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Biscuit production from composite flours of wheat and yellow maize: A linear programming, physicochemical, and quality-based approach

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Abstract

Food enrichment plays a critical role in the food industry, with a significant influence on the nutritional value of various food products and their potential health advantages when consumed. The demand for nutritious food products has led to significant advancements in the technology used for the production of biscuits, with the aim of enhancing their nutritional characteristics. Therefore, the objective of the present work was to develop nutritionally optimised biscuits using a linear programming model. The study focused on the optimisation of biscuit ingredients, specifically wheat and yellow maize flour, with or without moringa leaf. The formulation process involved the use of conventional methods and a linear programming model. The resulting biscuits were then analysed for their proximate, sensory, functional, and anti-nutritional properties. The biscuits formulated using the linear programming (LP) model exhibited superior qualities compared to other groups. These biscuits had a protein level ranging from 17.5 to 15.4%, and significantly improved organoleptic properties. The concentration of anti-nutritive compounds showed a notable decrease in the LP group compared to the conventionally prepared biscuits. Therefore, the use of a linear programming model can be adopted for the formulation of biscuits that have high nutritional value.

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Introduction

Nowadays, there is a prevailing focus on the consumption of healthy foods that are low in calories and glycaemic index while simultaneously being abundant in dietary fibre and protein. Given the recent emergence of infectious diseases, such as COVID 19, there is a growing emphasis on the prioritisation of nutritionally balanced and health-promoting dietary content in food products in order to effectively address global demands. Food products that are already familiar and acceptable to the general population are particularly suitable for use in food enrichment (Goubgou *et al.,* 2021).

Among popular foods, biscuits are promising fortifiable food products for addressing nutritional or functional needs due to their general acceptance, ready-to-eat status, palatability, convenience, shelf stability, and affordability (Nogueira and Steel, 2018). Compared with cakes and breads, biscuits have a longer shelf life, and are more resistant to microbial spoilage. However, it should be noted that biscuits have relatively low protein content, often ranging from 6 to 7%, and are lacking in dietary fibre.

Conversely, biscuits have high sugar and fat, rendering them a suboptimal option from a nutritional perspective (Renzetti and van der Sman, 2024). As a result, improving the protein content of biscuits by incorporating protein-rich ingredients can effectively address the requirement for increased protein intake, and compensate for the absence of certain limiting amino acids.

As a consequence, composite flours have emerged, wherein several flours obtained from different sources, including cereals, legumes, and others are combined, with or without the inclusion of wheat flour (Dhankhar *et al.,* 2021). Several composites have been formed through the

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combination of wheat flour with alternative cereal- or legume-based flours. The use of ingredients, especially those derived from underutilised parts of plants and legumes, which not only provide nourishment to the body but also have historical significance in terms of disease prevention and treatment, has recently attracted considerable attention (Alam *et al.*, 2014).

Moringa is a natural food source that can enhance the efficacy of other dietary components. *Moringa oleifera* is a well-cultivated species in the Moringaceae family, and its overall acceptance in most developing countries can be attributed to its capacity to improve nutrition, foster food security and rural development, and contribute to sustainable land conservation. The leaves, seeds, and flowers are valuable sources of nutrients, and utilised in the field of phytotherapy as medicinal substances. Moringa leaves are a great source of nutrients, and an exceptional source of minerals and vitamins; a major feature is their high protein content due to their amino acid composition (Natsir *et al.*, 2019).

Most food formulations are made using the conventional “trial and error” method, whereby pre-selected ingredients are mixed and adjusted until the final product meets the taste and nutritional requirements of the target consumers. This method takes a lot of time, as food developers are required to iterate these processes extensively to achieve a satisfactory product, ultimately producing a product that may fail to meet pre-established product specifications in terms of quality, cost, nutrition, and sensory appeal. To this end, linear programming is a technique that can replace conventional food formulation processes. Linear programming (LP) is a mathematical modelling technique used for the optimisation of a linear objective function (maximisation or minimization) subject to linear equality and inequality constraints (Varghese and Srivastav, 2022).

There have been several studies by nutritionists on the use of LP for optimising the human diet (Parlesak *et al*., 2016). A study undertaken by Ferrari *et al.* (2020) to define sustainable diets by using LP resulted in the development of a healthy dietary pattern that achieved a reduction of 48% in greenhouse emissions (GHGE) in males, and 50% in females. Similarly, in a study conducted by Colombo *et al.* (2020), it was found that the provision of nutritionally appropriate school meals for students in grades 0 - 9 may be achieved while simultaneously reducing GHGE. The study utilised a linear programming model to demonstrate that school meals can be both ecologically sustainable and healthy. Nevertheless, the utilisation of this model for the development of product formulations is seldom among food technologists (Sheibani *et al.*, 2018).

To date, there is a lack of reported studies examining the use of LP for the purpose of optimising the nutrient composition of biscuits and evaluating the nutritional, sensory, functional, and antinutritional properties of the resulting product. Therefore, the primary objective of the present work was to obtain good-quality biscuits, and optimise the ingredients for a unique composition of biscuits. These components were derived from wheat, maize, or moringa leaf powder, and their formulation was optimised using LP. The secondary objective was to investigate the physicochemical, organoleptic, and antinutritional properties of LP-formulated products compared to conventional processing.

