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DEVELOPMENT, PROXIMATE EVALUATION, AND OPTIMIZATION OF FUNCTIONAL BREAKFAST CEREAL FROM INDIGENOUS INGREDIENTS (MINNA, NIGERIA)

The object of the research is an optimal wholesome breakfast cereal.

The problem to be solved is to make a wholesome breakfast cereal by using local ingredients with complementary nutritional and health-promoting qualities rather than mono-grain products. This will lessen the global epidemic of malnutrition and diet-related diseases such as diabetes, obesity, overweight and heart diseases. In order to improve nutritional quality, the formulation substituted natural flavorings, artificial colors, sweeteners, synthetic minerals, and preservatives with natural ones. It also made use of experimental design and numerical optimization of ingredient proportions and processing parameters to achieve improved nutritional qualities. Five components, two processing parameters constrained D-optimal mixture-process experimental design was employed in the research. The design constraints were: malted finger millet flour (20–60%), malted roasted Bambara groundnut flour (10–40%), turmeric powder (5–15%), moringa leaf powder (2–5%), date fruit powder (5–20%), salt (0.3%); screw speed (70–150 rpm) and barrel temperature (90–100°C). Numerical optimization, via desirability function technique, yielded an overall desirability index of 0.7 with optimized components and factors levels as: 42.7% malted finger millet, 40.0% malted roasted Bambara groundnut, 5% date fruit, 2% moringa leaf powder, 10% of turmeric powder, 0.3% salt, 110°C barrel temperature and 110 rpm screw speed. The optimal quality of the breakfast cereal were: 12.5% protein, 67.4% carbohydrate, 6.9% moisture content, 3.6% ash content, 2.4 crude fiber and 7.2% crude fat. The optimal formulation conditions obtained can serve as a data base for future production in food processing industries.

Keywords: *breakfast cereal, desirability index, mixture, constrained d-optimal, optimal formulation conditions.*

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1. Introduction

In the last few years, the demand for functional foods has gained much importance. As the world continues to evolve, there is a growing recognition of the key role of functional foods as they provide a health benefit beyond the basic nutritional functions.

Malnutrition, dietary deficit, diseases and food insecurity are global menace, and incorporation of different functional ingredients into diets is one of the vital remedies to this menace. Combining of locally sourced ingredients; finger millet, Bambara groundnut, date fruit, moringa leaf and turmeric which are both nutritious and of immense health benefit, in the formulation and processing of breakfast cereal is needful. This is to meet the rising need of consumption of functional foods all over the world.

Breakfast cereals are grain food made for human consumption commonly consumed with milk, sugar or fruit with or without further cooking and usually taken for breakfast [1, 2]. They are usually mono-grain products processed from grains like wheat, rice, corn, oats and others. Morning cereals are made using a number of processes, such as cooking, shaping, drying, and adding other components like yeast, coloring, flavorings, sweeteners, vitamins, minerals, and preservatives [1]. It has been reported that a lot of existing breakfast cereals are characterized with high rapidly digestible starch, high glycemic index, low dietary fiber, prevalent artificial sweeteners; and the harmful metabolic consequences of these include type 2 diabetes, heart diseases and overweight [3]. As a result, there is a growing need to consume functional foods in order to prevent diet-related diseases that are plaguing the globe. Additionally, artificial sweeteners, colors, flavors, and synthetic minerals that come with most breakfast cereals needs to be replaced with natural colors, flavors and sweeteners found in our locally available ingredients [1]. Functionally, even the biggest food processing industries in the world hardly ever make use of experimental design and numerical optimization techniques as effective tools for developing new food products with particular functional ingredients, and improving overall quality and safety [4, 5].

Indigenous crops with tremendous health benefits and are potential sources of protein, energy, dietary fiber and micronutrients when processed into breakfast cereals includes Bambara groundnut, finger millet, date fruit, *Moringa oleifera* leaf, turmeric. When compared to other traditional cereals, finger millet has vast untapped health-boosting qualities. The grains are easy to digest, low in glycemic index, and rich in bioactive compounds [6]. Bambara groundnuts are a reasonably priced source of protein, particularly in light of the high cost of animal protein. It has a higher protein score (80%) than cowpea (64%) and soy bean (74%) and is higher in critical amino acids than other legumes [7]. Bambara groundnut is rich in phytochemicals such as flavonoids and anti-nutritional factors (ANFs) [8]. *Moringa oleifera* leaf is a readily available leafy vegetable that can be used to fortify several food products or meals to address micronutrient deficiencies [9]. *Moringa oleifera* plant, particularly its leaves are rich in essential amino acids and minerals such as calcium, phosphorus, potassium and iron. Antioxidant, antimicrobial, anti-inflammatory, antiulcer, antispasmodic, hypotensive and antitumor agent potential are found in moringa leaves [10]. Date fruit is a good source of dietary potassium and provides wide range of essential nutrients [11]. Date can serve as a natural sweetener and high in antioxidants and bioactive compounds. It is a good source of energy and dietary fiber [12]. Turmeric is a natural food colorant and a preservative [13]. Turmeric is rich in bioactive compound curcumin, which is also responsible for its health impacting properties such as anti-microbial, anti-inflammatory, and antioxidant effect against microorganisms and free radicals that causes diseases and aging [14, 15].

