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Sugar-free 'Saba' *(Musa acuminata x balbisiana)* Banana-Based Drop Cookies Formulation Utilizing an Optimization Technique

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Abstract

Introduction:
Excessive sugar consumption has been linked to various health issues, including diabetes, which is a growing concern in the Philippines. The need for healthier food alternatives has driven the development of sugar-free products. Saba bananas *(Musa acuminata x balbisiana)*, known for their natural sweetness and nutritional content, offer an ideal solution for sugar replacement in baked goods. This study aims to create sugar-free drop cookies using Saba banana *(Musa acuminata x balbisiana)* puree as a sugar substitute, utilizing an optimization technique.
Objective:
The objective of this study is to formulate a sugar-free Saba *(Musa acuminata x balbisiana)* banana -based drop cookies, optimized for cost and nutrition, specifically targeting 30-59-year-old males.
Methods:
A linear programming (LP) optimization technique was employed to formulate cookie recipes that meet the nutritional requirements of 30-59-year-old males at the lowest possible cost. Ingredients were selected based on their nutritional values and costs, and seven recipe variations were generated. A survey of 127 male respondents from Lanao del Norte provided insights into their food preferences and socioeconomic factors.
Results:
The optimization process produced seven recipes, with the top two least-cost recipes selected for sensory evaluation. The cost of these cookies ranged from PHP 3.00 to PHP 3.95 per serving, significantly lower than commercially available alternatives. The cookies met the recommended energy, fat, carbohydrate, and protein requirements.
Conclusion:
This study successfully formulated affordable and nutritious sugar-free Saba *(Musa acuminata x balbisiana)* banana-based drop cookies using an optimization technique. These cookies offer a healthier alternative to commercial products, meeting the nutritional needs of target consumers while being cost-effective. The application of linear programming in food formulation proves to be a valuable tool for producing healthier food options without compromising quality or affordability.
Keywords: Saba banana *(Musa acuminata x balbisiana)*, sugar-free cookies, optimization technique, linear programming, nutritional value, healthy snacks, diabetes prevention, low-cost food formulation, banana-based products, nutrient optimization.

1. Introduction

Banana is known as "common man's fruit" and is considered as one of the most important global food crops (after rice, wheat and maize) grown in more than 100 countries worldwide [1]. Because bananas are fruiting all year round and contain sufficient nutrients for energy source, the crop is considered as a readily available food commodity, which may serve as a substitute for other seasonal food crops. Hence, it significantly contributes to food and income security of people engaged in its production and trade, particularly in developing countries like the Philippines. Moreover, it is a vital source of food especially in rural areas as a supplement or substitute to staple food such as rice and corn [2]. According to the Philippine Bureau of Agriculture Statistics, banana production was estimated at around 2 million metric tons [3]. However, a considerable amount of this fruit is wasted due to inadequate processing and preservation techniques [4], poor post-harvest handling, over ripening, poor storage, poor transportation, or overproduction at certain times of the year [5].

The Philippines is one of the 38 countries and territories of the IDF Western Pacific region. 537 million people have diabetes in the world and 206 million people in the Western Pacific Region; by 2045 this is estimated to rise to 260 million [7]. According to a preliminary data between January and September 2023, 6.4 percent of deaths in the Philippines were caused by diabetes mellitus diseases. Deaths from such illnesses peaked in

2020 when the share of deaths was 6.5 percent. Diabetes mellitus is diagnosed when glucose is high in the blood [6]. Introducing a sugar-free drop cookie made from Saba bananas *(Musa acuminata x balbisiana)* using an optimization technique offers a promising option for individuals concerned about their sugar intake and its potential health effects. Excessive sugar consumption has been linked to various health issues, including an increased risk of developing conditions like diabetes.

By replacing or reducing added sugars with Saba banana *(Musa acuminata x balbisiana)* puree, these cookies can provide a healthier alternative for individuals looking to manage their sugar intake. Saba bananas *(Musa acuminata x balbisiana)* are known for their natural sweetness, nutritional richness, and versatility in culinary applications. They offer a source of energy and essential nutrients while reducing the reliance on refined sugars.

The formulation of Saba banana *(Musa acuminata x balbisiana)* based drop cookies with no added sugar is motivated by the increased concern for the health effects of escalating sugar consumption worldwide [8]. Concerns over excessive added sugar consumption and its detrimental consequences on health have grown in recent years. In order to produce baked goods that are compatible with better dietary preferences, there has been a trend toward investigating alternative ingredients and cutting-edge procedures. A practical method for lowering added sugars in cookies while increasing their nutritional content is to use Saba bananas *(Musa acuminata x balbisiana)*, which are renowned for their essential natural sweetness, nutritional richness, and varied culinary applications.

