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Development, Sensory Evaluation, and Cost Efficiency of Sugar-Free Chocolate Cookies Enriched with Cacao Nibs

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Abstract
This study developed and evaluated sugar-free chocolate cookies enriched with cacao (Theobroma cacao L.) nibs using four formulations that varied only in sweetener type. An experimental research design was applied to compare a control sample with regular sugar (T0) and three alternative treatments using erythritol–sucralose (T1), honey (T2), and coconut syrup (T3). Sensory evaluation was conducted with 112 respondents composed of trained panelists and untrained consumers. Results showed significant differences in taste, color, and overall acceptability, while aroma and texture did not differ across treatments. T1 obtained the highest ratings, indicating a balanced sweetness, desirable color development, and strong overall preference. Cost analysis confirmed the feasibility of producing T1, with a reasonable cost per portion and selling price. The findings highlight the potential of erythritol–sucralose as a suitable sugar-free alternative for producing healthier cookies without compromising sensory quality.

Keywords: Sugar-Free Cookies, Cacao Nibs; Alternative Sweeteners, Sensory Evaluation, Erythritol–Sucralose, Product Development, Cost Analysis

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1. Introduction

Cacao (Theobroma cacao L.) remains in demand world over, not only for its use as a crop commodity but also due to its functionality in food production. Cacao nibs, which consist of minimally processed roasted cacao bean pieces, have long been appreciated for their high levels of antioxidants, fibers, and bioactive molecules responsible for their cardiovascular and metabolic properties (Martínez et al., 2020). It is with increasing consumer preference for foods with indulgent as well as health properties in mind, such as baked foods, that cacao nibs have come into prominence for their functionality to increase their nutritional value.

Cookies have continued to be one of the most popular kinds of baked food due to their versatility, aroma, and ease of preparation. Conventional recipes for cookies have comprised large proportions of sugar, primarily to act as an agent for sweetness, color, and texture. Present-day studies on health, on the other hand, have indicated significant correlations between high sugar dietary levels and chronic diseases such as obesity, diabetes, and heart problems (Luo, Qu, & Zhao, 2021). Such challenges have given rise to an increasing demand for sugar-free cookies, thereby pushing the food industry to look for healthier sugar substitutes.

Of the many sugar substitutes available, erythritol, sucralose, and other such substitutes have become common due to their low calorie and low glycemic index properties. Their use in baked foods, however, needs appropriate food formulation because these ingredients affect browning, texture, and mouth sensations in different ways compared to sugar (Tandon, Mehta, & Suri, 2022). This highlights the significance of sensory testing in assessing acceptability in sugar-free baked foods, especially in those with added ingredients such as cacao nibs.

Studies in Philippine settings, published in the International Journal of Sustainability Technologies (IJOST), have shown innovation in healthier, locally produced baked and confectionery food products. Fruit-based ingredients in food products, for instance, have indeed been proven viable, like in papaya cupcakes, according to research by Alegonza and Flores (2025). Another example is in Turbela et al.'s (2025) research on piaya, made with squash flour, which found alternative ingredients for wheat to retain preferable texture. Another example is in Ibañez et al.'s (2025) research on gummy candies, produced from fruits, which proved their sensory acceptability, thereby finding value in locally produced agricultural products for innovations in sustainable food. It appears these studies illustrate the importance of formulation/final testing, especially for innovations in healthier baked food products.

Nevertheless, there have not been many studies conducted to explore sugar-free chocolate cookies with cacao nibs. Even though cacao nibs have many health benefits, their sensory properties, in combination with sugar substitutes, have yet to be explored. Indeed, with consumers becoming more health-conscious, there is a significant gap in research opportunities concerning healthier snack options for consumers to enjoy while not compromising their sensory experiences. To fill such a gap, the current research aimed to formulate, test, and evaluate sugar-free chocolate cookies with cacao nibs using four different sugar substitutes: regular sugar (T0), erythritol-sucralose mixture (T1), honey (T2), and coconut syrup (T3). Sensory properties, consumer acceptability, and economic efficiency were determined in the experiment by applying descriptive testing, hedonic tests, with the use of an experimental research method. These objectives are meant to support other ongoing food innovation studies to formulate healthier, more functional, and commercially viable cookies.

