH is associated with darker brown tones [29]. Increases in a* and b* values may also be attributed to enhanced Maillard reactions and the natural yellowish tint of SA-CBS [31,3].

Total color difference (ΔE*) values indicated perceptible changes in the following comparisons: 0% vs. 75% (4.56), 0% vs. 100% (10.36), 25% vs. 75% (3.50), 25% vs. 100% (9.75), 50% vs. 100% (7.77), and 75% vs. 100% (6.50). Other pairwise comparisons did not result in noticeable differences.

3.2 Consumer Acceptability of Chocolate Cupcakes with SA-CBS powder

Consumer acceptability of the cupcake samples, assessed by 45 untrained panelists using a 9-point hedonic scale, is presented in Table 2. Parameters evaluated included appearance, texture, taste, and overall acceptability.

3.2.1 Cupcake Appearance

Sensory evaluation confirmed instrumental findings. Appearance scores ranged from 6.89 to 6.97 for cupcakes with 0% to 75% SA-CBS powder. A significantly lower score of 5.26 was observed for the 100% SA-CBS sample. Significant differences in appearance were detected between the 100% SA-CBS sample and the 0% to 50% SA-CBS samples.

Cupcakes with 0–75% SA-CBS received favorable appearance scores (6.89–6.97), while the 100% SA-CBS cupcake received significantly lower ratings. The lighter, redder tone of the 100% sample may have appeared overbaked or artificial, negatively affecting perception [19]. A strong negative correlation between appearance scores and color parameters (L*, a*, b*) further supported this.

3.2.2 Cupcake Texture

Texture ratings for the 0% to 75% SA-CBS samples ranged from 6.17 to 6.91, while the 100% SA-CBS sample received a significantly lower score of 5.55. Significant differences were noted between the 100% SA-CBS sample and the 25% substitution levels. Texture acceptability decreased significantly at 100% SA-CBS, corresponding to increased instrumental hardness. This can be attributed to SA-CBS's high water-binding capacity and interference with gluten development, which reduce moisture retention and increase firmness [32,33]. Samples with 25–50% substitution retained a moist, spongy texture that panelists found appealing.

3.2.3 Cupcake Taste

Taste scores ranged from 6.06 to 7.15 for the 0% to 75% SA-CBS samples, with the 50% SA-CBS sample receiving the highest score. The 100% SA-CBS sample had the lowest taste rating of 5.90. Significant differences were observed between the 50% and 75% SA-CBS samples, and between the 50% and 100% SA-CBS samples. Taste scores peaked at 50% SA-CBS, while the 0%, 50%, and 75% samples were moderately acceptable. The 100% SA-CBS cupcake received the lowest score, likely due to off-flavors and slight bitterness introduced by higher SA-CBS concentrations. Lower substitution levels were described as having a sweet, chocolatey taste, which

Table 2. Mean scores of chocolate cupcake samples in the different sensory attributes during the Consumer acceptability test

Cupcake Sample	Overall Acceptability	Appearance	Texture	Taste
Formulation 1 (0% SA-CBS)	6.93 ± 1.55^{a}	6.89 ± 1.46^{a}	6.54 ± 1.53^{ab}	6.58 ± 1.61^{abc}
Formulation 2 (25% SA-CBS)	6.61 ± 1.50^{a}	6.93 ± 1.55^{a}	6.63 ± 1.39^{a}	6.97 ± 1.47^{ab}
Formulation 3 (50% SA-CBS)	7.24 ± 1.45^{a}	6.97 ± 1.44^{a}	6.91 ± 1.41^{ab}	7.15 ± 1.55^{a}
Formulation 4 (75% SA-CBS)	6.39 ± 1.22^{a}	6.65 ± 1.46^{ab}	6.17 ± 1.68^{ab}	6.06 ± 1.73^{bc}
Formulation 5 (100% SA-CBS)	6.26 ± 1.74^{a}	5.26 ± 1.53^{b}	$5.55^{B} \pm 1.70^{b}$	5.9 ± 1.85^{c}

Mean values ± SD (n=3). Values with different superscripts within the same column indicate a significant difference ($p<0.05$).

declined at higher SA-CBS inclusion levels.

3.2.4 Overall Acceptability and Panel Feedback

Overall acceptability scores ranged from 6.26 to 7.24, with no significant differences observed among the formulations. This suggests that consumer acceptance was maintained regardless of the level of SA-CBS substitution. Overall acceptability was statistically comparable across all formulations; however, the 50% SA-CBS cupcake recorded the highest numerical acceptability score. This was attributed to its moist crumb, chocolate-rich flavor, and appealing dark appearance. Panelists highlighted a slightly grainy texture and crunchy crust in higher substitution samples, identifying them as areas for potential improvement.