Materials and methods

Raw materials

The ingredients used were wheat flour, margarine, sugar, eggs, milk powder, baking powder, yellow maize, and dried moringa leaves, which were purchased from a local market in Owo, Nigeria. To obtain maize flour, the kernels were separated from impurities such as dirt and infested kernels, and divided into two parts, one of which was weighed and dry-milled in an attrition mill. The other portion of the weighed maize kernels was combined with desiccated moringa leaves in a 1:1 ratio, and subjected to dry milling to create a maize-moringa blend, as shown in Figure 1.

Preparation of biscuits

Biscuits were prepared using the creaming method outlined by Okaka (1997) with minor modifications. The sugar and fat were creamed in a mixing bowl using a paddle to produce a creamy mixture, followed by the addition of composite flour and other dry ingredients. The dough was kneaded manually, rolled out to a thickness of 5 mm, and cut into desired shapes and sizes. It was baked for 20 min in a hot oven, then cooled and packed individually in an airtight container. Control samples were prepared from 100% wheat flour without the incorporation of composite flours. Figure 1 depicts the flow diagram illustrating the process of biscuit preparation.

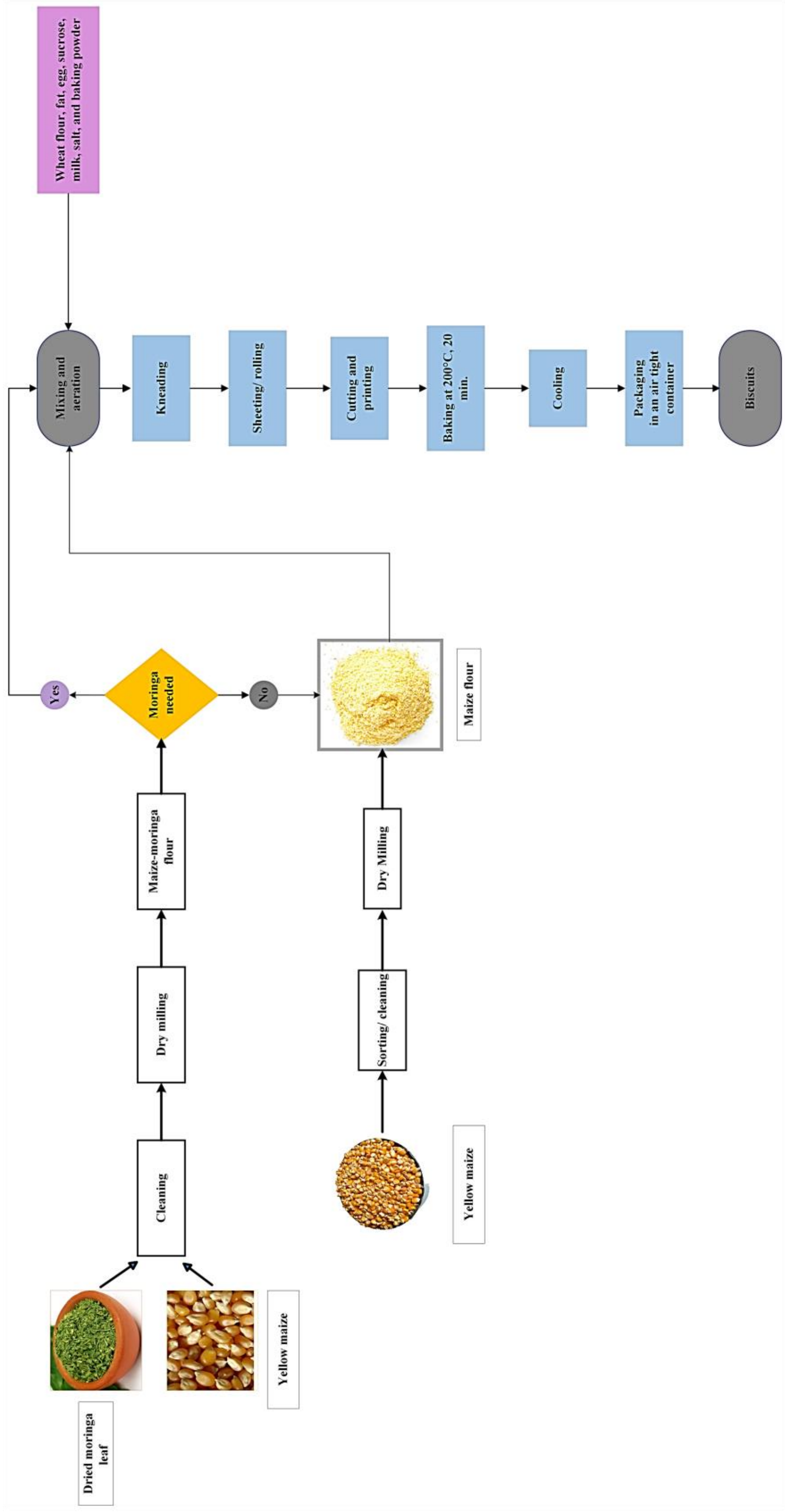

Figure 1. Flow diagram of biscuit production using composite flours.