This study aims to develop a formulation for sugar-free drop cookies made from Saba bananas *(Musa acuminata x balbisiana)* using an optimization technique, specifically linear programming (LP). As concerns over excessive sugar consumption and its associated health risks, such as diabetes, continue to grow, there is a pressing need for healthier, nutritionally balanced food options. LP is a mathematical method used to determine the optimal allocation of limited resources, making it ideal for refining ingredient selection to achieve both nutritional and cost-effectiveness in food products. It involves formulating a problem with linear relationships, defining constraints, and finding the optimal solution by maximizing or minimizing an objective function. LP is widely used in various fields such as economics, engineering, and operations research to optimize resource allocation, production schedules, and logistics [12-13]. Its ability to solve complex problems efficiently makes it a valuable tool in decision-making and optimization [14].

By applying LP, this study optimizes the formulation of Saba banana *(Musa acuminata x balbisiana)*based cookies to retain the desired taste and texture while minimizing added sugar. The findings demonstrate the feasibility of producing affordable, sugar-free cookies without compromising sensory quality. This research contributes to the growing range of healthier snack options and highlights the potential of optimization techniques in developing low-sugar baked goods at a reasonable cost [9].

The application of optimization techniques in food formulation has proven to be highly effective in achieving both cost-efficiency and nutritional balance. Previous studies have demonstrated the success of such methods in various contexts. For instance, research on backyard swine feed formulations used locally available ingredients to meet nutrient and cost requirements effectively [15]. A similar approach was applied to Holstein dairy cattle, optimizing nutrient intake with locally available by-products to ensure least-cost feed rations [16]. These methods are particularly relevant for the current study, as they provide a solid framework for developing cost-effective, nutritionally balanced formulations, such as the Saba banana *(Musa acuminata x balbisiana)* based cookies without added sugar.

In public food programs, the challenge is to create affordable yet nutritious food products that meet consumer preferences. A study involving snack formulation for Filipino secondary school students applied a linear programming model to develop cost-effective, nutrient-rich snack options that were well-received by students [17]. This aligns with the goal of creating Saba banana *(Musa acuminata x balbisiana)* based *(Musa acuminata x balbisiana)* cookies that are both nutritious and palatable. Additionally, similar optimization techniques were employed to develop grower-stage broiler chicken feeds, demonstrating the broad applicability of these methods across different types of food production [18].

Optimization techniques also contribute significantly to raw material management in small-scale food production. In a study involving loaf bread production, the use of integer linear programming optimized the bakery's production plan to maximize profit while maintaining product quality [19]. A comparable approach in pre-starter swine feed formulation ensured that essential nutrients were included at a reduced cost, offering valuable insights for efficient resource utilization in food production [20]. These examples underscore the potential of optimization techniques to enhance both the quality and cost-effectiveness of food products, as seen in the

formulation of saba banana *(Musa acuminata x balbisiana)* based cookies.

This research lies in the desire to create a healthier version of drop cookies by replacing or reducing added sugars with Saba banana *(Musa acuminata x balbisiana)* puree, while still maintaining the taste, texture, and overall quality of the cookies. The use of an optimization technique adds a systematic approach to the process, ensuring that the resulting cookies meet the desired criteria in terms of taste, texture, and appearance.

2. Methods

In this paper, a linear programming model was used to come up with recipe for Saba banana *(Musa acuminata x balbisiana)* based drop cookies which met the nutrient requirements at low cost. In order to identify the constraints for the LP model, reasonable ingredients which are locally available and of minimum cost were identified. To do this, a review was made on the best but cheap food sources that meet the nutrient requirement for calories, fats, carbohydrates and proteins. Moreover, the prices of each of the identified ingredients were gathered and canvassed from local public markets and grocery stores Table 1 shows the nutritional value of each ingredient per serving size.

The determination of nutritional content of every ingredient was based on the data from Nutritionvalue.org. The ingredients were further divided according to serving size deemed reasonable and practical to be used as fillings. The nutritional content per 100 g was also divided according to serving sizes. The cost was based on edible parts per 100g. The cost was similarly divided according to serving sizes identified in the nutrient content bases. The data on nutrient contents and costs collected during these steps were utilized in the developing of the model recipe for snacks. Linear programming was used to select combination of these ingredients to come up with a recipe.