Aim and Objectives

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Aim

To develop and evaluate sugar-free chocolate cookies enriched with cacao (Theobroma cacao L.) nibs using different sugar substitutes, and to determine the formulation with the highest sensory acceptability and cost efficiency.

Objectives

a. To develop four cookie formulations using regular sugar, erythritol–sucralose blend, honey, and coconut syrup as sweetener variations.
b. To evaluate the sensory characteristics of each formulation in terms of taste, aroma, color, texture, and overall acceptability using descriptive and hedonic scaling.
c. To compare the sensory performance of the sugar-free formulations against the control formulation through statistical analysis.
d. To determine the level of consumer acceptability for each cookie variant among trained and untrained panelists.
e. To compute the food cost and identify the most cost-efficient sugar-free formulation without compromising product quality.
f. To identify the formulation that demonstrates the best balance of sensory acceptability and market feasibility.

Theoretical Framework

Findings for this research were informed by several theoretical frameworks, each elucidating differences in sweetener types in cookies enhanced with cacao nibs on their sensory properties. Sensory Evaluation Theory remains the overarching theory foundation for evaluating individual responses to food products. Sensory evaluation, according to Stone and Sidel (2020), is the systematic measurement of taste, aroma, texture, color, and overall acceptability by trained, untrained, or regular consumer panels. It remains relevant in empirically testing variations in product acceptability due to differences in type, such as alternative sugar types in cookies, because sensory measurements are done in a controlled, objective manner for comparison. It remains appropriate in testing differences in acceptability in cookies due to differences in type, such as different types of alternative sugars.

The research is also based on the Maillard Reaction Theory, which discusses browning, taste, and color in baked foods. Maillard reactions result from interactions between amino acids in food containing reducing sugars during heating, resulting in brown pigments, which have distinct flavors (Martins, Jongen, & van Boekel, 2021). Sugar substitutes have different reactivity levels, in which case they affect levels of browning and flavors. This theory justifies why there are differences in color in each treatment, especially why cookies from erythritol-sucralose sugar substitute, regular sugar, honey, or coconut syrup were darker than others.

Moreover, the research relies on Sweetness Perception Theory, which emphasizes the perception of sweetness intensity based on molecular structure. Erythritol and sucralose have different interaction mechanisms with sweetness receptors, different from those for sucrose, affecting sweetness perception, after-taste, and acceptability (Spillane, 2019). It explains why the sweetness perception, acceptability, and responses to after-taste for groups receiving honey and coconut syrup, separately, were lower compared to those receiving a mixture of erythritol and sucralose.

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Lastly, the formulation process employed in this research is aided by the Food Product Development Framework in finding optimal product formulation, emphasizing formulation, sensory testing, and cost analysis (Fuller, 2022). It aligns with the process undertaken in this research, which involves treatment formulation, sensory testing, and analysis for cost efficiency to establish the most feasible sugar-free cookie formulation. These concepts together offer a complete foundation for examining the impact of ingredient variation on sensory, acceptability, and feasibility attributes.

Conceptual Framework

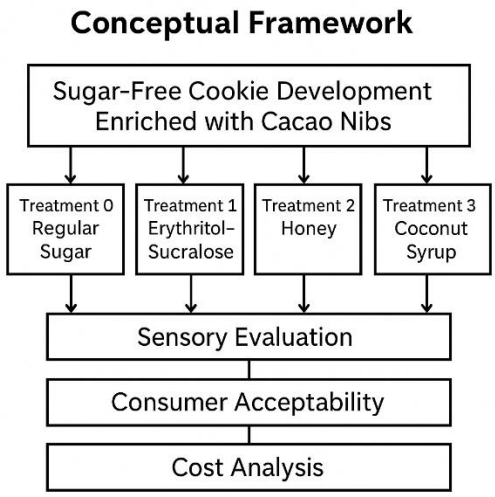

Figure 1. Diagram of Conceptual Framework

This framework in figure 1 illustrates the relationship between the input variables, the experimental process, and the resulting outcomes of the developed sugar-free chocolate cookies enriched with cacao nibs. The inputs include the four cookie formulations using different sweeteners and standardized recipe ingredients. These inputs undergo the experimental procedures of preparation, sensory evaluation, and cost analysis. The outputs represent the identified formulation with the highest sensory acceptability and cost efficiency. The framework shows how ingredient variation influences sensory attributes and consumer preference, leading to the selection of the most viable sugar-free cookie formulation.