Functional properties of composite flours

For the functional properties of the flour blends used for biscuit preparation, the bulk density, swelling index, and gelation concentration were determined according to Olatunde *et al.* (2016) with modifications.

Antinutritive characteristics of the formulated biscuits

Phytate

Phytic acid content was determined as outlined by Essien and Akpan (2014). Briefly, 4 g of pulverised material was soaked in 100 cm^3 of 20% HCl for 3 h, and filtered. Following that, 25 mL of the filtrate was transferred to a 100-mL conical flask, and an indicator solution of 5 mL of 0.3 mL of NH_4SCN was added. To the flask, 50 mL of distilled water was added for proper acidity, and titrated against $FeCl_3$ which contained about 0.00195 g/mL of Fe^{3+} in $FeCL_3$ solution. The phytate content was calculated in mg/100 g or g/100 g using Eqs. 1-3:

$$\text{Phytic acid} = \frac{\propto \times 8.24}{1000} \times \frac{100}{sample\ weight} \quad \text{(Eq. 1)}$$

$$\frac{mg}{100\ g} \text{ of Phytic acid} = \propto \times \frac{1.95 \times 1.19 \times 3.55}{sample\ weight} \times 100 \quad \text{(Eq. 2)}$$

Note: $Iron\ equivalent\ = Titre\ \times\ 1.95 \times\ 1.19$ (Eq. 3)

where, $\propto$ = titre value.

Saponin

The saponin content was determined as described by Harborne (1998). A known weight of the ground sample was dispensed into a 250-mL flask with 100 cm^3 of 20% ethanol, and heated in a water bath (Biobase, China) with constant stirring for 1 h at 55°C. The residue was filtered and re-extracted with 20 mL of 20% ethanol. The volume of combined extracts was reduced to 40 mL over a water bath at about 55°C. After transferring the concentrate into a 250-mL separating funnel, 20 mL of diethyl ether was added, and the mixture was vigorously shaken. The ether layer was discarded, and the aqueous layer was retained; 20 mL of *n*-butanol was added to the aqueous layer in a 100-mL beaker, and decanted. The percentage content of saponin was determined (g/100 g) using Eq. 4:

$$\%\ \text{Saponin} = \frac{W_3 - W_2}{W_1} \times 100 \quad \text{(Eq. 4)}$$

Oxalate

The oxalate content was determined as described by Uzombah *et al.* (2019). Briefly, 1 g of sample was placed into a 100-mL conical flask with 50 mL of 1.5 N H_2SO_4. It was then filtrated, and 25 mL of the filtrate was dispensed into a 100-mL conical flask, and titrated at high temperature (80 - 90°C) against a 0.1 M $KMnO_4$ solution until a faint colour developed and remained for at least 30 s. Oxalate was calculated in mg/100 g using Eq. 5:

$$\text{Oxalate}\left(\frac{\text{mg}}{100\text{ g}}\right) = \frac{Titre\ value \times 0.9004}{sample\ weight} \quad \text{(Eq. 5)}$$

Alkaloid

The alkaloid content was determined as described by Harborne (1998). Briefly, 2 g of sample was weighed into a 250-mL beaker, 100 mL of 20% acetic acid in ethanol was added, and the mixture was covered for 4 h. The extract was filtered and concentrated in a water bath to one-fourth of the original volume (25 mL/100 mL). Using the drop-by-drop method, a concentrated NH_4OH solution was added until precipitation was complete, then filtered with previously weighed filter paper. The filtrate mix was washed with NH_4OH to ascertain complete precipitation, and re-filtered with the same filter paper. The filter paper was dried with the residue (alkaloid) in the oven, and the alkaloid was calculated as a percentage g/100 g using Eq. 6:

$$\%\ \text{Alkaloid} = \frac{W_2 - W_1}{Weight\ of\ sample} \times 100 \quad \text{(Eq. 6)}$$

where, W_1 = initial weight of the dried filter paper, and W_2 = weight of the filter paper + alkaloid precipitate.

Tannin

The tannin content was determined as described by Uzombah *et al.* (2019). Briefly, 0.2 g of sample was mixed with 10 mL of 70% acetone, and shaken on a water bath shaker for 2 h at 30°C. The mixture was centrifuged, and the supernatant was stored on ice. Next, 0.2 mL of the supernatant was dispensed into a test tube with 0.8 mL of distilled H_2O. A standard tannic acid solution (0.125 g/250 mL), equivalent to 0.5 mg/mL, was prepared and added to test tubes containing 1 mL of sample solution (0.2 mL + 0.8 mL H_2O), 0.5 mL of Folin reagent, and 2.5 mL of 10% Na_2CO_3. The same was done for 1 mL of standard tannin solution (0.5 mg/mL). It was vortexed and allowed to incubate at room temperature for 40 min. Then the absorbance or transmittance of the serial dilution of standard was measured, and the sample was read at 725 nm with the reagent blank at zero. The tannin was calculated as a percentage using Eq. 7:

$$\%\ \text{tannin} = \frac{100}{W} \times \frac{as}{at} \times \frac{c}{1000} \times \frac{vt}{va} \qquad \text{(Eq. 7)}$$

where, W = sample weight, *as* = absorbance of the test sample, *at* = absorbance of the standard tannin solution, *c* = concentration of the standard tannin solution, *vt* = total volume of the extract, and *va* = volume of the analysed extract.

