Formulation and Optimisation of aFunctional Breakfast Cereal from Selected Locally Available Ingredients

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Abstract:
In this study, a functional breakfast cereal was formulated, extruded and optimised to improve on the nutritional qualities employing mixture design and response surface approach, using combinations of malted finger millet, malted roasted Bambara groundnut, date fruit, *moringa oleifera* leaf, and turmeric. the design matrix for the formulation was created using a constrained d-optimal mixture-process experimental design with five mixture components: malted finger millet (20%–60%), malted roasted bambara groundnut (10%–40%), date palm fruit powder (5%–20%), moringa leaf powder (2%–5%), turmeric powder (5%–15%), salt (0.3%), and two processing factors: screw speed (70–150 rpm) and barrel temperature (90–100^{o}c). desirability function approach of numerical optimisation was applied to attain the ideal conditions for the functional breakfast cereal's formulation, with a single attractiveness index of 0.5, which was obtained with optimised mixture components and process parameter levels of 40.0% malted roasted bambara groundnut, 42.7% malted finger millet, 5% powdered date fruit, 2% powdered moringa leaf, 10% powdered turmeric, and 0.3% salt (maintained constant), using 110^{o}c barrel temperature and 110rpm screw speed. results obtained revealed that the best formulation gave a breakfast cereal with the following quality properties; 75.58% carbohydrate, 5.79% protein, 7.43% moisture content, 7.28% crude fat, 3.40% ash content, 0.51% crude fibre, 391.03 k/cal gross energy, 0.16 mg/100g vitamin e, 2.48 mg/100g vitamin b, 1.83 mg/100g vitamin a, 0.69 µg/100g vitamin d, 9.8 x 10^3 (cfu/g) bacteria count, 4.6 x 10^3 (cfu/g) fungi count, 151.32% swelling power, 0.57 g/cm^3 bulk density, 18.2% oil absorption capacity, 0.68 water activity 12.0% water absorption capacity, 82.4^{o}c gelation temperature, 56.0 water solubility index, 170 (mg/kg) calcium 51 (mg/kg) sodium, 167.76 (mg/kg) potassium, 11.77 (mg/kg) iron, 116.60 (mg/kg) magnesium 1.13 (mg/l) zinc, 3.71 (mg/l) phosphorus, 17.9 (n) hardness, 122.7 (n) chewiness 1.89 expansion ratio, texture (6.1), taste (4.9), mouthfeel (4.8), colour (4.2), flavour (5.5) and overall acceptability (4.9).

Keywords: Breakfast cereal, process parameters,desirability,mixture-process, component proportions, quality properties.

1.0 Introduction

breakfast cereals are grain food made for human intake that are typically eaten for breakfast together with milk, sugar, or fruit, either cooked or not (1,2). They are made using a number of processes, including as cooking, shaping, drying, and adding additional components like yeast, colourants, flavourants, sugar alternatives, micronutrients, and stabilizers (1). Cereal grains such as wheat, oats, corn, rice, and others are commonly used to make breakfast cereals, which are mono-grain goods. recently, attention has been drawn by some evaluations that majority of existing breakfast foods are high in rapidly digestible starch, high glycaemic indices, and some with low dietary fibre and artificial sweeteners or increased added sugars which contribute to harmful metabolic consequences such as type 2 diabetes, overweight, and heart diseases. (3). thus, the need for consumption of functional food to curb diet-related sicknesses ravaging the world. There is also a need to replace the flavouring agents, sweeteners, artificial colours and synthetic minerals that come with breakfast cereals with natural flavours, sweeteners and colours which are inherent in our indigenous ingredients (1). Even the biggest and most prosperous businesses in the world hardly ever use experimental methodology and computational optimization method as effective instruments for creating new food products with particular functional ingredients, changing food compositions, and improving overall quality and safety (4, 5).

When turned into morning cereals, locally accessible agricultural products including finger millet, Bambara groundnut, moringa leaf, turmeric, and date fruit can provide energy, protein, dietary fiber, and minerals. compared to other traditional grains, finger millet offers several untapped health-promoting properties. The grains are high in bioactive components, have a low glycaemic index, and are easily digestible (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 aminoalkanoic acid than other legumes (7). phytochemicals as flavonoids and anti-nutritional factors (anfs) are abundant in bambara groundnuts (8). *moringa oleifera* leaf is an easily accessible green vegetable that can be utilized to fortify several food products or meals to address micronutrient deficiencies (9). *moringa oleifera* plant, particularly its leaves are abundant in minerals including iron, potassium, calcium, phosphorous, and vital amino acids. the leaves of moringa is known to have antimicrobial, antioxidant, antiulcer, anti-inflammatory, antispasmodic, hypotensive and antitumor agent potential (10). date fruit is an excellent source of dietary potassium and a variety of other vital minerals (11). you can use dates as sugar alternatives and high in antioxidants and bioactive substances. it is an excellent root of fibre and energy (12). turmeric is a natural food colourant and a preservative (13).turmeric is rich in bioactive compound curcumin, which is also responsible for its therapeutic properties such as anti-inflammatory, antibacterial and antioxidants action against free radicals and microbes that cause illnesses including aging (14,15).

