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PLACKETT-BURMAN DESIGN FOR SCREENING FORMULATION VARIABLES IN BANANA (*MUSA ACUMINATA*) COOKIES

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ABSTRACT
Cookies are one of the most popular baked goods and may be utilized to incorporate nutritionally enhanced flours. Banana (*Musa acuminata*) flour is high in resistant starch and dietary fiber, which is beneficial for health. However, adding it to a product might alter its quality. This study uses a Plackett-Burman experimental design to assess formulation variables influencing the sensory acceptability and physicochemical attributes of banana-based cookies. Seven independent variables on varying amounts of all-purpose flour, butter, brown sugar, white sugar, salt, and baking powder were identified. The sensory acceptability (color, smell, taste, texture, and overall acceptability) as well as the physical and chemical parameters, such as pH, color (L*, a*, b*), water activity, moisture content, and total soluble solids, were measured. Effect estimates indicated that all-purpose flour, salt, and vanilla extract exerted strong positive influences on all sensory qualities. Butter and brown sugar, on the other hand, have adverse effects when used in large quantities. White sugar and baking powder exhibited minimal influence within the tested range. The cookies had a pH level of 6.53 to 7.55, a water activity level of 0.40 to 0.61, and a moisture content level of 4.82% to 7.34%. This indicates longer shelf-life stability of the product. These results indicate that the Plackett-Burman design is useful for quickly screening variables and that banana flour could be a useful ingredient in making cookies.

KEYWORDS: Plackett–Burman design, sensory acceptability, physicochemical properties, banana cookies

INTRODUCTION
Cookies are a popular baked snack because they are easy to eat, taste tasty, and last a long time. Cookies are a type of ready-to-eat food that people of all ages eat. They are often eaten with drinks or as side dishes and are suitable bakery products that can be enriched with flours (Bravo-Nunez and Gomez, 2021). Cookies are usually made using wheat flour, sugar, oil, and eggs. They are easy to prepare, which makes them useful for changing ingredients and adding nutrients (Aziah *et al.,* 2012; Guine and Florenca, 2024).

Recently, more and more people are becoming interested in functional meals. This has led to the creation of baked goods made with composite flours from fruits, tubers, and legumes. These substances can enhance dietary fiber levels, alter starch digestibility, and encourage the use of underutilized agricultural resources (Agama-Acevedo *et al.,* 2012; Masri *et al.,* 2014). Cookies are thought to be especially suitable for these kinds of alterations since they can handle moderate changes to their formulations without making them less appealing to customers (Manley, 2011).

Banana (*Musa acuminata*) is one of the most widely produced tropical fruits, and in many places where it is grown, it is a major agricultural product. A wide variety of products are made from bananas; however, the majority of the crops are lost after harvest because they cannot be preserved for long periods, leading to waste from changes in postharvest quality or oversupply in the market. Making shelf-stable foods like flour from bananas is an effective method to reduce waste, and they can be added to foods (Khoozani *et al.,* 2019).

Unripe banana flour has a beneficial functional property due to its resistant starch and dietary fiber, which are beneficial for lowering blood sugar and aiding in digestion (Munir *et al.,* 2024).

The addition of banana flour to baked goods improves their taste, texture, and appearance aside from being gluten-free (Karamadan *et al.,* 2025). However, it has been reported that the flours' textural quality is affected by pasting property caused by the final viscosity after cooking and cooling (Kumar *et al*., 2019; Ahmed *et al.,* 2020; China *et al.,* 2022). This could contribute to the quality of the dough aside from the varying formulation factors contributing to the quality of cookies.

To achieve acceptable taste and texture in banana cookies, the functional interactions among formulation ingredients must be systematically assessed. Statistical experimental design provides efficient methodologies for the simultaneous evaluation of multiple formulation variables in food product development. The Plackett–Burman design is one such method that is frequently used to identify the most important parameters affecting product quality while minimizing the number of experimental runs (Plackett and Burman, 1946; Gregor *et al*., 2024). This approach is beneficial in the initial phases of product development, employed to evaluate critical variables prior to conducting additional optimization studies (Plackett and Burman, 1946). Previous studies on banana-based cookies have mainly focused on flour substitution ratios or overall consumer acceptability, lacking systematic screening methods to assess the cumulative effects of various formulation variables. Consequently, a comprehensive assessment is essential to ascertain the principal formulation parameters affecting both the sensory acceptance and the physicochemical characteristics of banana cookies, thereby establishing a scientific foundation for formulation enhancement and subsequent optimization. This study utilized the Plackett–Burman screening design to evaluate the impact of specific formulation variables on the sensory acceptability and physicochemical characteristics of banana (*Musa acuminata*) cookies.