Proximate composition analysis

The proximate composition (protein, fat, moisture, ash, and crude fibre) of all the sample groups was analysed in accordance with Association of Official Analytical Chemists (AOAC, 2002) methods 934.01, 984.27, 992.15, 978.10, and 920.37, respectively. The food energy was obtained using the Atwater factor. This was calculated by multiplying the values of protein, carbohydrate, and fat by a factor of 4.0, 4.0, and 9.0 kcal/g, respectively, finding the sum of their products, and expressing the result in kilocalories.

Sensory evaluation

The 9-hedonic scale was used to rate the sensory parameters of the biscuits. The panellists were drawn from a polytechnic community in Owo, Nigeria, and were trained to evaluate the biscuits based on colour, texture, flavour, taste, and general acceptability.

Linear programming

A linear programming model was devised to formulate mixtures of wheat, maize, and maize-moringa flour with the objective of maximising the nutritional content of biscuits. These formulations were designed using the proximate composition of ingredients from various sources, including USDA (United States Department of Agriculture) and IITA (International Institute of Tropical Agriculture). For the conventional formulation, wheat flour was replaced at a 60:40 ratio of maize and maize-moringa flour.

Statistical analysis

Utilising Microsoft Excel Premium Solver, the linear programming model was solved and optimised to determine the precise amounts of wheat and maize flour required for the recipe. The data were analysed using Microsoft Excel. The Tukey test was used to distinguish statistically significant differences in the means of the samples. In order to ascertain a statistically significant difference between the samples at a significance level of 5%, ANOVA was performed.

Results and discussion

Developing linear programming model for nutritionally optimised biscuits

The formulation of flours yielding a nutritionally optimised biscuit was performed using LP, and can be found in Table 1, which is summarised in terms of locally available materials and biscuit ingredients. According to Varghese and Srivastav (2022), LP algorithm requires a specific objective, whether maximisation or minimisation, where an objective function is a linear expression used to calculate the profit, cost, and production quantity of a given model. The first step in using LP to standardise biscuit ingredients and optimise their nutritional value is the selection of ingredients.

Yellow maize or moringa leaves were included to fulfil nutrient constraints. Yellow maize flour is rich in omega-6 fatty acids, dietary fibre, magnesium, protein, and vitamin B_6, which are vital for heart health, optimal bowel function, and fighting infections (Adesanmi *et al.*, 2020). In addition, the dried leaves of the moringa plant contain essential nutrients, such as proteins, minerals, and phenolic compounds that can improve the nutrition of individuals and communities (Natsir *et al.*, 2019).

The decision variables represented the options available to us in terms of the ingredients: wheat and maize. While the constraints (either one or more) for this given problem were defined by the proximate composition of each of the individual ingredients, which was the set of all possible combinations of the decision variables. A feasible solution was then obtained when all our constraints were satisfied, including the total and amount of ingredients required for the biscuit formulation.

The LP objective function was then expressed in the form of Eq. 8:

Table 1. Optimised results of flour blends based on overall ingredients.

Ingredient (g)	% on flour basis	Control	Conventional formulation		LP formulation	
		A	B	C	D	E
Wheat flour		200	120	120	140.5	140.5
Yellow maize flour		-	80	-	59.5	-
Maize-Moringa blend		-	-	80	-	59.5
Fat	40	80	80	80	80	80
Beaten egg	20	40	40	40	40	40
Sucrose	60	120	120	120	120	120
Milk	4	8	8	8	8	8
Salt	2	4	4	4	4	4
Baking powder	1	2	2	2	2	2

Control (A), conventional formulation without moringa (B), conventional formulation with moringa (C), LP Model without moringa (D), and LP Model with moringa (E).

Maximise:

$$Protein\ (W+M) + Fibre\ (W+M) + Carbohydrate\ (W+M) + Fat\ (W+M) \quad \text{(Eq. 8)}$$

where, W = wheat, and M = maize.

Eqs. 9 - 14 show the individual protein, fibre, carbohydrate, and fat of each of the components that contribute to the overall nutritional component (protein, fibre, and carbohydrate) of the formulation.

Constraints:

$$\text{Protein: } 13.7\text{W} + 7.88\text{M} \leq 10 \quad \text{(Eq. 9)}$$

$$\text{Fibre: } 12.2\text{W} + 2.5\text{M} \leq 10 \quad \text{(Eq. 10)}$$

$$\text{Carbohydrate: } 72.57\text{W} + 76\text{M} \leq 0 \quad \text{(Eq. 11)}$$

$$\text{Fat: } 1.87\text{W} + 0\text{M} \leq 0 \quad \text{(Eq. 12)}$$

$$\text{Target: } W + M = 200 \quad \text{(Eq. 13)}$$

$$\text{Non-negativity constraints: } \text{W} + \text{M} \geq 0 \quad \text{(Eq. 14)}$$