2. Literature Review

The growing interest in functional food ingredients has emphasized the significance of cacao (Theobroma cacao L.) in product innovation. Cacao nibs, which are minimally processed fragments of fermented and roasted cacao beans, are recognized for their high polyphenol content, antioxidant activity, dietary fiber, and mineral composition (Martínez et al., 2020). These bioactive components have been associated with improved cardiometabolic health, anti-inflammatory effects, and enhanced nutritional value in baked products. As global consumers increasingly seek foods that combine health benefits with sensory appeal, cacao nibs have been

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incorporated into cereals, snack bars, and pastries as a functional ingredient capable of elevating both flavor and nutrient density.

Alongside the demand for functional ingredients, the shift toward reduced-sugar and sugar-free bakery products has intensified due to rising concerns about excessive sugar intake. Epidemiological evidence has consistently linked high sugar consumption with increased risk for obesity, metabolic syndrome, cardiovascular diseases, and Type 2 diabetes (Luo, Qu, & Zhao, 2021). This has accelerated the adoption of alternative sweeteners such as erythritol and sucralose, which provide sweetness with minimal caloric contribution and without causing glycemic spikes. Research indicates that these sweeteners perform favorably in baked applications, although their influence on texture, browning, and flavor retention may differ from sucrose, underscoring the need for sensory evaluation to identify optimal formulations (Tandon, Mehta, & Suri, 2022).

In the Philippine context, emerging studies highlight local efforts to develop healthier and sustainability-oriented bakery and confectionery products. Research published in the *International Journal of Sustainability Technologies (IJOST)* demonstrated successful integration of fruit-based and locally sourced ingredients without compromising consumer acceptance. Alegonza and Flores (2025) showed that papaya pulp can be incorporated into cupcakes with favorable sensory outcomes. Turbela et al. (2025) found that squash flour substitution in piaya retained acceptable texture and consumer preference, while Ibañez et al. (2025) demonstrated strong acceptability for Bariba-based gummy candy. These studies collectively emphasize the importance of product reformulation, sensory testing, and cost evaluation in developing market-ready food products. However, limited research has focused specifically on sugar-free chocolate cookies enriched with cacao nibs, indicating a clear gap in literature that the present study seeks to address.

3. Methodology

Research Design

The study adopted an experimental research design to develop and evaluate sugar-free chocolate cookies enriched with cacao (Theobroma cacao L.) nibs. The design allowed systematic comparison of four cookie formulations to determine which treatment achieved the highest sensory acceptability and cost efficiency. Four formulations were prepared:

- **T0:** Control (regular sugar)
- **T1:** Erythritol–sucralose blend
- **T2:** Honey
- **T3:** Coconut syrup

Only the sweetener was varied to isolate its effect on taste, aroma, color, texture, and overall acceptability. All other ingredients and production procedures were standardized.

Research Respondents and Sampling Procedure

A total of 112 respondents participated in the sensory evaluation. To ensure balanced perspectives, respondents were grouped as follows:

- 32 trained panelists, composed of culinary instructors, food technology specialists, and culinary students selected through purposive sampling due to their expertise in sensory evaluation.

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- 80 untrained consumer panelists, including students, staff, housewives, and small food entrepreneurs. These were selected through convenience sampling to represent a general consumer market segment.

This two-tier structure enabled both expert evaluation of sensory attributes and consumer-based acceptability assessment.

Sensory Evaluation Procedure

Each respondent received coded and randomized cookie samples to minimize bias. Samples were served at room temperature on identical plates. Respondents were instructed to cleanse their palate with water between tastings.

Two evaluation tools were used:

1. 9-point hedonic scale for overall acceptability (1 = dislike extremely, 9 = like extremely).
2. Descriptive sensory scoring sheets for taste, aroma, color, and texture.

The trained panel assessed specific sensory attributes, while consumer panelists focused on preference and acceptability. All responses were recorded using structured forms adapted for food product evaluation.