Production of breakfast cereal was assessed from a blend of finger millet, wheat, soybean, and peanuts. It reported an enhancement in protein, fiber, and mineral content as legume supplementation increased [16]. Without using the optimization technique that the current research used, they concentrated on enhancing the nutritional composition through ingredient supplementation by trial-and-error formulation to identify the optimal combination of ingredients capable of producing optimum nutritional quality. Another research, which focused on nutritional quality effectively showed that fortification enhanced the protein quality, amino acid profile content, and some functional properties of the cereal rather than the creation of a functional product with specific health-promoting benefits [17]. They did not investigate a more comprehensive combination of indigenous functional ingredients, which is taken into consideration in the current research by combining Bambara groundnut, date fruit, moringa, and turmeric with finger millet, since they used finger millet, soybean cake, and carrot pomace for nutritional benefits. In order to determine the ideal ingredient proportion capable of producing the best nutritional qualities, a team of researchers created breakfast cereal in 2021. They used specific blend ratios without using sophisticated optimization tools, like Response Surface Methodology, mixture design, and numerical optimization [18]. Although they used date as natural sweetener, but they excluded high functional plant sources such as moringa and turmeric. Instead of using finger millet, which has a lower glycemic index, better antioxidant qualities, higher calcium content, and a better mineral profile, the researchers used sorghum.

Additionally, while the current research achieved improved nutrient density and functional quality, the previous research did not examine the interactive effects of multiple functional ingredients.

The object of research is an optimal wholesome breakfast cereal.

The aim of research is to develop, evaluate proximate properties and optimize functional breakfast cereal from Bambara groundnut, finger millet, Moringa leaf, date fruit and turmeric. These can be achieved through the following:

1) to prepare the ingredients for formulation into flours and powders and determine their proximate properties;

2) to formulate and extrude the breakfast cereal blends from the ingredients;

3) to determine the proximate compositions of the developed breakfast cereal;

4) to carry out statistical analysis and optimize the formulated breakfast cereal based on the proximate properties.

2. Materials and Methods

2.1. Materials

The materials used which are finger millet, Bambara groundnut, date fruit, turmeric and fresh *Moringa oleifera* leaves were purchased from Kure market, Minna, Niger state, Nigeria. The local dried date (Dabino) dark brown, elongated and wrinkled harvested at fully ripe dry stage (Tamr stage) was used. The cream and white cultivar and early-maturing variety of Bambara groundnut was used. *Moringa oleifera* cultivar which is the main cultivated species in Nigeria with high leaf biomass harvested at early stage was used in the research. Local red-seeded land race of finger millet was used. Locally adapted types, mature rhizome turmeric with bright yellow-orange interior obtained at maturity stage with brown skin was used in this research.

2.2. Methodology

2.2.1. Tools and apparatus

Harvard LTE laboratory oven (0Q1055) Riley Industries Ltd. England, GallenKamp Muffle Furnace 2500, Henan Dming Technology Co., Ltd. Japan, 500 kg/h Hammer crusher (4.5 hp) China, with 0.75 mm screen size, Single-screw food extruder of 304:18.5 barrel length to diameter ratio, 18 mm screw diameter ratio, and 1.74 kW power, 304 barrel length and 6 mm die diameter, Model DGH Electrothermal oven, China, Supertek Glassware (100–500 ml) Measuring Cylinders, Shiv Dial Sud & Sons, China, Mettle PC2000 Weighing Balance, China, Binatone Blender with Grinder Model BLG-452, China, Gallenkamp Kjeldahl Apparatus Ray Export, India and Soxhlet Apparatus A. Gallenkamp & Co., Ltd, England.

2.2.2. Sample preparation

2.2.2.1. Preparation of malted finger millet flour (MFMF)

The ingredients for the formulation of the functional breakfast cereal were prepared into flour and powders using standard methods.

Malted finger millet flour was made using the method outlined in [19]. The finger millet grains were first cleaned and winnowed to remove undesirable items and defective grains. The grains were then spread out in a thin layer on moist jute bags and bathed with water on a regular basis to promote sprouting. Following 48 hours of malting, the grains were dried in a hot air oven (MODEL DHG Electrothermal oven, China) for 15 hours at 65°C. The dry malted grains were ground in a Binatone Blender with Grinder (Model BLG-452, China) and sieved through a 0.4 mm mesh screen to create malted finger millet flour. After that, the flour was stored until it was needed in high-density polyethylene (HDPE) bags.

2.2.2.2. Malted roasted Bambara groundnut flour preparation (MRBGF)

Malted roasted Bambara groundnut flour (MRBGNF) was produced as described in [20]. The Bambara groundnut seeds were thoroughly cleaned with tap water after being cleaned and sorted to remove any debris. The seeds were placed on jute bags and allowed to sprout for 48 hours under moistened jute bags after being soaked in warm water (40–50°C) for eight hours. The germinated seeds were equally spread out on oven trays and dried for ten hours at 65°C in a hot-air oven (MODEL DHG Electrothermal oven, China). Following the physical removal vegetative components, the dried seeds were winnowed. The cleaned malted seeds were roasted for 40 minutes at 130°C in the same oven, cooled, ground in a Hammer mill, and sieved through a 0.4 mm mesh screen to produce fine MRBGNF. The flour was stored in high-density polyethylene (HDPE) bags prior to usage.

2.2.2.3. Date fruit preparation (DFP)

The dry date fruits were first sifted to remove any broken seeds before the seeds were manually removed (de-pitting). The fruits were sliced into smaller pieces and then oven-dried at 75°C for six to eight hours until completely dry. To create fine, uniform particles, the dried pieces were pulverized using a dry kitchen grinder (Binatone Blender with Grinder Model-452, China), mashed with a mortar and pestle, and sieved through a 0.35 mm screen [21]. The resultant date palm fruit powder was kept at room temperature in air-tight plastic containers.