Proximate composition

Table 2 displays the proximate composition of all the biscuit samples analysed (including the control samples). The moisture level of the samples ranged from 4.5 to 7.5%, showing significant differences between the formulated samples. Moisture content determination is often used as a measure of shelf stability, since a moisture content level below 10% indicates good keeping quality and low spoilage activity (Aderinola *et al.*, 2020). Sample E had significantly higher moisture content (7.50%, $p \leq 0.05$) compared to the other formulated samples. Furthermore, it is worth noting that the moisture content of the LP group was greater than that of the conventional group, which could be attributed to the different optimisation models used in the biscuit formulation. Among the various groups, it was observed that the samples containing moringa (C and E) had higher moisture content compared to samples B and D without moringa (4.5 and 5.5, respectively, $p \leq 0.05$). The observed disparities can be attributed to the propensity of moringa leaves to augment the moisture levels of the biscuits, which agreed with Wabali *et al*. (2020). Rathnayake and Navarathna (2017) reported similar observations with functional biscuits prepared from wheat and moringa leaf flours.

The percentage of ash content varied from 0.5 to 1.5%, and demonstrated a significant decrease in all formulated biscuits compared to the control sample. The ash content of sample A was found to be the highest at 1.50%, whereas samples B, C, and D exhibited the lowest ash content at 0.50%, with no significant differences observed among them. Among all the composite samples examined, sample E had slightly elevated ash content, which could have been due to the use of the LP model and moringa. In a study conducted by Das et *al*. (2018), it was observed that

Table 2. Proximate composition of biscuit products from different flour blends.

Sample	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate (%)	Energy (calories)
A	6.00 ± 0.02^{b}	1.50 ± 0.05^{a}	8.75 ± 0.90^{c}	9.00 ± 0.77^{b}	0.25 ± 0.05^{c}	74.50 ± 1.54^{b}	414^{b}
B	4.50 ± 0.25^{d}	0.50 ± 0.20^{c}	7.88 ± 0.01^{d}	5.00 ± 0.10^{d}	0.25 ± 0.10^{c}	81.87 ± 0.50^{a}	404^{d}
C	6.00 ± 0.04^{b}	0.50 ± 0.01^{c}	7.00 ± 0.05^{e}	10.00 ± 0.61^{a}	1.75 ± 0.00^{a}	74.75 ± 0.63^{b}	417^{a}
D	5.50 ± 1.00^{c}	0.50 ± 0.06^{c}	17.5 ± 0.50^{a}	8.00 ± 1.80^{c}	0.50 ± 0.72^{bc}	68.00 ± 0.56^{c}	414^{b}
E	7.50 ± 0.54^{a}	1.00 ± 0.09^{b}	15.4 ± 1.05^{b}	10.00 ± 0.01^{a}	0.75 ± 0.64^{b}	65.35 ± 0.89^{d}	413^{c}

Values are mean ± standard deviation of triplicate samples ($n = 3$). Tukey test was employed to determine significant differences between means. Means within the same column followed by different lowercase superscripts are significantly different ($p \leq 0.05$). Control (A), conventional without moringa (B), conventional with moringa (C), LP Model without moringa (D), and LP Model with moringa (E).

composite biscuits exhibited ash values in the range of 0.79 - 1.09%. Similar results were reported by Rabie *et al.* (2020) regarding the ash content of cookies supplemented with moringa leaves and seed powder (0.61 - 1.79%). The obtained results suggested a reduced concentration of total inorganic minerals.

In the present work, varying levels of crude protein were observed from 7 to 17.5%, and LP groups D and E exhibited the highest protein contents (17.5 and 15.4%, respectively). Conversely, the conventional group had the lowest protein contents (7.00 and 7.88%, respectively). In contrast to the samples prepared using conventional formulations, samples D and E, which underwent LP optimisation, had much higher protein content. The protein content of the optimised biscuits was higher than that reported in several studies that also examined the utilisation of composite flours in biscuit production (Farzana and Mohajan, 2015); hence the rationale behind employing LP optimisation techniques in the production of biscuits that are optimally nutritional. Interestingly, samples containing moringa (C and E) had significantly lower protein levels compared to composite biscuits without moringa. This finding is intriguing, considering that other studies have demonstrated that moringa is a highly abundant protein source (Kar *et al.*, 2013). In contrast, Ogunsina *et al*. (2011) revealed that cookies enriched with moringa seed flour exhibited increased protein content.

The fat content of the composite biscuits was significantly different ($p < 0.05$) from that of the control sample (9.0%). The samples with the highest fat content were samples C and E, which contained moringa (10.00 and 10.00%), and the lowest was recorded in samples B and D (5.00 and 8.00%, respectively). The increase in fat in the moringa-supplemented group may be linked to the inherently higher lipid content in moringa leaves. Kar *et al.* (2013) revealed that oils from the leaves contained a high amount of polyunsaturated fatty acids, especially linoleic and linolenic acids. Upon comparison between the formulated samples and the control sample, it was observed that the application of LP optimisation improved the fat content in sample D more than that in conventional sample B. The fat content range observed in the present work (5.00 - 10.00%) differed from previous studies that have employed composite flours for biscuit production (Olatunde *et al.*, 2016; Aderinola *et al.*, 2020).