Panel feedback noted that the 25% and 50% SA-CBS samples had a moist texture and chocolatey flavor. Some panelists noted a slightly grainy mouthfeel and crunchy crust in the 75% and 100% SA-CBS samples. In terms of color perception, cupcakes with 0% to 50% SA-CBS were generally described as dark brown, while those with 75% and 100% substitution appeared lighter. These observations were consistent with instrumental color analysis, which showed increased L* values at higher substitution levels.

3.2.5 Correlation of Physical, Instrumental, and Sensory Attributes

To explore relationships between physical, instrumental, and sensory attributes, a heat map was generated (Figure 2). Appearance scores were strongly negatively correlated with L*, a*, and b* values, indicating a preference for darker cupcakes with lower red and yellow tones. The strong inverse correlation with a* values highlight the impact of excessive redness on appearance perception. While moderate browning is typically associated with desirable, golden-brown baked goods, excessive redness or darkness may be perceived as signs of overbaking or burnt flavors [31].

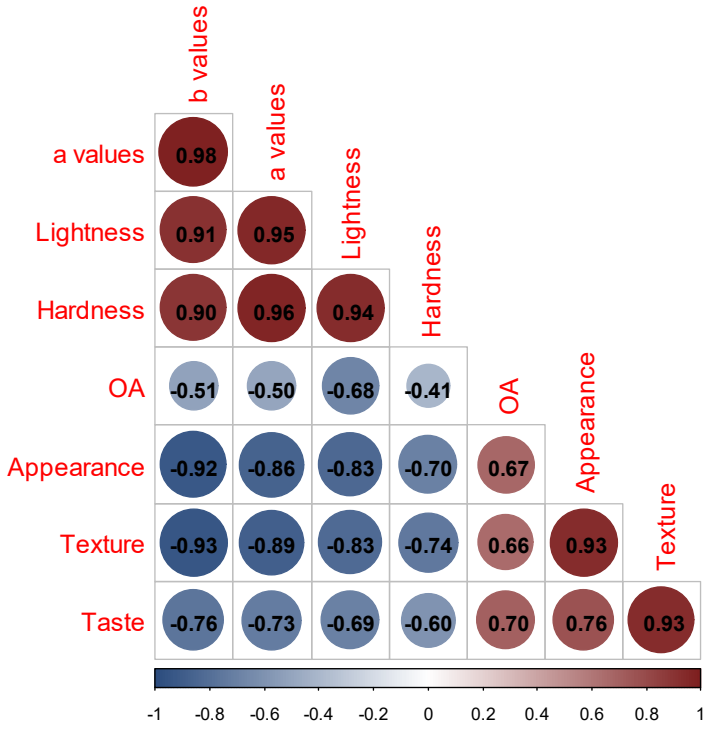

Figure 2. Heat map showing the correlation between physical measurements and sensory scores of chocolate cupcakes with varying levels of SA-CBS powder. Values range from +1 (strong positive correlation) to –1 (strong negative correlation), indicating how changes in physical attributes relate to sensory perceptions.

Similarly, elevated L* and b* values resulting from higher SA-CBS concentrations may have contributed to an undesirable yellowish or pale appearance, further reducing visual appeal. Texture scores showed a strong negative correlation with hardness, suggesting that increased hardness reduced perceived texture acceptability. This may be attributed to the drier, denser, and tougher mouthfeel associated with high levels of SA-CBS powder, a consequence of its high fiber content.

3.2.6 Selection of the most desirable cupcake formulation

Based on the results of the consumer acceptability test, the 50% SA-CBS cupcake was selected for further proximate analysis. Although overall acceptability was similar among most samples, only the 0%, 25%, and 50% SA-CBS samples showed no significant differences in appearance, taste, and texture scores. The 50% substitution level was selected based on favorable panelist feedback, which emphasized its moist texture, rich chocolate flavor, and dark appearance. Thus, the 50% SA-CBS cupcake was selected for proximate analysis as it balanced favorable sensory attributes with maximum SA-CBS incorporation.

3.3 Proximate Analysis of the most desirable cupcake formulation

The proximate composition of the 50% SA-CBS cupcake formulation is presented in Table 3. Parameters analyzed included moisture, ash, crude fat, crude fiber, crude protein, nitrogen-free extract (NFE), and total sugar content.