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2.2.2.4. Turmeric powder preparation (TP)

Turmeric powder was processed as described in [22]. The rhizomes were cleaned, cut with a potato chip slicer, and then air-oven dried at 75°C. The rhizomes were dried, crushed, and sieved through a 300 µm mesh screen before being stored in plastic containers at room temperature until needed.

2.2.2.5. Preparation of moringa leaf powder (MLP)

Moringa leaf powder was made using the method described in [23]. After the leaves were detached from their petioles, any sick or damaged leaves were discarded. They were thoroughly cleansed with water and allowed to drain in perforated baskets for fifteen minutes in order to lessen microbial contamination. The leaves were dried in an air oven after being thinly spread out on a mesh pan at 50°C. The leaves were dried, ground into a fine powder using a dry blender (Binatone Blender with Grinder Model BLG-452, China), sieved, and then placed in glass jars.

2.2.3. Proximate analysis of the ingredients for formulation of the breakfast cereal

The proximate properties of the ingredients for the formulation of breakfast cereal were determined using standard methods [24, 25].

2.2.4. Experimental design and formulation of breakfast cereal

The constrained values of the mixture components and process parameters as shown in Table 1 were:

- malted finger millet flour (20–60%);
- malted roasted Bambara groundnut flour (10–40%);
- date fruit powder (5–20%);
- *Moringa oleifera* leaf powder (2–5%);
- turmeric powder (5–15%);
- salt (0.3%) and processing parameters;
- screw speed (70–150 rpm);
- barrel temperature (90–100°C).

Constrained D-optimal mixture-process experimental design with 100 experimental runs using Design Expert 13.0 software package was applied in the research as shown in Table 2.

Table 1

Design constraints for components and process parameters

Low Bound	Constraints	Title	Constraints	Upper bound
20	≤	*A*: Malted finger millet flour	≤	60
10	≤	*B*: Malted roasted Bambara groundnut flour	≤	40
5	≤	*C*: Date fruit powder	≤	20
2	≤	*D*: Moringa leaf powder	≤	5
5	≤	*E*: Turmeric powder	≤	15
–	–	*F*: Salt	=	0.3
–	–	$A+B+C+D+E+F$	=	100
70	–	*G*: Screw speed	–	150.00
90	–	*H*: Barrel temperature	–	130.00

Notes: *A* – malted finger millet flour, *B* – malted roasted Bambara groundnut flour, *C* – date fruit powder, *D* – moringa leaf powder, *E* – turmeric powder, *F* – salt, *G* – screw speed, and *H* – barrel temperature

Table 2

Experimental design matrix

Run	MFMP (%)	MRBGP (%)	DFP (%)	MLP (%)	TP (%)	Salt (%)	Screw Rate (rpm)	Barrel temperature (°C)
1	60.00	10.00	11.20	3.50	15.00	0.30	150	90
2	40.20	40.00	12.50	2.00	5.00	0.30	150	90
3	60.00	16.20	5.00	3.50	15.00	0.30	150	130
...	...	...	...	...	...	...	...	...
98	34.70	40.00	5.00	5.00	15.00	0.30	150	110
99	56.40	10.00	16.40	2.00	15.00	0.30	110	130
100	20.00	39.70	20.00	5.00	15.00	0.30	150	90

The formulated samples were extruded in Food Science and Technology Laboratory, Federal University of Agriculture Abeokuta (FUNAAB), Nigeria using a locally fabricated using a single-screw extruder with the extruder barrel length to diameter ratio (304:18.5), Screw diameter (18 mm), 1.74 kw power, barrel length (304 mm), die length (0.8 cm) and die diameter (6 mm). Water was added to the ingredients using the pre-hydration method, and 25% moisture was reached during initial processing. With the use of thermocouples to regulate the heat and adjustable heaters affixed to the barrel, the extruder barrel was let to warm up prior to processing. The extruder was manually fed, and the feed rate was changed so that the screw flights were consistently filled and feed buildup was prevented.

2.2.5. Proximate composition of formulated breakfast cereal

2.2.5.1. Moisture content

Quality indices which includes moisture content, crude protein, crude fat, crude fiber and ash content were evaluated using standard methods [24], while carbohydrate was determined by difference [25].

The moisture content was calculated using the established approach of [24]. First, clean crucibles were cooled in a desiccator (W_1) after being dried to a constant weight in a hot air oven at 100°C. A precisely weighed 2 g of finely ground sample was put into the crucibles (W_2) and dried at 100°C in an air oven until a consistent weight was reached (W_3). The moisture content was then determined using equation on a dry weight basis

$$\%\ \text{Moisture on a dry basis} = \frac{W_2 - W_3}{W_2 - W_1}\cdot 100, \quad (1)$$

where W_1 – weight of desiccator (g); W_2 – weight of sample (g); W_3 – weight of dried sample (g).

2.2.5.2. Protein determination

The micro-Kjeldahl method, as described by [24], was used to determine the crude protein concentration. In this process, 0.5 g $CuSO_4$ (as a catalyst), 0.1 g selenium, and 2 g Na_2SO_4 were added to the sample flask. Boiling the mixture until it turned translucent broke it down. Following that, 100 milliliters of distilled water were used to dilute the digest. Before titrating against 0.01 N HCl, 5 ml of this solution was taken, combined with boric acid, methyl blue, and methyl red, and heated.