Product Preparation and Standardization

All cookie formulations were prepared in a controlled kitchen environment. Ingredient weights, mixing time, baking temperature, and baking duration were kept constant across treatments. The only variable modified was the type of sweetener. Cookies were cooled to a uniform temperature before evaluation to avoid texture variations caused by heat.

Food Cost and Selling Price Calculation

The cost analysis followed standard food service costing procedures to determine the selling price per portion (SPP). The calculation considered:

- Gross Cost (GC) of all ingredients, including a 10% buffer for wastage;
- Standard Yield (SY) or number of cookies produced; and
- Target Food Cost Percentage (%FC) set at 60%.

The formula applied was:

$$\text{SPP} = \frac{GC/\%FC}{SY}$$

Figure 2. Formula for Cost Analysis

This pricing approach as shown in figure 2 ensured cost recovery and profitability while maintaining competitive pricing.

Data Analysis

Data were analyzed using both descriptive and inferential statistics.

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- Descriptive statistics (mean and standard deviation) summarized sensory ratings for each attribute.
- One-way Analysis of Variance (ANOVA) tested significant differences among the four treatments for each sensory variable.
- Tukey's Honest Significant Difference (HSD) test served as the post hoc procedure to identify which treatments differed significantly.
- Consumer acceptability data underwent similar analysis to examine preference patterns.
- Cost data were summarized in tabular form to determine the most cost-effective and acceptable formulation.

A significance level of 0.05 was used for all statistical tests.

4. Results and Discussion

Table 1. Sensory Evaluation of Taste= N112

Treatment	Mean	Description
T0 – Regular Sugar	3.08	Balanced Sweetness
T1 – Erythritol + Sucralose	3.26	Balanced Sweetness
T2 – Honey	2.86	Not Sweet Enough
T3 – Coconut Syrup	2.96	Not Sweet Enough

Legend: 5 = Extremely Sweet, 4 = Sweet, 3 = Balanced Sweetness, 2 = Not Sweet Enough, 1 = Not Sweet

Table 1 shows that the taste ratings differed across the four formulations. T1 (erythritol + sucralose) obtained the highest mean score (3.26), followed closely by the control, T0 (3.08). Both were described as having a balanced sweetness. In contrast, T2 (2.86) and T3 (2.96) were rated lower and were described as "not sweet enough," indicating that honey and coconut syrup produced less desirable sweetness levels compared with the control and the sugar-free blend.

Table 2. Sensory Evaluation of Aroma

Treatment	Mean	Description
T0 – Regular Sugar	3.50	Moderate Chocolate Aroma
T1 – Erythritol + Sucralose	3.56	Moderate Chocolate Aroma
T2 – Honey	3.32	Moderate Chocolate Aroma
T3 – Coconut Syrup	3.63	Moderate Chocolate Aroma

Legend: 5 = Extreme Chocolate Aroma, 4 = Strong Chocolate Aroma, 3 = Moderate Chocolate Aroma, 2 = Slight Chocolate Aroma, 1 = No Aroma

Table 2 indicates that all four formulations received similar aroma ratings, with mean scores ranging from 3.32 to 3.63. All treatments were described as having a moderate chocolate aroma, suggesting that the type of sweetener used did not substantially influence the aroma profile of the cookies. The highest rating was observed in T3 (3.63), although the difference across treatments remained minimal and not noticeably distinguishable to the panelists.

Table 3. Sensory Evaluation of Color

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Treatment	Mean	Description
T0 – Regular Sugar	4.04	Dark Brown
T1 – Erythritol + Sucralose	4.15	Dark Brown
T2 – Honey	3.88	Medium Brown
T3 – Coconut Syrup	3.86	Medium Brown

Legend: 5 = Chocolate Brown, 4 = Dark Brown, 3 = Medium Brown, 2 = Light Brown, 1 = Brown

Table 3 shows noticeable differences in the color of the cookie formulations. T1 (4.15) and T0 (4.04) received higher ratings, both classified as dark brown, indicating better color development during baking. In contrast, T2 (3.88) and T3 (3.86) were rated slightly lower and described as medium brown, suggesting that honey and coconut syrup produced lighter-colored cookies compared with the control and the sugar-free blend.