To identify further which food to enhance and as to how much would be the cost, a survey was conducted in Salvador, one of the municipalities of Lanao del Norte in the southern part of the Philippines. The respondents were 127 males ranging in age from 30 to 59 years old. The survey was conducted using a guided questionnaire to find out the socioeconomic status of the respondents and their food preference. Survey results revealed that all the respondents are of low socioeconomic position, with most of their income coming from daily pay and farming. According to this information, their family has a low and average income. According to the survey, most of them consumed at least 2-3 (50-55g/cookie) cookies for their snack based on their daily budget of Php20 with their preferences. The survey further revealed that most of the respondents have allowance for snacks of Php 5-10 (USD 0.13-0.23) daily to spend for snacks and that the top three food preferences were banana cue, bread and pastry products (cookies) and biscuits and crackers.

For the purpose of this study, bread and pastry product (cookie) was chosen being the top food preference. However, upon initial evaluation, the nutrient contents of existing cookie recipes as shown in Table 2 were not compliant to the nutrient requirement as reflected in Table 3. Thus it is imperative to enhance it in such a way that it conforms to the nutrient requirement at the least cost. The cost for ingredients was set to Php5.00 (USD 0.097) which was also based on the survey result regarding the respondents' daily income allotted for snacks. In the formulation of the ingredients for the model recipe, the nutrient content of each ingredient were carefully considered. The recommended energy intake for Male Filipino from 30 to 59 years old as presented by Tee et al. (2023) was followed. The minimum and maximum required energy and nutrient intake referred to the daily intake intended for Male Filipinos [9]. Failure to follow this nutrient requirement may affect the nutrient requirement of the respondents.

Linear programming model for recipe formulation:

Minimize $Z =$

$$(8x_1)+(11x_2)+(12x_3)+(9.5x_4)+(10.3x_5)+(39.75x_6)+(38.5x_7)+(8x_8)+(10x_9)+(2x_{11})+(0.5x_{12})+(1x_{13})+(1x_{14})+(12x_{15})+(13x_{16})+(5x_{17})+(14x_{18})+(12x_{19})+(10x_{20})+(13x_{21})+(23x_{22})+(24x_{23})+(24.5x_{24})+(2x_{25})+(52x_{26})$$

subject to:

$$x_1 \geq 1 \quad (1)$$
$$x_2 \geq 1 \quad (2)$$
$$x_6 \geq 1 \quad (3)$$
$$x_{10} \geq 1 \quad (4)$$
$$x_{11} \geq 1 \quad (5)$$
$$x_{13} = 1 \quad (6)$$
$$x_{17} \geq 1 \quad (7)$$
$$x_{19} \geq 1 \quad (8)$$
$$x_{25} = 1 \quad (9)$$

$$\sum_{i=1}^{n} \mathrm{D_i x_i} \geq 2420 \quad (10)$$

$$\sum_{i=1}^{n} \mathrm{D\_ix_i} \leq 2783 \quad (11)$$

$$\sum_{i=1}^{n} \mathrm{E_i x_i} \geq 40.35 \quad (12)$$

$$\sum_{i=1}^{n} \mathrm{E_i x_i} \leq 80.7 \quad (13)$$

$$\sum_{i=1}^{n} F_i x_i \geq 352.75 \quad (14)$$

$$\sum_{i=1}^{n} F_i x_i \leq 415 \quad (15)$$

$$\sum_{i=1}^{n} G_i x_i \geq 72 \quad (16)$$

$$\sum_{i=1}^{n} G_i x_i \leq 82.8 \quad (17)$$

$$\sum_{i=1}^{n} C_i x_i \leq 5 \quad (18)$$

$$x_i \geq 0 \text{ for } i = 1,2,.....,26 \quad (19)$$

Table 1: Nutrional value and cost of each ingredients per serving size. source: (Nutritionvalue.org)