Globally, food items that can improve human nutrition and health in new ways are gaining popularity. Mixture-Design and response surface methodology experimental design strategy was employed in this study to create and refine a functional morning cereal using ingredients that are readily available indigenously with improved nutritional, micronutrients, functional, physicochemical and sensory properties. There is insufficient information on the systematic formulation and optimisation of extruded locally sourced health-oriented morning cereal from indigenous nigerian raw materials like date, bambara groundnut, finger millet, turmeric, and moringa leaf using mixture-design to optimise nutritional, functional and sensory properties, though some studies may have reported the development of composite and functional breakfast cereals from legumes and cereals.

2.0.Materials and Methods

2.1.Experimental Materials

2.2.1 Raw Material Sourcing

date palm fruit, bambara groundnut, finger millet, turmeric, fresh moringa leaves and turmeric were acquired from the kure modern market, minna, niger state. cultivar/variety and degree of maturity were determined based on agronomic procedures and practices in nigeria. the cream and white cultivar and early-maturing variety of bambara groundnut was used. local red-seeded land race of finger millet was used. the local dried date (dabino) dark brown, elongated and wrinkled harvested

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at fully ripe dry stage (tamr stage) 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. locally adapted types, mature rhizome turmeric with bright yellow-orange interior obtained at maturity stage with brown skin was used in this research. all the samples were taken to processing laboratory of food science and technology department, fut, minna, nigeria where they were prepared.

2.1.1Sample Preparation

Using the procedure outlined by (16), finger millet was malted and turned into flour (mfmf). In order to promote sprouting, the finger millet after being cleaned and washed were spread out on jute sacks. After 48 hours, it was dried in a hot air oven (model dgh elecrothermal oven). The method described by (17) was used to prepare Bambara groundnut flour that has been malted and roasted (mrbgnf). Bambara groundnuts were scrubbed, properly cleansed with tap water, and immersed in warm water (40–50°c) for eight hours. To encourage sprouting, the seeds were placed on jute bags and covered with a damp jute bag for 48 hours. The germinated seeds were evenly distributed on oven trays and dried for ten hours at 65°c in an air oven. The vegetable portions of the dried bgn seeds were then manually removed and winnowed. After being cleaned, the malted bgn was equally distributed on trays, roasted for 40 minutes at 130 degrees celsius in an air oven, and then chilled. After cooling, the roasted seeds were ground into a fine flour and passed through a 0.4 mm mesh screen. The method described by (18) was used to prepare date powder (dfp). dry date palm fruits were cleaned, de-pitted and sliced into bits. after being oven-dried for six to eight hours at 75 degrees celsius, the dry dates samples were mashed, ground in a dry kitchen grinder (binatone blender with grinder model-452), and sieved. The method of (19) was used to make moringa oleifera leaf powder (mlp). The leaves were removed from the petiole, washed and dried in an air oven at 50°c and scattered on a mesh. After being ground up with a dry blender and sieved, the dried leaves were put into glass jars. Turmeric powder (tp) was made using the procedure outlined in (20). After being washed and sliced, the rhizomes were dried at 75°c in an air oven. After being ground, the dry rhizomes were packed in plastic bowls after being sieved. High density polythene bags (hdpe) were used to store malted roasted Bambara groundnut flour (mrbgnf) and malted finger millet (mfmf), while turmeric powder (tp) and date fruit powder (dfp) were kept in air tight plastic containers. All the samples were kept under environmental circumstances before usage.

2.2.Methodology

2.2.1.Tools and Equipment: hammer crusher were utilized as tools and apparatus (500kg/h, 4.5hp) with 0,75mm 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 6mm die diameter, model dgh electro thermal oven, digital vernier caliper (±0.02mm), ph-600 digital ph meter, binatone blender with grinder model blg-452, centrifuge model e-pendorf 5810r, 100-500ml graduated glass vessel, and mettle pc2000 weighing machine, aqualab 4te water activity meter, m500-100 at testometric texture analyser, gallenkamp kjeldahl apparatus and soxhlet apparatus.

2.2.2 Design of Experiments

the formulation was carried out with limited amounts of the mixture's ingredients; malted finger millet flour (20%-60%), date fruit powder (5%–20%), moringa oleifera leaf powder (2%–5%), turmeric powder (5%–15%), and malted roasted bambara groundnut flour (10%–40%), salt (0.3%) and processing parameters; screw speed (70-150rpm) and barrel temperature (90-100^{o}c) employing the limited d-optimal mixture-process experimental design method which generated the design matrix for 100 experimental test runs. the design constraints and design matrix are presented in tables 1 and 2 respectively. data collected were analysed and model equations using the design expert 13.0 software package, establishing a relationship between the quality indices and the proportions of mixture components and processing parameters was created. numerical optimization was used to determine the ideal manufacturing circumstances based on predetermined optimization targets and individual quality desirability indices through desirability function technique.