Following digestion, the sample was placed in a 500 ml Kjeldahl flask with anti-bumping chips and washed with 250 ml of distilled water. Three drops of 1% phenolphthalein indicator were added after 70–120 ml of 40% NaOH was gradually added down the flask's side. A 500 ml conical flask with 125 ml of 4% boric acid and four drops of mixed indicator was used to catch the ammonia generated during the distillation process.

The flasks were placed on a Kjeldahl distillation device, and the process was carried out until a 125 ml distillate was obtained. The distillate was then titrated using 0.5 M H_2SO_4. The same procedures were used to prepare a blank without the sample.

Equation was used to compute the crude protein content

$$\%N = \frac{0.014 \cdot M \cdot V}{\text{Weight of test sample}} \cdot 100,$$

$$\%\ \text{Crude Protein} = \%\ \text{Nitrogen}\ (N), \quad (2)$$

where M – actual molarity of acid; V – volume of H_2SO_4 used.

2.2.5.3. Crude lipids

The Soxhlet extraction method, as outlined by [24], was used to determine the lipid content. The extraction flask was first weighed (W_1). Two grams of each sample, wrapped in filter paper, were added to the Soxhlet extraction thimble. After the thimble was inserted into the Soxhlet extractor and the appropriate volume of petroleum ether was added, the flask was attached to the apparatus. It was extracted at 40–60°C for six hours. Following extraction, the lipid remained in the flask while the petroleum ether was collected. The extract was chilled in a desiccator, dried at 100°C to eliminate any remaining solvent, and then weighed (W_2). The lipid content was calculated using equation

$$\%\ \text{Crude lipid content} = \frac{W_2 - W_1}{\text{weight of sample}} \cdot 100, \quad (3)$$

where W_1 – weight of extraction flask (g); W_2 – weight of dried extract (g).

2.2.5.4. Crude fiber

The technique according to [24] was used to calculate the crude fiber content. A 200 ml solution of 1.25% sulfuric acid was added to two grams of finely ground material, and the mixture was heated for thirty minutes. After filtering the mixture through linen or muslin cloth placed over a funnel, all of the acid was eliminated by washing it in boiling water. After that, the residue was added to 200 milliliters of boiling sodium hydroxide (NaOH) solution and heated for an additional half hour. After that, all alkali was removed by washing it with boiling water and a 1% hydrochloric acid (HCl) solution. The residue was drained, moved to a silica ash crucible, dried to constant weight in an air oven at 100°C, cooled in a desiccator, and then weighed (C_1).

After being dried, the sample (C_1) was burned for two hours at 550°C in a GallenKamp muffle furnace (Tactical 308), cooled in a desiccator, and then weighed again (C_2). Equation was used to get the crude fiber content

$$\%\ \text{Crude fibre} = \frac{C_1 - C_2}{\text{Weight of Original Sample}} \cdot 100, \quad (4)$$

where C_1 – weight of dried sample; C_2 – weight of burnt sample; C_1–C_2 provides the weight loss during combustion.

2.2.5.5. Ash content

A porcelain crucible was first dried for ten minutes at 100°C in a Harvard/LTE Vulcan laboratory oven, chilled in a desiccator, and then weighed using a Mettle PC 2000 balance (W_1). Two grams of finely powdered sample were added to the crucible, and the total weight (W_2) was recorded. The sample was ignited and then placed in a GallenKamp muffle furnace (Tactical 308, 0–1000°C) set at 550°C for five to sixteen hours until a consistent weight was reached. After cooling in a desiccator, the crucible containing the resultant ash was weighed (W_3). Equation was used to calculate percentage ash content [24]

$$\%\ \text{Ash Content} = \frac{W_3 - W_1}{W_2 - W_1} \cdot 100, \quad (5)$$

where W_1 – weight of dried crucible; W_2 – weight of sample (g); W_3 – weight of resultant ash (g).

2.2.5.6. Carbohydrate

The combined percentages of moisture, ash, crude fat, crude protein, and crude fiber were subtracted from 100 to determine the total carbohydrate content [25]

Carbohydrate = 100% – (% Moisture + % Ash + % Crude Lipid + + % Crude Protein + % Crude Fiber).

2.2.6. Statistical analysis and numerical optimization

Data generated for the quality indices were analyzed for statistical significance by developing models and model equations linking them with processing parameters and mixture components proportions using Design Expert 13.0 Software package. The selected models were fitted to the data using regression analysis and model parameters were estimated. The adequacy of the models was evaluated by model significance p-value less than 0.05 lack-of-fit (p-value greater than 0.05) (≥0.05), adequate precision ratio (>4) and coefficient of determination (R^2). These matrices helped to determine goodness of fit of the model, and their ability to predict the response variables (proximate compositions) under different conditions.

The ideal formulation conditions for the breakfast cereal were found via numerical optimization based on the desire function. To determine an overall desirability score between 0 and 1, each response variable was first transformed into an individual desirability function. These were then aggregated using the geometric mean. The best formulation conditions could be found using this method. Desirability indices (d_i) were calculated by assigning optimization targets to each parameter. The numerical optimization produced desirability-ranked solutions that displayed the precise ratios of components and process variable values that met the specified requirements and attained the maximum level of overall desire [26].

3. Results and Discussions

3.1. Preparation and proximate analysis of the formulation ingredients

The practical work and analysis regarding this research were carried out in Food Processing Laboratory of Agriculture and Bioresources Engineering Department (ABE) of FUT, Minna. The ingredients used for the formulation of the functional breakfast cereal were prepared by standard methods into flours and powders and the proximate properties are presented in Table 3.