MATERIALS AND METHODS

Experimental design

Several input variables that may affect the process and formulation of the vacuum-fried tuna skin were identified based on a series of preliminary trials and literature gathered. A Plackett–Burman screening design was employed to evaluate seven independent variables as shown in ***Table 1***: all-purpose flour (APF), butter (B), brown sugar (BS), white sugar (WS), salt (S), baking powder (BP), and vanilla extract (VE), each tested at two levels (***Table 2***). Banana flour was fixed at 100 g per formulation. Eggs were standardized at 44 g per 100 g total flour; therefore, formulations containing 200 g total flour received 88 g egg. Eight experimental runs were conducted following the 7-variable, 8-run Plackett-Burman (PB) design (Plackett and Burman, 1946).

Table 1. Minimum and maximum levels of formulation variables evaluated in the Plackett–Burman screening design.

Variables	Minimum (-)	Maximum (+)
All-purpose flour (APF)	0	100
Butter (B)	50	60
Brown Sugar (BS)	40	60
White Sugar (WS)	30	40
Salt (S)	0	3
Baking Powder (BP)	6	8
Vanilla Extract (VE)	5	10

Values are expressed as percentages relative to the total formulation or banana flour basis, as specified. The addition of APF is based on the 100-grams banana flour (BF). Based on the total amount of all-purpose flour and banana flour

Table 2. Plackett–Burman experimental design matrix for banana (*Musa acuminata*) cookie formulations.

Run	Pattern	APF (%)	B (%)	BS (%)	WS (%)	S (%)	BP (%)	VE (%)
1	+++-+--	100	60	60	30	3	6	5
2	++-+--+	100	60	40	40	0	6	10
3	+-+--++	100	50	60	30	0	8	10
4	-+--+++	0	60	40	30	3	8	10
5	+--+++-	100	50	40	40	3	8	5
6	--+++-+	0	50	60	40	3	6	10
7	-+++-+-	0	60	60	40	0	8	5
8	-------	0	50	40	30	0	6	5

Values are expressed as percentages relative to the total formulation or banana flour basis, as specified.

Preparation of banana cookies

First, all dry ingredients, such as the banana flour, all-purpose flour, brown sugar, white sugar, salt, and baking soda, were sifted and weighed according to the specific requirements of each treatment. They were mixed together in a clean bowl. In a separate container, an electric mixer was used to cream the butter, vanilla extract, and eggs. The dry mixture was slowly added to the wet mixture with constant beating until a smooth dough was formed. The dough was put into piping bags and then cut into rounds on baking trays to make sure they were all the same size. The cookies were baked at 190°C (375°F) for 15 to 20 minutes, or until the edges were a light golden brown. The cookies were cooled to room temperature before being stored in airtight containers.

Sensory evaluation

Sensory evaluation was conducted using 40 untrained panelists under standard test conditions. Samples were coded and presented in randomized order. Panelists evaluated color, odor, taste, texture, and general acceptability using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). Drinking water was provided for palate cleansing between samples. The posed minimal risk because samples were conventional food products, and participation involved only sensory rating without collection of personal identifiers.

Determination of physicochemical parameters of banana cookies

pH determination

To assess the pH of banana cookies, 5 g of the sample was mixed with 50 mL of distilled water and stirred for 5 minutes before being measured using a calibrated digital pH meter.

Water activity determination
Water activity (aw) was measured using a water activity analyzer at room temperature, and samples were allowed to equilibrate in sealed circumstances. The moisture content was determined according to the standard method of the Association of Official Analytical Chemists (AOAC, 2019) by drying the samples in a hot-air oven at 105°C until they reached a consistent weight. The results were given as a wet weight.
Color measurement
Instrumental color was evaluated by using a colorimeter operating under the CIELAB system, and results were recorded as L* (lightness), a* (red–green), and b* (yellow–blue) coordinates.
Total soluble solids
Total soluble sugar (TSS) was determined using a calibrated refractometer with a measurement range of 0–30 °Brix. Two (2) grams of each sample were weighed and mixed with three (3) mL of distilled water. The mixture was thoroughly stirred in a 50 mL beaker until a uniform slurry was obtained. The resulting diluent was further mixed to ensure homogeneity, after which one to two drops were placed onto the prism of the refractometer for measurement. TSS values were recorded and expressed in °Brix. The final TSS values were calculated using the following equation:

$$\%TSS = \frac{°Brix\ reading \times weight\ of\ sample\ after\ dilution}{weight\ of\ sample\ before\ dilution}$$

Statistical analysis
Sensory acceptability data for each run was analyzed in Tibco version 13.5. Parameter estimates and Pareto charts were generated to determine the main effect of the different variables on the sensory acceptability and physicochemical responses of the banana cookies. The effect of each variable may be either positive or negative. The variables were then ranked based on the order of their significant effect from the Pareto chart. ANOVA was performed at a 95% confidence level ($p < 0.05$).