---------- Ingredients ----------

Weight	ITEMS	CALORIES	FAT	CARBOHYDRATES	PROTEIN	COST (php)
100g	Raw saba-banana	105	0.4	27	1.3	8
108 g	Coconut flour	336	10.7	62.4	15.6	11
120 g	Whole wheat flour	408	3	86	16	12
125 g	All-purpose flour	455	1.2	95	13	9.5
100 g	Banana flour	346	1.8	88	3.9	10.3
56 g	Unsalted butter	408	48	0	0.5	39.75
60 g	Salted butter (anchor)	500	55	0	0	38.5
56 g	margarine	340	38.4	0.3	0	8
56 g	Canola oil	496	56	0	0	10
5 g	Baking powder	2.4	0	1.3	0	2
3 g	Baking soda	0	0	0	0	0.5
2 g	Iodized salt	0	0	0	0	1
5 g	Vanilla extract	12	0	0	0	1
73 g	Unsalted roasted native peanut	428.5	36.5	15.5	18	12
100 ml	Vitasoy milk	63.6	2.1	7.9	3	13
96 g	Evaporated milk	126	7.2	9.6	6.3	5
30 g	Fortified powdered milk	139.1	6	17.3	4.5	14
32 g	Powder whole milk	121.5	0.2	17.5	12	12
50 g	Whole egg	72	4.8	0.4	6.3	10
13.3 g	Dried mangoes	335	1.3	82.5	2.5	12
21.5 g	Raisins	129	0.2	34	1.3	13
33 g	Almond slice	303	24.2	10.6	10.6	23
32 g	Walnut	650	65	14	15.5	24
35.5	Dates	300	0.5	79.5	2.6	24.5
30 g	banana flavoring	0	0	1	0	2
30 g	Cashew nuts	567	46	32.2	15.1	52

Table 2: Nutrient composition and cost of existing cookie recipes

Recipes	Calories	Fats (g)	Carbohydrates (g)	Protein (g)	Cost (php)
1 serving	3004	98.9	489.1	53.19	6
2 servings	6008	197.8	978.2	106.38	12

Table 3: Minimum and maximum required energy intake for snacks Male 30-59 years old. Source: (Tee et al., 2023)

Nutrients	Calories	Fats (g)	Carbohydrates (g)	Protein (g)
Minimum Requirement	2420	40.35	352.75	72
Maximum Requirement	2783	80.7	415	82.8

Table 4: Ingredient composition and cost of various formulated saba-banana cookies recipes

Ing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Cost
Rec	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	(php)
1	100	187	-	311	-	56	-	-	-	5	6	-	13	-	-	-	30	-	-	-	-	-	-	-	30	-	3.00
3	100	187	-	311	-	56	-	-	-	10	3	-	5	-	-	-	30	-	50	-	-	-	-	-	30	-	3.05
7	200	162	-	266	-	28	-	-	18.5	7.5	3	-	5	-	-	-	45	-	100	-	-	-	-	-	30	-	3.09
4	100	154	-	335	-	56	-	-	-	10	4.5	-	5	-	-	-	45	-	50	-	-	-	-	-	30	-	3.10
5	100	130		339	-	56	-	-	-	10	4.5	-	5	-	-	-	45	-	75	-	-	-	-	-	30	-	3.26
2	300	168	80.4	210	-	56	-	-	-	5	3	-	5	-	-	-	30	-	50	-	-	-	-	-	30	-	3.36
6	200	108	-	219	-	56	-	-	-	10	4.5	-	5	-	-	-	45	25	100	-	-	-	-	24.1	30	-	3.95

Ingredients: 1. Raw saba-banana
2. Coconut flour
3. Whole wheat flour
4. All-purpose flour
5. Banana flour
6. Unsalted butter
7. Salted butter
8. margarine
9. Canola oil
10. Baking powder
11. Baking soda
12. Iodized salt
13. Vanilla extract
14. Unsalted roasted native peanut
15. Vitasoy milk
16 Evaporated milk
17. Fortified powdered milk
18. Powder whole milk
19. Whole egg
20. Dried mangoes
21. Raisins
22. Almond slice
23. Walnut
24. Dates
25. banana flavoring
26. Cashew nuts

Ing: Ingredients
Rec.: Recipe

Table 5: Nutrient composition and cost of various formulated saba-banana drop cookies

Recipes	Calories	Fats (g)	Carbohydrates (g)	Protein (g)	Cost
1	2454.27	80.70	391.80	72.00	3.00
3	2455.13	80.70	392.80	72.00	3.05
7	2420.00	80.70	379.65	73.29	3.09
4	2510.33	80.70	400.78	72.00	3.10
5	2482.70	80.69	389.48	72.00	3.26
2	2510.00	80.70	415.00	72.00	3.36
6	2420.00	80.70	380.71	72.00	3.95

This study aimed to come up with enhanced cookie recipes for Filipinos that met nutrient requirement at a minimum cost. For the purpose of this study this study, the nutrient requirement for males of 30-59 years old was considered. Moreover, the RENI for this particular age bracket and gender met the maximum RENI of 60-69 years old both male and female.