Table 3

Proximate composition of the ingredients for breakfast cereal formulation

Sample	Moisture content	Crude fiber	Ash content	Crude lipid	Crude protein	Carbohydrate
Turmeric powder (TP)	4.433	7.833	6.400	10.333	6.833	64.167
Date fruit powder (DFP)	5.917	6.2	2.083	6.983	4.750	79.833
Moringa leaf powder (MLP)	4.417	4.417	8.200	10.400	12.493	60.073
Malted finger millet flour (MFMF)	4.200	2.683	2.350	7.067	7.867	75.833
Malted Bambara G/nut flour (MBGNF)	3.517	8.700	3.017	10.950	11.970	61.847
Malted roasted Bambara G/nut flour	3.100	3.950	2.933	8.167	14.057	67.793

The ingredients were prepaid into malted finger millet flour (MFMF), malted roasted Bambara groundnut flour (MRBGNF), date fruit powder (DFP), moringa leaf powder (MLP), and Turmeric powder (TP).

3.2. Formulation and extrusion of the breakfast cereal

The formulations of the breakfast cereals were done based on the design matrix as shown in Table 2. The formulated samples were extruded in Food Science and Technology Laboratory, FUNAAB, Nigeria. Samples of the formulated and extruded breakfast cereal are presented in Fig. 1.

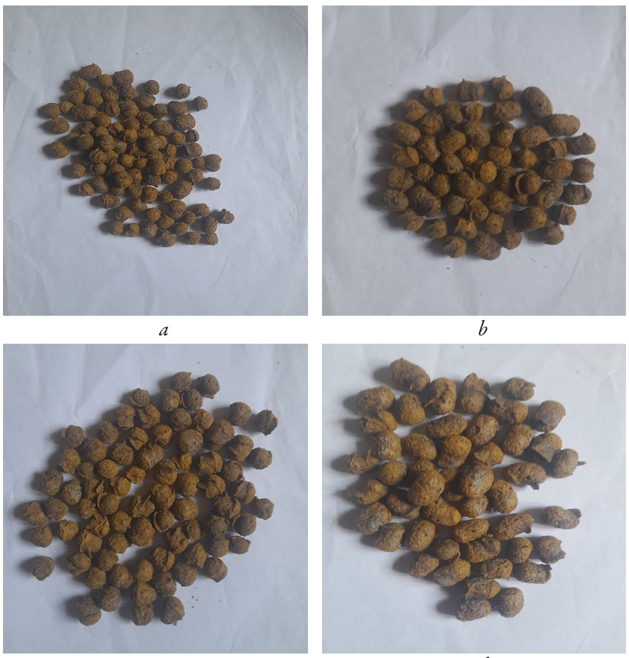

Fig. 1. Samples of the extruded breakfast cereals: *a* – plate 1; *b* – plate 2; *c* – plate 3; *d* – plate 4

Plates 1 to 4 are samples of the extruded breakfast cereal. They all came out well with good texture maintaining the shape of the die.

3.3. Determination of the proximate properties of the functional breakfast cereal

Proximate compositions of the extruded breakfast cereals are presented in Table 4.

Table 4

Experimental results of proximate properties of formulated breakfast cereals

Run	Y_{cp}, %	Y_{fat}, %	Y_{fiber}, %	Y_{mc}, %	Y_{ac}, %	Y_{cho}, %
1	11.9	9.2	1.75	7.75	3.9	65.5
2	11.97	18.15	2.05	7.95	3.65	56.23
3	10.5	0.42	2.8	8.55	3.4	74.33
...	...	...	...	...	...	...
98	4.97	7.73	1.6	5.85	4.1	75.75
99	4.3	9.23	2.9	4.5	3.45	75.62
100	10.33	8.43	0.65	11.8	3.7	65.08

Notes: Y_{cp} – crude protein; Y_{fat} – crude fat; Y_{fiber} – crude fiber; Y_{mc} – moisture content; Y_{ac} – ash content; Y_{cho} – carbohydrate. Summary of the proximate composition of the 100 run experiments were presented

3.4. Statistical analysis and optimization of functional breakfast cereal

Statistical analysis of the experimental data based on proximate composition was done as shown in the summary statistics in Table 5. Numerical optimization was employed using the constraints in Table 6, and applying desirability function to obtain the optimal breakfast cereal as shown in Table 7.

From Table 6, all the mixture components, processing parameters, and responses such as crude fat, crude fiber, ash content and carbohydrate were kept in range, while crude protein was targeted and moisture content was minimized.

The optimization solutions gave the formulation conditions with the Selected (Solution 1) as shown in Table 7.

Table 5

The summary statistics of the regression analysis of proximate properties of prepared breakfast cereal (indicating only significant terms)

Response	Sources	p-value	F-value	R^2	Adjusted R^2	Predicted R^2	$C.V$ (%)	Signal-to-noise ratio
Y_{cp}	Model	<0.0001	3.17	0.5039	0.3452	0.0716	33.11	7.1343
	L/Mixture	0.0104	3.55	–	–	–	–	–
	ABC	0.0200	5.65	–	–	–	–	–
Y_{fat}	Model	0.0205	3.05	0.1139	0.0766	0.0175	37.04	5.4169
	L/Mixture	0.0205	3.05	–	–	–	–	–
Y_{fiber}	Model	0.0243	2.27	0.1850	0.1035	0.0032	31.00	9.6324
Y_{mc}	G	0.0450	4.13	0.3576	0.0915	-0.3279	16.00	4.9321
	G^2	0.0052	8.20	–	–	–	–	–
	Model	0.1580	1.34	–	–	–	–	–
	L/Mixture	0.7317	0.5056	–	–	–	–	–
	BH^2	0.0024	9.91	–	–	–	–	–
	EG^2	0.0040	8.87	–	–	–	–	–
Y_{ac}	Model	0.0177	1.99	0.3214	0.1602	0.1558	7.02	8.2621
	L/Mixture	0.6377	0.6368	–	–	–	–	–
Y_{cho}	Model	0.0105	2.04	0.3945	0.2008	–0.0667	6.09	7.1935
	L/Mixture	0.0138	3.36	–	–	–	–	–