RESULTS AND DISCUSSION
The Plackett–Burman design is widely used as a screening tool applied in food product development to identify formulation variables with the greatest influence on product quality prior to optimization. This approach is particularly useful when multiple ingredients interact to affect sensory perception and physical characteristics (Montgomery, 2013; Granato *et al.,* 2020). In the present study, all-purpose flour, butter, brown sugar, salt, and vanilla extract were identified as significant contributors to the sensory acceptability of banana cookies (***Figure 1***).

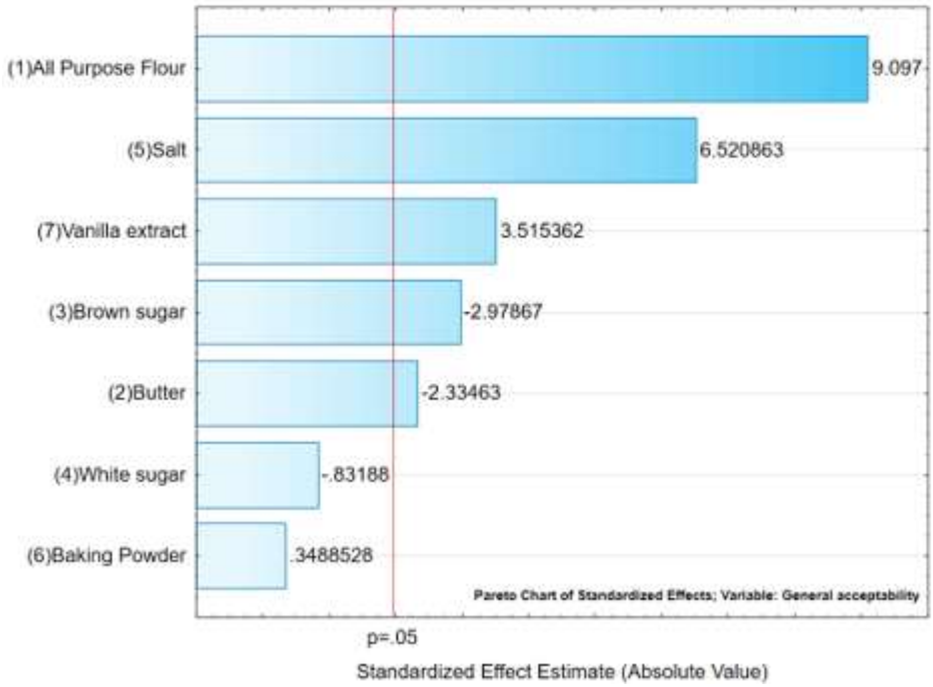

Figure 1. Pareto chart showing the standardized effects of formulation variables on the overall sensory acceptability of banana (Musa acuminata) cookies.

Effects of formulation variables on sensory acceptability
All-purpose flour (wheat flour) showed a strong positive effect on overall acceptability. Wheat flour contributes gluten-forming proteins that improve dough cohesion, elasticity, and structural integrity, which are critical in cookie systems containing gluten-free ingredients such as banana flour. Gluten helps cookies maintain their shape during baking in addition to giving them the proper flavor and texture (Day, 2011).
Prior research conducted by Ismail *et al.* (2018) and Mamat *et al.* (2020) demonstrates that the partial replacement of wheat flour with non-gluten flours requires a sufficient incorporation of wheat flour to maintain optimal texture and meet

consumer preferences. The increased sensory acceptability observed with higher quantities of all-purpose flour in this study coincides with the function of gluten in maintaining composite-flour cookie matrices. Karaman *et al.* (2025) demonstrated that banana flour can be utilized to produce gluten-free cookies.

Butter significantly affected sensory acceptability, with higher levels having a negative effect. Fat acts as a shortening agent in cookies by reducing the formation of gluten networks and softening them (Pareyt *et al.*, 2010). But too much fat can make cookies spread too much, make them too soft or greasy, and make them less stable, which might affect consumer preference (Manley, 2011). Studies on biscuit and cookie formulations show that a moderate amount of fat improves flavor and texture, while excessive fat makes them less crisp and affects handling quality (Pareyt *et al*., 2009). The downward trend in this study indicates that the panelist did not deem a higher quantity of butter acceptable.