Crude fibre is a quantitative assessment of the presence of non-digestible carbohydrates, namely cellulose and lignin, in foods. The biscuit samples exhibited a range of crude fibre content, varying from 0.25 to 1.75%. Sample C, formed by the conventional moringa formulation, recorded the highest fibre content of 1.75%. Similar results have been reported by Olatunde *et al.* (2016). In addition, the crude fibre content of the samples was low, with the exception of samples C and E, which exhibited crude fibre contents of 1.75 and 0.75%, respectively. LP optimisation had only a slight effect on the composition of the fibre compared to the control. The use of moringa in the formulation had a significant impact on crude fibre content, as evidenced by a study conducted by Rathnayake and Navarathna (2017).

There was significant variation in the total carbohydrate content of the composite biscuits, potentially attributed to variations in protein, moisture, and fat levels within the product. The carbohydrate contents of biscuit samples D and E were found to be the lowest at 68 and 65.35%, respectively, which can be attributed to the optimisation of the nutrient composition of these formulations. In contrast, sample B exhibited the highest carbohydrate content (81.87%). Nevertheless, the samples supplemented with moringa exhibited lower carbohydrate levels than their counterparts. Our results were consistent with those of a study that showed that the addition of moringa and *Ocimum sanctum* leaves to biscuits decreased carbohydrate content (Dhankhar *et al*., 2021).

The energy value refers to the caloric content of food through oxidation. The present work observed a variation in the energy values of the biscuit samples, with values ranging from 404 to 417 calories. The energy value of the biscuits produced from the LP-optimised blends was similar to that of the control sample.

Sensory evaluation

The sensory properties of food are useful indicators for assessing differences in food products, flavour quality, consumer preferences, and attribute intensities. Figure 2 illustrates the mean scores pertaining to the panellists' preferences. The participants provided ratings for the samples using a nine-point hedonic scale ranging from 1 to 9, where 1 was disliked extremely, and 9 was liked extremely. Biscuits were assessed for taste, colour, texture, flavour, and overall acceptability.

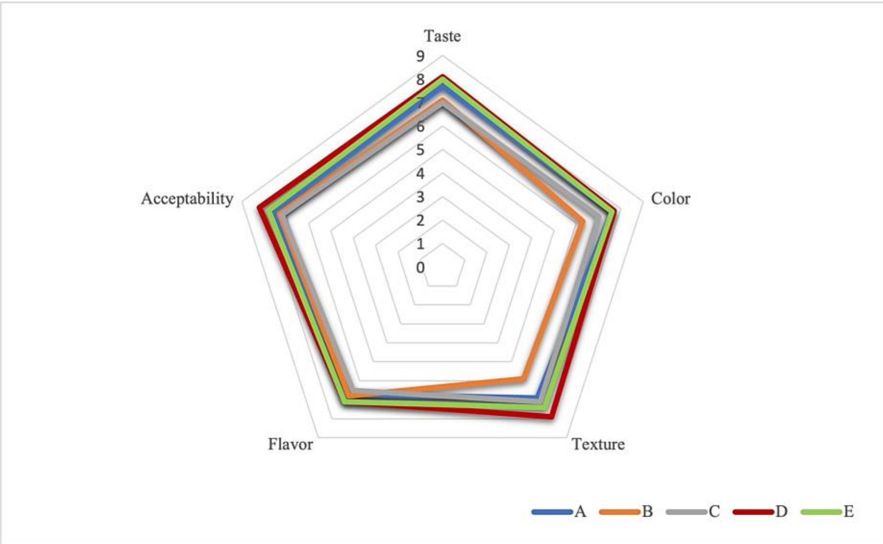

Figure 2. Radar chart of sensory properties of biscuits prepared from composite flours. A: Control, B: conventional formulation without moringa, C: conventional formulation with moringa, D: LP Model without moringa, and E: LP Model with moringa.

Sensory attribute scores were consistently high across all biscuit samples. In general, the control sample produced solely from 100% wheat (A) was not significantly different from the other samples; however, the texture of sample B was significantly different ($p < 0.05$). In addition, for acceptability, none of the samples differed significantly, even though samples D and E had the highest average acceptability scores. Furthermore, it was observed that samples with moringa, C and E, had lower acceptability compared to the formulations without moringa. The study conducted by Nwakalor (2014) yielded comparable outcomes when examining biscuits prepared from different ratios of wheat and moringa leaf flours. The potential correlation between the concentration of phytochemicals presents in moringa and their influence on the flavour and appearance of biscuits is worth exploring. In comparison to other types of flour, wheat flour often exhibits superior baking quality.

Biscuits prepared based on the LP formulations (D and E) had the highest mean taste scores compared to the other formulations, although this was not statistically significant ($p > 0.05$). The optimisation of wheat flour with maize flour using LP produced good results, as the samples were only significantly different in texture, and had the highest scores for taste, flavour, colour, texture, and acceptability. According to Varghese and Srivastav (2022), the utilisation of LP presents a viable strategy for developing cookies with high nutritional value, thus offering a potential solution to the issue of malnutrition.

Functional properties of biscuit blends

Table 3 depicts the functional properties of the biscuit's composite flours. The parameters of bulk density, swelling index, and least gelation concentration (LGC) were assessed. Functional properties reflect the complex interaction between proteins and all other food components. They are parameters that have a crucial role in determining the application and utilisation of raw materials across different food products (Adebowale *et al.*, 2012). Based on the findings of the present work, there was no significant difference observed in the functional characteristics of the biscuit blends.