Notes: Y_{cp} – crude protein; Y_{fat} – crude fat; Y_{fiber} – crude fiber; Y_{mc} – moisture content; Y_{ac} – ash content; Y_{cho} – carbohydrate. The regression analysis for the proximate properties was summarized as shown

Table 6

Constraints for optimization of the formulated breakfast cereal

Title	Target	Lower bound	Upper bound	Maximum weight	Minimum weight	Significance
Malted finger millet flour	in range	20	60	1	1	3
Malted, roasted Bambara groundnut flour	in range	10	40	1	1	3
Date fruit powder	in range	5	20	1	1	3
Moringa leaf powder	in range	2	5	1	1	3
Turmeric powder	in range	5	15	1	1	3
Screw speed	in range	70	150	1	1	3
Barrel temperature	in range	90	130	1	1	3
Crude protein	target = 16.28	2.67	16.28	1	5	5
Crude fat	in range	0.42	18.15	1	1	3
Crude fiber	in range	0.5	4.2	1	1	3
Moisture content	minimize	4.5	11.8	1	1	3
Ash content	in range	2.6	4.6	1	1	3
Carbohydrate	in range	56.23	79.98	1	1	3

Table 7

Optimization solutions for formulated breakfast cereal

No.	A	B	C	D	E	F	G	H	Y_{cp}	Y_{fat}	Y_{fiber}	Y_{mc}	Y_{ac}	Y_{cho}	D_1	–
1	42.7	40.0	5.0	2.0	10.0	0.3	70.0	94.0	12.5	7.2	2.4	6.9	3.6	67.4	0.7	Selected
2	46.8	40.0	5.0	2.0	5.9	0.3	70.9	110.3	11.4	7.4	1.6	6.0	3.7	68.1	0.7	–
3	46.9	39.8	5.0	2.0	5.9	0.3	128.4	100.8	11.3	7.3	3.3	6.3	3.7	68.2	0.7	–
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
88	49.7	10.0	20.0	5.0	15.0	0.3	112.1	130.0	6.4	6.4	2.8	7.0	3.7	74.6	0.4	–
89	43.6	27.7	13.8	3.8	10.9	0.3	110.0	110.0	6.3	7.2	2.4	7.0	3.7	73.2	0.4	–
90	42.7	40.0	5.0	2.0	10.0	0.3	70.0	94.0	12.5	7.2	2.4	6.9	3.6	67.4	0.7	–

Notes: *A* – malted finger millet; *B* – malted roasted Bambara groundnut; *C* – date fruit; *D* – moringa leaf; *E* – turmeric; *F* – salt; *G* – screw speed; *H* – barrel temperature

3.5. Discussion

3.5.1. The preparation and proximate analysis of the formulation ingredients

The ingredients for the formulation of the functional breakfast cereal which includes finger millet, Bambara groundnut, date fruit, moringa leaf and turmeric were prepared by standard methods into malted finger millet flour (MFMF), malted roasted Bambara groundnut flour (MRBGNF), date fruit powder (DFP), moringa leaf powder (MLP) and turmeric powder (TP) and were stored under ambient condition in suitable containers till use. They were further analyzed for proximate properties using standard methods [24, 25] and gave results such as 7.867% protein, 75.83% carbohydrate, 7.067% crude lipid, 2.68% crude fiber, 2.36% ash and 4.2% moisture content for malted finger millet flour which are comparable to existing report [27].

3.5.2. Formulation and extrusion of the breakfast cereal

The formulation of the breakfast cereal was carried out using different combination of malted finger millet paste (MFMP), malted roasted Bambara groundnut paste (MRBGNP), date fruit powder (DFP), moringa leaf powder (MLP), turmeric powder (TP), salt (S), and water (W), which was used to prepare pre-extrusion feed mixtures. A statistical experimental design using constrained D-optimal mixture-process technique with Design Expert 13.0 software package was used to generate the Design Matrix for 100 experimental test runs as shown in Table 2. The extrusion was carried out using a single-screw extruder and gave good textured extrudate samples which were oven-dried, cooled and kept for further analysis.

3.5.3. Proximate analysis of the functional breakfast cereal

The dried extrudate samples were evaluated for proximate composition before optimization as shown in Table 4. The results (Mean values); 71.46% carbohydrate, 7.78% crude protein, 3.67% ash, 2.13% crude fiber, 7.76% moisture content and 7.09% crude fat) were comparable to existing report of breakfast cereal from blends of sorghum flour, Bambara groundnut flour and date fruit flour with 10.37% crude protein, 75% carbohydrate, 1.76% ash, 0.88% crude fiber, 9.2% moisture content, 2.12% crude fat [18]. However these values were improved on after optimization, especially moisture, protein and carbohydrate.