In the linear programming formulation presented, the objective function Z is the sum of the product of the cost of the different ingredients and their corresponding quantities included in the formulation. The ingredients and their corresponding nutritional value and cost per serving are shown in Table 1. In this LP formulation, x_i (i = 1,2...., n) denotes the quantity of each food ingredients considered in the recipe formulation. The cost for each ingredient is denoted by Ci. Moreover, Di, Ei, Fi, and Gi, correspond to the amount of calories, fats, carbohydrates and proteins nutrient in each of the food ingredients as shown.

The values on the right hand side of the LP model above corresponds to the minimum and maximum nutrient recommendations based on Table 2. Constraint (1) provides that the banana ingredient must not be less than 1 serving, constraints (2) specifies that coconut flour ingredient must not be less than 1 serving. Constraint (3), (4), (5) which are unsalted butter, baking powder and baking soda, respectively, provides that they must not be less than 1 serving. Constraint (6) provides that vanilla extract must be equal to 1 serving only. Constraints (7) and (8) which are fortified powdered milk and whole egg provides that it must not be less than 1 serving. Constraint (9) specifies that banana flavouring must be equal to 1 serving.

Constraint (10) indicates that calories must not be less than 2420 kcal while constraint (11) requires that it must not exceed 2783 kcal. Constraint (12) necessitates that fat must not be less than 40.35g and not more than 80.7g (13). Moreover, Constraint (14) provides that carbohydrate must not be less than 352.75g while must not exceed 415g (15). Constraint (16) indicates that protein must not be less than 72g while constraint (17) specifies that it must not exceed 82.8g. Constraint (18) imposes that the total cost of the formulation must not exceed PHp5.00 (USD 0.097), while constraint (19) ensures that each ingredient must not be less than zero.

3. Results and Discussion

This study considered the various combinations of 26 food ingredients taken 26 (25, 24, 23 and so on at a time) in order to come up with a recipe that met the nutrient requirements of 30-59 year-old males at low cost. Linear Programming (LP) models were formulated by considering each possible combinations of the different ingredients and then solving the resulting LP

models using the excel solver. Seven (7) possible recipes had been obtained. These recipes, their ingredient composition and corresponding costs are shown in Table 5. It can be seen in Table 5 that recipe 1 is the cheapest recipe which costs PhP 3.00 (USD 0.058), while recipe 6 is the most expensive with a cost of Php 3.95 (USD 0.077). The cheapest recipe consisted of Saba-banana *(Musa acuminata x balbisiana)*, coconut flour, all-purpose flour, unsalted butter, baking powder, baking soda, vanilla extract, fortified powdered milk, and banana flavoring while the most expensive recipe consisted of Saba banana *(Musa acuminata x balbisiana)*, coconut flour, all-purpose flour, unsalted butter, baking powder, baking soda, vanilla extract, fortified powdered milk, powdered whole milk, whole egg, dates, and banana flavoring.

The nutrients content of the 7 least cost recipes are shown in Table 5. It can be observed that all 7 recipes satisfied the recommended nutrients as shown in Table 3. Furthermore, notice in Table 2 that a serving size of existing cookie recipe, costs more than of the formulated recipe as shown in Table 5, exceeds the calorie, fat, and carbohydrate limit as reflected in Table 3. This explains that while a serving of existing cookie recipes costs twice as much as the formulated one, its nutritional value is not so different. Furthermore, the standard recipe may not be as laborious as the formulated recipe, but it also lacks the variation of flavor that the formulated recipe has.

Among the 7 model recipes formulated by LP, Recipes 1 and 3 were the top two least cost recipes and had minimum ingredients to be prepared; hence they were less laborious when it comes to food preparation and production.

4. Conclusion and Recommendation

Based on the survey results, people prefer to spend less their snacks, hence their option was to buy delicious foods that were low-cost. However, their food preference do not meet the nutrient requirement. Thus, a linear programming model was utilized to develop snack item. In the formulation of linear programming model, 7 recipes were produced where the nutrient and energy requirement for 30-59 year-old males were met. The cost for these recipes was minimal. Because of these, common folks particularly males are given the chance to enjoy delicious and nutritious snack items that can be bought at cost within their budget. It should be noted that the cost of the new cookie recipes were cheaper than the cost of the existing cookie the people buy from their favorite bakeries, the energy and nutrient content of each of these recipes, met the minimum requirement. It is recommended that these recipes may be produced in bakeries to provide highly nutritious, less expensive and delicious snack items. Furthermore, it is also recommended that other possible nutrients be explored for a more varied flavor for this food item.

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