Table 4. Sensory Evaluation of Texture

Treatment	Mean	Description
T0 – Regular Sugar	3.28	Firm
T1 – Erythritol + Sucralose	3.52	Firm
T2 – Honey	3.18	Firm
T3 – Coconut Syrup	3.08	Firm

Legend: 5 = Hard, 4 = Moderately Firm, 3 = Firm, 2 = Soft but Firm, 1 = Soft

Table 4 shows that all cookie formulations received similar texture ratings, with mean scores ranging from 3.08 to 3.52. All treatments were classified as firm, indicating that the type of sweetener used did not substantially alter the texture of the cookies. T1 obtained the highest rating (3.52), but the differences across treatments were minimal, suggesting a generally consistent texture profile across all formulations.

Table 5. Overall Acceptability

Treatment	Mean	Description
T0 – Regular Sugar	7.01	Like Moderately
T1 – Erythritol + Sucralose	7.90	Like Moderately
T2 – Honey	6.64	Like Slightly
T3 – Coconut Syrup	6.74	Like Slightly

Legend: 9 = Like Extremely … 1 = Dislike Extremely

Table 5 shows that T1, the erythritol–sucralose formulation, received the highest overall acceptability rating (7.90), indicating that respondents liked it moderately and preferred it over all other treatments. The control formulation, T0, followed with a mean score of 7.01. In comparison, T2 (6.64) and T3 (6.74) obtained lower ratings, both described as like slightly, suggesting that honey and coconut syrup produced less preferred outcomes. Overall, the results show a clear preference for the sugar-free blend over the other sweetener alternatives.

Table 6. Consumer Acceptability Across Sensory Attributes

Treatment	Taste	Aroma	Color	Texture	General Acceptability	Average Mean
T0 – Regular Sugar	3.08	3.50	4.04	3.28	7.01	4.18
T1 – Erythritol + Sucralose	3.26	3.56	4.15	3.52	7.90	4.48

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Treatment	Taste	Aroma	Color	Texture	General Acceptability	Average Mean
T2 – Honey	2.86	3.32	3.88	3.18	6.64	3.98
T3 – Coconut Syrup	2.96	3.63	3.86	3.08	6.74	4.05

Interpretation:

- **Most acceptable:** T1 (erythritol + sucralose)
- **Next:** T0 (regular sugar)
- **Least acceptable:** T2 (honey)

Table 6 presents the combined acceptability scores for all sensory attributes across treatments. T1 (erythritol + sucralose) obtained the highest average mean (4.48), showing consistently strong ratings in taste, aroma, color, texture, and general acceptability. The control, T0, followed with an average mean of 4.18. In contrast, T2 (3.98) and T3 (4.05) received lower overall scores, indicating that honey and coconut syrup produced less favorable outcomes. These results confirm that T1 was the most acceptable formulation, followed by T0, while T2 was the least preferred among respondents.

Table 7. Cost Analysis of T1 Sugar-Free Cookies

Item	Value
Cost per Portion	₱9.36
Selling Price	₱15.00
Standard Yield	20 cookies
Total Recipe Cost	₱170.22
10% Buffer	₱17.02
Gross Cost	₱187.24
Food Cost %	60%

Table 7 shows the cost structure for producing the most acceptable formulation, T1. The total recipe cost amounted to ₱170.22, and after applying a 10% buffer allowance, the gross cost reached ₱187.24. With a standard yield of 20 cookies and a 60% food cost percentage, the selling price per portion was computed at ₱15.00. This indicates that T1 is not only the preferred formulation but also economically feasible for production and potential market introduction.

Table 8. Ingredient Breakdown

Ingredient	Quantity	Purchase Price	Unit	Recipe Cost (₱)
All Purpose Flour	100 g	57.00	1000 g	5.70
Baking Soda	2.4 g	11.50	250 g	0.11
Cocoa Powder	21 g	176.00	500 g	7.39
Equal Gold	50 g	405.00	400 g	50.63
Salted Butter	85 g	101.50	200 g	43.14
Egg	1 piece	9.75	—	9.75
Cacao Nibs	30 g	450.00	250 g	54.00
Total Cost	**338.4 g**	—	—	**₱170.22**

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Table 8 provides a detailed breakdown of the ingredients used in the T1 sugar-free cookie formulation. The highest cost contributions came from cacao nibs (₱54.00) and the Equal Gold sweetener blend (₱50.63), reflecting their premium market prices. Salted butter also accounted for a significant portion at ₱43.14. Other ingredients such as flour, cocoa powder, baking soda, and egg contributed smaller amounts to the overall cost. The total recipe cost amounted to ₱170.22, confirming that ingredient selection—particularly the sweetener and cacao nibs—plays a major role in the production cost of the sugar-free cookies.