3.5.4. Statistical analysis and optimization of the breakfast cereal

The data generated from generated from the 100 runs experiment based on proximate composition was subjected to statistical analysis. ANOVA was used to determine the significance of factors and their interactions on the response variable (proximate properties), while the regression analysis was used to develop mathematical relationship between decision variables and the response variables. Design Expert 13.0 Software was used to provide the various models that described the relationships, such as linear, quadratic, cubic and special models. Regression analysis was used to fit the selected models to the data and model parameters. Adequacy of the models were evaluated by combination of diagnostic test indicators or threshold such as $R^2 \geq 0.50–0.7$, model significance (p-value ≤ 0.05), Lack-of-fit test ($p \geq 0.05$), Adequate precision (>4). This is mostly applicable for mixture-experiment where Scheffe-type models is applicable. From the summary statistics of the regression analysis of each of the proximate properties indicating significant terms, the following analogies were made.

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Crude protein model: the crude protein model and ingredient proportions (Linear Mixture) are significant with *p*-values less than 0.05, according to the results of the crude protein statistical analysis. With a *p*-value of 0.02, the interaction between the quantities of malted finger millet, date fruit, and turmeric (ACE) is significant. The sources of variations account for 50.39% of the changes in crude protein, according to the R^2 value of 0.5039. The adjusted R^2 of 0.3452 (difference larger than 0.2) and the predicted R^2 of 0.0716 do not match, indicating that the model may be overfitting the analyzed data and cannot be utilized to interpolate crude protein with reliability. A sufficient signal is indicated by the adequate precision ratio of 7.134. This implies that the design space can be navigated and morning cereal predictions can be made using the crude protein model.

Crude fat model: the results of analysis of crude fat content showed that the crude fat model is significant ($p \leq 0.05$) and crude fat of the formulated breakfast cereal is significantly influenced, at 5% level of significance, by the proportions of finger millet, Bambara groundnut, date fruit, moringa and turmeric, judging from the linear mixture *p*-value of 0.0205. The R^2 value of 0.1139 indicates that 11.39% of the variation in crude fat is explained by the sources of variations. The adjusted R^2 of 0.0766 and the Predicted R^2 of 0.0175 agree (difference less than 0.2). This implies that the model can be used for interpolation and is not unduly sensitive to the analyzed data. A sufficient signal is indicated by an adequate precision ratio of 5.417. For specified values of each component of the breakfast cereal, the model may be used to navigate the design space and forecast the crude fat content.

Crude fiber model: from the results of analysis of crude fiber, the crude fiber model and the ingredients proportions (linear mixture) are significant with p-values less than 0.05. Other significant terms are both the first and second order of screw speed (G and G^2). This implies that the screw speed at first and second order significantly influenced, at 5% levels of significance the crude fat of the breakfast cereal. The R^2 of 0.1850 implies that 18.50% of the variations in crude fiber are explained by the sources of variation. The predicted R^2 of 0.0032 is in agreement with the adjusted R^2 of 0.1035 (difference less than 0.2). This suggests the model can be employed for interpolation. Adequate precision ratio of 9.634 indicates an adequate signal. This means that the crude fiber model can be used to navigate the design space and make predictions about the crude fiber of the breakfast cereal.

Moisture content model: according to the results of the moisture content analysis, the moisture content model is not significant ($p \geq 0.05$), and the linear mixture p-value of 0.7317 indicates that the ingredient proportions do not significantly affect the moisture content of the prepared breakfast cereal at the 5% level of significance. Two interaction factors significantly influenced the moisture content of the breakfast cereal; proportion of malted roasted Bambara groundnut with second order barrel temperature and proportions of turmeric with second order screw speed (BH^2 and EG^2). According to the R^2 of 0.3576, the sources of variation account for 35.76% of the fluctuations in moisture content. The overall mean may be a more accurate predictor of the moisture content than the corrected fitted model, according to the negative predicted R^2 of –0.3279. A sufficient signal is indicated by an adequate precision ratio of 4.9231. This means that the moisture content model can be used to make predictions about the moisture content of the breakfast cereal.

Ash content model: the results of the statistical analysis of ash content revealed that the ash content model is significant with a *p*-value less than 0.05, but the proportions of the ingredients are not significant. This suggests that the proportions of malted finger millet, malted roasted Bambara groundnut, date fruit, moringa, and turmeric do not significantly affect the ash content of the prepared breakfast cereal at the 5% level of significance, based on the linear mixture p-value of 0.6377. Adequate precision ratio of 8.2621 indicates an adequate signal. This means the ash content model can be used to navigate the design space and make predictions for the ash content of the breakfast cereal for given levels of each factor. The negative predicted R^2 of – 0.1558 implies that the overall mean may be a better predictor of ash content than the current fitted model. The R^2 value of 0.3214 indicates that the model explains 32.14% of the variability in the ash content.

Carbohydrate model: with *p*-values of 0.0105 and 0.0138, respectively, the results of the carbohydrate content data demonstrated significance for both the ingredients proportion and the carbohydrate content model. The proportion of date fruit with turmeric and the proportion of malted finger millet, date fruit, and turmeric (CE and ACE) were two interaction factors that had a significant impact on the carbohydrate content of the prepared morning cereal. The negative predicted R^2 of –0.0667 implies that the overall mean may be a better predictor of carbohydrate than the current fitted model. Adequate precision ratio of 7.1935 indicates an adequate signal and the model can be used to navigate the design space and make predictions about the carbohydrate content for given levels of each factor. A ratio greater than 4 is required to use model for predictions.

Numerical optimization based on the proximate properties using Design Expert was employed using some set of constraints as presented in Table 6. 90 desirability solutions (component proportions and process parameters) found were presented summarily in Table 7. Applying the desirability function technique, the selected formulation (Solution 1) that produced the optimal breakfast cereal with highest desirability index of 0.7 was achieved with 42.71% malted finger millet, 40.0% malted roasted Bambara groundnut, 5% date fruit, 2% moringa powder, 10% turmeric, 0.3% salt with 70 rpm screw speed and 94°C barrel temperature.