The moisture content of the 50% SA-CBS cupcake was 39.50%. Ash content was measured at 2.58 ± 0.15%, indicating a relatively high mineral content. Crude fat content was 24.75 ± 0.28%, and crude fiber was 0.2416 ± 0.01%. Crude protein content reached 20.65 ± 0.12%, while the nitrogen-free extract (NFE) was 12.27 ± 0.76%. Total sugar content was 250.55 ± 14.20 mg/g. Its proximate composition showed a moisture content which was slightly higher than typical ranges, which may have enhanced freshness and mouthfeel [34]. Ash content reflected the mineral-rich nature of SA-CBS, especially its potassium and magnesium content [35]. Fat content (24.75%) largely originated from butter and oil, while the SA-CBS powder contributed minimally [36]. The measured crude fiber (0.24%) highlighted the potential of SA-CBS as a functional ingredient for dietary fiber enrichment [5]. Protein content (20.65%) resulted from the combined contributions of eggs and SA-CBS, which provide moderate protein levels [35]. The nitrogen-free extract and total sugar levels reflected contributions from wheat flour and sugar in the cupcake formulation [37].

Table 3. Proximate composition of chocolate cupcake sample with 50% SA-CBS substitution

Parameter	
Moisture Content (%)	39.50 ± 0.45
Ash Content (%)	2.58 ± 0.15
Fat Content (%)	24.75 ± 0.28
Fiber Content (%)	0.2416 ± 0.01
Protein Content (%)	20.65 ± 0.12
Nitrogen-Free Extracts (%)	12.27 ± 0.76
Total Sugars (mg/g)	250.55 ± 14.20

Mean values ± SD (n=3)

CONCLUSION

This study formulated chocolate cupcakes by substituting cocoa powder with varying levels of strong-alkalized cocoa bean shell (SA-CBS) powder. Results showed that SA-CBS significantly affected the physicochemical and sensory properties of the product, particularly at higher substitution levels. Specific volume, texture, and color were most impacted, with 100% substitution resulting in denser, less appealing cupcakes. The 50% SA-CBS formulation emerged as the optimal level, maintaining desirable sensory qualities, such as moist texture, rich chocolate flavor, and acceptable appearance, while providing a proximate composition that supports its potential as a value-added bakery product. Proximate analysis of this formulation revealed 39.50% moisture, 2.58% ash, 24.75% fat, 0.24% fiber, 20.65% protein, 250.55 mg/g total sugars, and 12.27% nitrogen-free extracts, supporting its potential as a nutrient-enriched bakery product.

These findings highlight the potential of SA-CBS powder as a functional ingredient in cocoa-based baked goods. Its incorporation offers a sustainable, cost-effective alternative to traditional cocoa powder. Importantly, the 50% substitution level preserved key sensory attributes, ensuring consumer acceptability. This research adds to the expanding literature on cocoa bean shell valorization, showcasing its effective incorporation in baked product formulations. With its favorable nutritional profile, sensory performance, and sustainability potential, SA-CBS can support the development of healthier, more resource-efficient food products.

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of the manuscript, conceptualization of the study design, data curation through management and organization of research data, formal analysis of the study findings, hands-on investigation, and the development of the methodology used in the study. Argel Largado was responsible for data curation, assisted in performing formal analysis, and assisted in project administration, including coordination and execution of study activities. John Joseph Menia contributed to data curation, assisted in performing formal analysis, and supported project administration by managing day-to-day project tasks. Romel Felismino provided contributions in the conceptualization of the study, secured project funding, and supervised the research process to ensure scientific rigor and integrity. Katherine Ann Castillo-Israel contributed to conceptualization and participated in funding acquisition and overall supervision of the project. Sheba Mae Duque took part in writing, review, and editing of the manuscript, conceptualized aspects of the research, acquired funding, and oversaw project administration and supervision across all phases of the study. All authors have reviewed and approved the manuscript for publication.

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Conflicts of Interest: The authors affirm that they do not hold any conflict of interest.

Ethical Statement: The Research Ethics Review Committee of Mary Mediatrix Medical Center reviewed and approved this study, assigning it the protocol code MMMC-RERC 0005-05-2024. Informed consent was obtained from all participants, and all data were anonymized to ensure confidentiality. All procedures adhered to ethical guidelines set forth by the ICH-GHCP and were reviewed and approved by the aforementioned review board. This work was supported by the Department of Science and Technology under Collaborative Research and Development to Leverage Philippine Economy (DOST-CRADLE) Program.

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