At greater concentrations, brown sugar had a significant negative effect on sensory acceptability, but white sugar had no effect at all. Brown sugar has molasses in it, which makes it more hygroscopic and keeps it from drying up. The result makes cookies softer, thicker, and chewier (Sampaio *et al.,* 2022). White sugar, on the other hand, has a crystalline sucrose structure that lets it spread more, is lighter in color, and has a crisp feel (Pareyt *et al*., 2009). Many studies indicate that people have different preferences for cookies based on how they want them to feel. For example, people often think that cookies that are too chewy are worse than crisp cookies (Ismail *et al.*, 2018; Karaman *et al*., 2025). The diminished acceptability linked to elevated brown sugar concentrations in this study corresponds with documented correlations between sugar functioning and texture preferences.

Salt made a big difference in how people perceived the taste of food. Breslin and Beauchamp (1997) mentioned that sodium chloride makes things taste better by making them sweeter, less bitter, and better at releasing flavor, even in sweet baked goods. Salt changes the rheology of the dough, making the gluten form stronger, which makes the dough less sticky and more elastic (Lawless and Heymann, 2010; Manley, 2011). Previous research has shown that sweet baked goods with too little salt have bland or unbalanced flavors, while the right amount of salt makes them taste better and more appealing (Rysova and Smidova, 2021). The positive effect seen in this study is consistent with these results.

Vanilla extract improved the products' smell, taste, and overall liking. It can enhance perceived sweetness through cross-modal odor-taste interactions, and this has been shown in controlled sensory studies with different types of food and consumer groups (Damodaran *et al*., 2017).

Vanillin, a volatile aromatic compound, enhances the taste of baked goods without the need for additional sugar (Fellows, 2017). According to Damodaran *et al.* (2017), the aroma of vanilla increases the flavor perception and acceptability in sweet bakery products, supporting the significance of adding vanilla in cookie formulation.

Physicochemical properties of the banana cookies

The pH values of banana cookies ranged from 6.53 to 7.55, corresponding to slightly acidic to near-neutral conditions (***Table 3***). These kinds of values are common for cookies and biscuits and are affected by the type of flour, sugar, and leavening agents used (Manley*,* 2011). In low-moisture baked products, pH plays a secondary role in microbial stability compared to water activity; however, it affects flavor perception, Maillard browning reactions, and leavening efficiency (Martins *et al.* 2000; Hosry *et al.,* 2025). The observed pH range is therefore suitable for both product quality and stability.

The water activity values were between 0.40 and 0.61, which are the characteristics for shelf-stable cookies and biscuits. Products that have a water activity of less than 0.60 usually have less microbial growth and last longer on the shelf (Labuza, 1980; Cauvain, 2016).

Table 3. Physicochemical properties of banana cookies (mean ± sd).

Run	L*	a*	b*	Water activity (aw)	pH	Moisture content (%)
1	56.94 ± 1.28^{c}	7.21 ± 0.34^{c}	27.87 ± 0.26^{b}	0.42 ± 0.02^{f}	6.87 ± 0.06^{d}	6.47 ± 0.32^{e}
2	53.85 ± 0.10^{d}	6.74 ± 0.08^{d}	26.68 ± 0.40^{c}	0.56 ± 0.01^{b}	7.34 ± 0.04^{b}	6.16 ± 0.36^{d}
3	51.49 ± 0.24^{e}	9.42 ± 0.03^{a}	29.80 ± 0.10^{a}	0.52 ± 0.01^{c}	7.51 ± 0.03^{a}	6.81 ± 0.50^{f}
4	51.31 ± 0.14^{e}	7.62 ± 0.09^{b}	25.29 ± 0.11^{d}	0.56 ± 0.01^{b}	7.04 ± 0.01^{c}	5.31 ± 0.07^{b}
5	58.20 ± 0.15^{b}	6.68 ± 0.12^{d}	27.18 ± 0.05^{b}	0.51 ± 0.01^{c}	7.32 ± 0.07^{b}	5.70 ± 0.42^{c}
6	52.53 ± 0.38^{de}	8.03 ± 0.09^{b}	26.03 ± 0.22^{cd}	0.40 ± 0.00^{f}	6.69 ± 0.02^{e}	4.89 ± 0.09^{a}
7	74.24 ± 0.72^{a}	2.78 ± 0.16^{e}	14.51 ± 0.33^{e}	0.61 ± 0.01^{a}	6.84 ± 0.01^{d}	6.67 ± 0.31^{e}
8	47.72 ± 0.25^{f}	9.06 ± 0.17^{a}	25.51 ± 0.42^{d}	0.44 ± 0.01^{e}	6.53 ± 0.05^{f}	5.40 ± 0.05^{bc}

Note: Values are mean ± SD (n = 3). Different superscripts within a column indicate significant differences ($p < 0.05$; Tukey's HSD).