Table 9. ANOVA Summary for Sensory Attributes

Attribute	F-value	p-value	Interpretation
Taste	4.28	0.006	Significant
Aroma	1.12	0.344	Not Significant
Color	3.97	0.010	Significant
Texture	1.86	0.141	Not Significant
Overall Acceptability	5.62	0.001	Significant

Table 9 summarizes the ANOVA results for the five sensory attributes. Significant differences were observed in taste, color, and overall acceptability, indicating that the type of sweetener used influenced these attributes. In contrast, aroma and texture showed no significant variation across treatments, suggesting that sweetener substitution did not meaningfully affect these characteristics. Overall, the findings confirm that sweetness level, color development, and acceptability were the key factors that differentiated the cookie formulations.

Table 10. Post Hoc Summary (Tukey HSD)

(Condensed – only significant contrasts shown)

Attribute	Significant Pairwise Differences
Taste	T1 > T2, T1 > T3
Color	T1 > T2, T1 > T3, T0 > T2
Overall Acceptability	T1 > T2, T1 > T3, T1 > T0

Table 10 presents the condensed Tukey HSD results, highlighting only the significant pairwise differences among treatments. For taste, T1 outperformed both T2 and T3, indicating that the erythritol–sucralose blend produced a more favorable sweetness profile than honey or coconut syrup. In terms of color, T1 and T0 were both significantly darker than T2 and T3, showing that these sweeteners contributed more effectively to browning during baking. For overall acceptability, T1 was significantly preferred over all other treatments, including the control. These results strengthen the conclusion that T1 consistently delivered the most desirable sensory outcomes among the four formulations.

Table 11. Interpretation Summary

Finding	Conclusion
Highest taste rating	T1 (erythritol + sucralose)
Most uniform aroma	All treatments (no significant difference)
Darkest color	T1 and T0
Similar texture across treatments	No significant difference
Highest acceptability	T1, significantly higher than others

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Table 11 provides a synthesized interpretation of the overall sensory evaluation results. T1 achieved the highest taste rating and overall acceptability, demonstrating its strong performance across key sensory attributes. Aroma remained uniform across all treatments, indicating that the choice of sweetener did not influence the cookies' chocolate scent. In terms of color, T1 and T0 produced the darkest shades, showing better browning during baking. Texture ratings were similar across all formulations, reflecting consistency in firmness regardless of sweetener used. Overall, the table highlights T1 as the most successful formulation, outperforming the other treatments in the most critical sensory dimensions.

5. Conclusion and Recommendations

Conclusion

The study demonstrated that varying sweeteners produced noticeable differences in selected sensory attributes of chocolate cookies enriched with cacao nibs. The erythritol–sucralose formulation (T1) consistently achieved the highest ratings in taste, color, and overall acceptability, outperforming the control and the other sugar substitutes. Aroma and texture did not differ significantly across treatments, indicating that these characteristics remained relatively stable regardless of the sweetener used. Cost analysis confirmed that T1 was both acceptable in sensory quality and feasible for production, with a reasonable selling price and manageable ingredient cost. Overall, the findings support the use of an erythritol–sucralose blend as an effective sugar-free alternative for developing healthier cookie products without compromising consumer satisfaction.

Recommendations

Future research may explore the use of additional natural or plant-based sweeteners to further improve consumer acceptability and expand healthy product options. Adjustments to the formulation, such as modifying cacao nib concentration or incorporating moisture-enhancing ingredients, may enhance the sweetness balance and texture of honey- and coconut syrup–based treatments. Conducting shelf-life studies is recommended to determine product stability, especially for sugar-free formulations that may behave differently during storage. Wider consumer testing involving diverse age groups and dietary profiles would also help validate market readiness. Researchers and food developers may consider scaling the T1 formulation for commercial trials, as it demonstrated strong sensory performance and economic viability.

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