The bulk density, expressed in gram per cubic centimetre or gram per millilitre, quantifies the weight of flour that a given volume is capable of accommodating. It is a requirement in packaging, raw material handling, and wet processing in the food industry, and generally depends on the spatial arrangement, density, and particle size of flour (Adebowale *et al.*, 2012). There was no significant difference in the bulk density of the formulations ($p > 0.05$); however, the flour obtained from the conventionally formulated mix had higher bulk density. Conversely, the bulk densities of the samples ranged from 0.65 to 0.84 g/cm^3, and there was no significant difference seen. However, it was noted that formulations lacking moringa (B and D) had lower bulk density compared to samples with moringa (C and E). The observed slight increase in bulk density of formulations C and E could be attributed to the decrease in maize flour content resulting from the incorporation of moringa. The bulk densities in the present work were similar to those previously reported for composite flours containing wheat, soybeans, and moringa leaf, which have been reported to range from 0.50 to 0.80 g/mL (Verem *et al.*, 2021). The present findings indicated that the bulk density of flour was influenced by its initial moisture content and particle size, since the bulk density of composite flour increased as other flour was combined with wheat flour.

Correspondingly, the swelling index data showed no significant difference between the conventional and LP-formulated composite flour formulations. Swelling index is dependent on various factors such as flour varieties, processing methods, particle sizes, and others (Chandra *et al.*, 2015). The observed swelling index values for the samples varied between 0.08 and 0.88 g/mL. Sample E had the highest swelling index, while sample B the lowest.

Furthermore, it was observed that the formulations containing moringa exhibited higher swelling index in comparison to the formulations without moringa or the control sample. The moringa formulations exhibited slightly higher swelling index, potentially due to their higher content of soluble components, particularly hydrophilic fibre. These soluble components are expected to bind enough water, thereby facilitating swelling, where the swelling power of flour serves as an indicator of the extent of associative forces within the granules (Dhankhar *et al.*, 2021).

The term "least gelation concentration" (LGC) is used to describe the protein concentration at which a gel may maintain its structure on an inverted tube without sloping. Table 3 displays the LGC data pertaining to the different composite formulations. LGC was not significantly different between the samples. Samples D and E did not exhibit any gel formation, but samples A, B, and C had gelation concentrations of 3%. The protein component's (gelatine) capacity improves with decreasing gelation concentration. The variation in the three basic components of flour—protein, carbohydrate, and lipid—and their interactions with one another ultimately determine the gelation concentration of flour (Chandra *et al.*, 2015). Similarly, another study on composite flour from wheat, acha, cowpea, and moringa leaf powder reported LGC values ranging from 2 - 4% (Orisa and Udofia, 2020).

Antinutritive analysis

Table 3 presents the assessment of the anti-nutritive properties of biscuits derived from various composite flours consisting of wheat, maize, and moringa. Anti-nutrients refer to compounds that bind and trap amino acids, essential minerals, and proteins in food formulations, hence impeding their absorption in the digestive system. The presence of oxalate in foods can form kidney stones that can obstruct the renal tubules, as roughly 80% of kidney stones are formed from calcium oxalate (Coe *et al.*, 2005).

The oxalate level observed in the samples varied between 4.41 and 8.82 mg/100 g, with samples B and C having significantly higher oxalate values than samples A, D, and E. Lowered oxalate values, D and E (4.41 and 4.95 mg/100 g, respectively), meant that the optimisation of the ingredients using LP

Table 3. Antinutritive and functional properties of wheat/maize blends.

Samples	Oxalate (mg/100 g)	Phytate (g/100 g)	Alkaloid (%)	Saponin (%)	Tannin (mg/g)	Bulk density (g/cm^3)	Swelling index (g/ml)	Least gelation determination (%)
A	5.22 ± 0.45^c	0.9888 ± 0.01^a	16 ± 0.75^b	21.3 ± 0.01^a	1.59 ± 0.86^c	0.67 ± 0.01^a	0.24 ± 0.05^a	3 ± 0.00^a
B	8.82 ± 0.23^a	0.8858 ± 0.00^a	6 ± 0.04^d	5.6 ± 0.55^d	0.46 ± 0.06^d	0.73 ± 0.01^a	0.08 ± 0.01^a	3 ± 0.00^a
C	7.29 ± 0.47^b	1.0094 ± 1.45^a	18.8 ± 0.56^a	7.5 ± 0.44^c	2.88 ± 0.63^b	0.84 ± 0.21^a	0.32 ± 0.02^a	3 ± 0.00^a
D	4.41 ± 0.54^c	0.5974 ± 1.08^a	11.6 ± 0.39^c	15.2 ± 0.21^d	0.27 ± 0.11^d	0.65 ± 0.39^a	0.15 ± 0.08^a	-
E	4.95 ± 0.02^c	0.8240 ± 0.25^a	6.8 ± 0.07^d	15.4 ± 0.89^b	7.97 ± 0.03^a	0.71 ± 0.50^a	0.88 ± 0.06^a	-

Values are mean ± standard deviation of triplicate samples (n = 3). Tukey test was employed to determine significant differences between means. Means within the same column followed by different lowercase superscripts are significantly different ($p \leq 0.05$). Control (A), conventional without moringa (B), conventional with moringa (C), LP Model without moringa (D), and LP Model with moringa (E).

considerably decreased their concentration, and as a result their capacity to form complexes with food nutrients, hence enhancing the bioavailability of nutrients in the samples. The concentration of oxalate in all samples was observed to be below the recommended daily intake (40 - 50 mg/100 g) (Keyata *et al.,* 2021).