During optimization process, goals or targets were set (Table 6). All the mixture components, processing parameters, and responses such as crude fat, crude fiber, ash content and carbohydrate were kept in range, while crude protein targeted 16.28 and moisture content was minimized. The mathematical expression for these two goals are diametrically opposing one another. It can be seen that one goal is lifting the system up, while the other goal is drawing the system down. So, in a multi-response research where different types and natures of goals are set; the desirability index value obtained becomes a compromised value. Setting a maximization target for some responses and a minimization target for some others will mathematically yield a compromised value. The goal of numerical optimization is to establish a condition, known as optimal condition, in terms of proportions (or percentages) of the ingredients and values of the process parameters; that will satisfy all the set targets and achieve an optimized product with the best quality characteristics. If the desirability index obtained is low (maybe less than 0.5 or 50%), it only suggests that the goals are too strict or mutually exclusive. The more the goals are relaxed (maybe targeting protein content of 115% instead of 16.28%), the better the desirability index approaches 1. In multi-response optimization research; lots of function mapping and enveloping are involved. Desirability index is simply a mathematical method of finding the optimum set of conditions [28].

3.5.5. Practical deliverables

Based on the set optimization goals, the optimization solution 1 (with the comment "Selected") expresses the optimal formulation conditions:

- *A* (malted finger millet flour) = 42.7%;
- *B* (malted, roasted Bambara groundnut flour) = 40%;
- *C* (date fruit) = 5%;
- *D* (moringa leaf) = 2%;
- *E* (turmeric) = 10%;
- *F* (salt) = 0.3%;
- *G* (screw speed) = 70 rpm;
- *H* (barrel temperature) = 94°.

If all the conditions are adhered to, the following quality properties of the breakfast cereals are expected: crude protein = 12.5%; crude fat = 7.2%; crude fiber = 2.4%; moisture content = 6.9%; ash content = 3.6%; and carbohydrate = 67.4%. The overall desirability index, d_i = 0.7 indicates that all the goals that were set during the optimization process were 70% achieved.

3.5.6. Research limitations

This research is a data-based (empirical) study, and in any such type of study employing numerical optimization, via desirability function, optimization can be done to target different categories of end users of a product (consumers, in this case). The experimental data becomes a data-base to which recourse can always be made to carry out optimization settings. All that is needed in satisfying different categories of consumers are the dietary requirements, in terms of the proximate properties studied. For future research, the scope of the responses considered can be broadened.

3.5.7. Prospect for further research

Further researches can be carried out on the effect of more process variables in the formulation and optimization of the breakfast cereal and the health attributes such as antioxidants, phytochemicals, anti-inflammatory, antibacterial properties of the breakfast cereal can be evaluated and optimized.

4. Conclusions

1. The ingredients for the formulation of the functional breakfast cereal were first prepared into powders and flours after which they were analyzed for proximate compositions and gave these results; malted finger millet (71.46% carbohydrate, 7.78% crude protein, 3.67% ash, 2.13% crude fiber, 7.76% moisture content and 7.09% crude fat), malted roasted Bambara groundnut (61.79% carbohydrate, 14.05% crude protein, 8.16% crude lipid, 2.93% ash content, 3.95%, 3.1% moisture content), date fruit powder (79.83% carbohydrate, 4.75% crude protein, 6.98% crude lipid, 2.08% ash content, 6.20% crude fiber and 5.91% moisture content), turmeric powder (64.16% carbohydrate, 6.83% crude protein, 10.33% crude lipid, 6.40% ash content, 7.83% crude fiber and 4.43% moisture content), moringa leaf powder (60.07% carbohydrate, 12.49% crude protein, 10.40% crude protein, 8.20% ash content, 4.41% crude fiber, 4.40% for moisture content).

2. The functional breakfast cereals was formulated with constrained D-optimal mixture-process experimental design, using Design Expert 13.0 software package as shown in Table 2, and processed through extrusion and the extrudates came out well with good texture, maintaining the shape of the die.

3. The breakfast cereals were evaluated for proximate properties and the mean values were given as 71.46% carbohydrate, 7.78% crude protein, 3.67% ash, 2.13% crude fiber, 7.76% moisture content and 7.09% crude fat.

4. Data generated for the quality indices were analyzed for statistical significance using the Design Expert software. Optimization of the breakfast cereal, based on the proximate properties was carried out applying numerical optimization, via desirability function technique, which yielded an overall desirability index of 0.7. From the selected Solution 1, optimal formulation conditions were established: 42.7% malted finger millet, 40.0% malted roasted Bambara groundnut, 5% date fruit, 2% moringa leaf powder, 10% of turmeric powder, 0.3% salt, 110°C barrel temperature and 110 rpm screw speed. This will serve as a data base for future production in food processing industries. The improved quality properties of the optimal breakfast cereal were: 12.5% protein, 67.4% carbohydrate, 6.9% moisture content, 3.6% ash content, 2.4 crude fiber and 7.2% crude fat.

Conflicts of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Authors' contributions

Princess Adgidzi: Resources, Investigation, Writing – original draft, Writing – review and editing, Funding acquisition; ***Samuel Olorunsogo***: Formal analysis, Data curation, Writing – review and editing; ***Segun Adebayo***: Supervision, Project administration, Writing – review and editing; ***Ocheme Ocheme***: Resources, Supervision, Project administration.

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