However, values close to 0.60 may decrease the physical quality, such as losing crispness and speeding up non-enzymatic browning reactions (Labuza, 1980). The moisture content values (4.82–7.34%) are in the range that has been reported for cookies. Moisture is inversely related to crispiness and affects the product's chewiness (China *et al*., 2022). These results show the significance of controlling formulation variables and packaging conditions during product storage.

All formulation variables had significant impacts on the color of the cookies. The color of cookies results primarily from caramelization and Maillard reactions. These reactions are affected by the type of sugar, the amount of protein, the amount of moisture, and the way the cookies are baked (Belitz *et al*., 2009). Brown sugar produces a darker color because of the molasses present, and more reducing sugars are available. White sugar, on the other hand, mostly makes things lighter and redder (Orlandi *et al*., 2017). The composition of flour also affects color by changing the structure of the dough, heat transfer, and browning kinetics (Ovando-Martinez *et al*., 2009). Results show that color strongly influences consumer perception; this variable is important in formulation changes.

The total soluble solids (TSS) were different for each treatment because the sugar levels were different and the ingredients in the formulation didn't dissolve as well. Refractometric analysis of cookie slurries can show how sugars and other ingredients interact with each other (Damodaran, 2017).

The amount of sugar used affects how sweet it tastes, how it reacts to browning, how it sticks to water, and how it develops texture while baking (Boz, 2019; Slade *et al*., 2020). Changes in the composition of sugar are connected to the changes in TSS.

Using banana flour in cookies has both functional and health benefits. Unripe banana flour is high in resistant starch and dietary fiber, which have been linked to lower glycemic response and better digestive health (Khoozani *et al*., 2019). The study by Agama-Acevedo *et al*. (2012) has shown that cookies made with banana flour have a lower predicted glycemic index and starch digestibility than traditional wheat-based cookies. These results indicate that banana flour may serve as a functional ingredient in baked goods, depending upon the optimization of formulation variables, ensuring acceptable sensory quality.

Variables with the most significant effect

Effect estimates show how the response changes when the factor goes from a low level (-) to a high level (+). ***Table 4*** shows that all-purpose flour had the best effect on all the sensory qualities. It is the most essential component making banana cookies look, smell, and taste better. Salt consistently has significant positive effects, showing its contribution to flavor improvement and the cookie's sensory acceptability. Vanilla extract had a small but important positive effect on all of the sensory characteristics, especially the smell and the overall acceptability. However, most sensory qualities were negatively affected by brown sugar and butter, indicating that they declined with the addition of more of these ingredients. White sugar and baking powder had little to no effect, according to the levels of formulation variables examined.

Based on the magnitude of the effect estimates, all-purpose flour had the greatest influence on the physical and chemical characteristics of banana cookies as well as their sensory acceptability. Second place went to salt and vanilla extract. White sugar and baking powder had no effect at all, but brown sugar and butter had some detrimental effects.

Table 4. Ranking of formulation variables subjected to Plackett-Burman screening based on the sensory acceptability and physicochemical responses of banana (*Musa acuminata*) cookies.

Rank	Variable	Sensory Effect Estimates (overall acceptability)	Sensory Direction	Key Physico-chemical Responses Affected*	Overall Importance
1	All-purpose flour	+0.71	Positive	pH, moisture content, TSS, L*, a*, b*	Highest
2	Salt	+0.51	Positive	L*, a*, b*	Very high
3	Vanilla extract	+0.27	Positive	L*, a*, b*	High
4	Brown sugar	−0.23	Negative	L*, a*, b*, moisture content	Moderate
5	Butter	−0.18	Negative	L*, a*, b*	Moderate
6	White sugar	−0.06	Negligible	L*, a*, b*	Low
7	Baking powder	+0.02	Negligible	Water activity, L*, a*, b*	Lowest

* significant at $p \leq 0.05$

CONCLUSION

The cookies' sensory acceptability was greatly affected by all-purpose flour, salt, and vanilla extract. Salt and brown sugar, on the other hand, changed the cookies' physicochemical properties. These results indicate that banana flour is a useful ingredient in producing cookies and can be further improved by optimizing these formulation variables.

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