Phytate, another compound present in plant-derived raw materials, has been observed to result in decreased micronutrient availability and protein digestibility. Phytates can form complexes with minerals by chelation, rendering them metabolically unavailable. The phytate values observed in the samples ranged from 0.5974 to 1.0094 g/100 g but were not significantly different between the samples. The phytate contents of samples D and E were lower compared to those of samples A, B, and C. LP optimisation reduced the phytate content of the biscuits; however, the inclusion of moringa was shown to elevate the phytate content in moringa-supplemented samples (C and E) in contrast to non-moringa-supplemented samples (B and D). This phenomenon could perhaps be attributed to the presence of additional substances derived from moringa, given that moringa leaves are known to possess a significant abundance of phytonutrients. Sample C had the highest phytate content, while sample D, made without moringa and formulated using LP, had the lowest. Studies have shown that certain food preparation techniques, such as milling, fermenting, germinating, or soaking have the potential to reduce the levels of phytic acid and protease inhibitors in foods (Uzombah *et al.,* 2019). Optimisation of the ingredients will thus minimise the levels of phytates in the biscuits.

Alkaloids are a class of nitrogenous organic compounds that possess toxic properties, and have the potential to exert adverse effects on several physiological systems, including immune, central nervous, and digestive systems. In the present work, different formulation techniques resulted in varying percentages of alkaloids in the composite biscuits. The range of alkaloid content observed was between 6 and 18.8%, and a significant difference in the alkaloid contents of the samples was observed ($p < 0.05$). Samples D, A, and C had the highest levels of alkaloid content, measuring at 11.6, 16, and 18.8%, respectively. Conversely, samples B and E had the lowest. In addition, biscuits prepared using LP exhibited a considerable decrease in alkaloid content compared to the control sample.

In actuality, the presence of saponins in the diet is so minimal that the likelihood of their causing harm is low. Nevertheless, saponins can form insoluble complexes with iron, zinc, and calcium, rendering these minerals inaccessible. Furthermore, saponins have several applications, such as dietary supplements, expectorants, and anti-inflammatory drugs due to their ability to impede Na^+ efflux by blocking the outward movement of Na^+ from the cell. As a result, there is an increase in intracellular Na^+ concentrations, which leads to the activation of the Na^+ - Ca^{2+} anti-porter. This activation results in elevated levels of cytosolic Ca^+, which subsequently promotes myocardial contractility, thereby reducing congestive heart failure (Schneider and Wolfling, 2004).

All the formulated samples exhibited varying amounts of saponins; sample A, which was made entirely of wheat, had the highest concentration (21.3%), followed by samples E (15.4%) and D (15.2%). The lowest concentration of saponin were found in samples B and C (5.6 and 7.5), then D and E. It is noteworthy that the samples supplemented with moringa (C and E) exhibited significantly higher levels of saponins compared to the samples without moringa (B and D).

The tannin content in the present work ranged from 0.27 to 7.97 mg/g, which fell below the established maximum tolerable level of 560 mg/100 g, except for sample E (7.97 mg/g) derived from a wheat-maize-moringa blend. This showed that the concentration of tannins in samples without moringa was significantly lower compared to the control sample. This was consistent with Wabali *et al.* (2020) who reported that biscuits prepared from the composites of wheat, walnut, and moringa seed flour increased the tannin content of the biscuits. In the present work, samples B and D (0.46 and 0.27 mg/g, respectively) without moringa had the lowest tannin concentration. The tannin levels in formulated supplementary flours made with sorghum, karkade, and soybean flours were also found to be lower (Keyata *et al.*, 2021). Even though plant tannins have been shown to have an anti-inflammatory effect that aids in the control of all symptoms of gastritis, esophagitis, enteritis, and irritating bowel disorder (Tong *et al.,* 2022), it is important to reduce tannins to improve the nutritional composition of foods, which not only reduce the bioavailability of nutrients, but also contribute to the discoloration of flour.

Conclusion

A linear programming model was successfully developed for the production and optimisation of biscuits made from wheat, yellow maize, and moringa flour. The application of a linear programming model yielded notable improvements in the proximate, sensory, and antinutritional properties of biscuits in comparison to biscuits formulated by conventional methods. Linear programming models can be adopted for biscuit production as opposed to labour-intensive and expensive conventional food formulation methods. It is noteworthy and significant that linear programming can be applied for high-scale production and low-scale formulation of diets. Therefore, it is recommended that biscuits be prepared using not only wheat flour, but also cereals or other legumes in order to enhance their nutritional attributes. Additionally, it is necessary to conduct further research about biscuits, including an assessment of their feasibility and an examination of their economic implications. Furthermore, it is worth investigating the potential correlation between the concentration of phytochemicals found in moringa and their influence on the flavour and appearance of biscuits.

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