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Table 1: Design Restrictions for Components and Process Parameters

Low Bound		Restrictions		Upper bound
20	≤	χ_1 (A): Malted Finger Millet Flour	≤	60
10	≤	χ_2 (B): Malted, Baked Bambara Groundnut Flour	≤	40
5	≤	χ_3 (C): Date Palm Fruit Powder	≤	20
2	≤	χ_4 (D): *Moringa oleifera* Leaf Powder	≤	5
5	≤	χ_5 (E): Turmeric Powder	≤	15
		c_1(F): Salt	=	0.3
		A+B+C+D+E+F	=	100
70		Z_1 (G): Screw Rate		150
90		Z_2 (H): Barrel Temperature		130

χ_1 = Malted Finger Millet Paste, χ_2 = Malted Baked Bambara Groundnut Paste
χ_3 = Date Palm Fruit, χ_4 = Moringa oleifera Leaf, χ_5 = Turmeric, c_1 = Salt, Z_1 = Screw Rate,
Z_2 = Barrel Temprature

Table 2: Experimental Design Matrix

Run	MFMP (%)	MRBGP (%)	DFP (%)	MLP (%)	TP (%)	Salt (%)	Screw Rate (rpm)	Barrel Heat (^{o}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
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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

After formulation, the extrusion was conducted employing a single-screw extruder with L/D (length-to-diameter) ratio of 304:18.5, thread diameter of 18 millimeter, power of 1.74 kW, barrel length of 304 millimeter, length of die 0.8 cm and die diameter (6mm). Pre-hydration method was used to add water to the ingredients, and 25% moisture was arrived at during preliminary processing. Making 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. Crude protein, crude fat, moisture, crude fiber and ash are examples of quality indexes evaluated with standard methods (21), while carbohydrate was determined by difference (22). Data generated for the quality indices were analysed for statistical significance by developing models and model equations linking them with processing parameters and mixture components proportions utilizing the design software. Regression analysis was used to fit the chosen models to the data, and model parameters were calculated. R^2, model significance (p-value ≤ 0.05), lack-of-fit (p-value ≥ 0.05), adequate precision ratio (> 4),

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and numerous other metrics were used to assess the models' sufficiency. These matrices aided in determining the model's goodness of fit and its capacity to forecast the response variables in various scenarios.

2.2.3 Numerical Optimisation

Numerical optimisation method was used to create the ideal formulation requirements for the cereal for morning using desirability function strategy. The optimization strategy is to obtain an improved characteristics of the prepared breakfast cereal applying empirical models from the experimental data. This was achieved by setting optimization goals for the decision variables and the responses to ensure that the nutritional qualities are improved on. The desirability function approach transforms respective dependent variable into a distinct desirability function by assigning a value between zero to one for each response variable, where zero is undesirable and one is target value. The optimisation goals ranges from maximising, minimising, keeping in range and targeting the process factors and component proportions. The individual desirability function is further combined into an overall desirability function using a geometric mean, and maximised into a desirability index/solution (di). The optimisation constraints schedule set for the first optimisation are presented in Table 3.

Table 3: Limitations for the screen Optimisation of the developed breakfast cereal

Title	Target	Lower Bound	Upper Bound	Minimum Weight	Maximum Weight		Significance
Malted Finger Millet Flour	Keep in range	20.00	60.00	1	1		3.0
Malted, Roasted Bambara Groundnut Flour	Keep in range	10.00	40.00	1	1		3.0
Date Palm Fruit	Keep in range	5.00	20.00	1	1		3.0
Moringa oleifera Leaf	Keep in range	2.00	5.00	1	1		3.0
Turmeric	Keep in range	5.00	15.00	1	1		3.0
Screw Rate	Keep in range	70.00	150.0	1	1		3.0
Barrel Heat	Keep in range	90.00	130.0	1	1		3.0
Total Protein	target = 16.28	2.67	16.28	1	5		5.0
Total Fat	Keep in range	0.42	18.15	1	1		3.0
Total Fibre	Keep in range	0.5	4.20	1	1		3.0
Moisture	Keep to minimum	4.5	11.80	1	1		3.0
Ash	Keep in range	2.6	4.60	1	1		3.0
Carbohydrate	Keep in range	56.23	79.98	1	1		3.0

To further create the best possible formulation to produce the highest-quality morning cereal, the formulation conditions from the first (best) five optimisation solutions
(Screen optimisation) were used to formulate and extrude fresh samples of the developed breakfast cereal. Extrudates obtained got characterised revealing proximate composition using standard method of (21), while carbohydrate was computed by difference (22).
Functional properties: Functional properties such as profile expansion index were determined as described by (23), bulk density as described by (24), water absorption capacity, water solubility index and swelling power as described by (25).
Texture analysis: The M500-100AT Testometric plus Texture Analyzer (Stable Micro Systems Ltd., Surry GU7 IJG, England) was used for the textural analysis according to (26).
Physicochemical analysis: The extrudates' physicochemical characteristics evaluated were; oxidation value as described by (27), pH as described by (16), free fatty acid as described by (28), water activity as described by (29),
Microbiological analysis: The technique outlined by (30) was used to calculate total plate counts. For every sample, five test tubes were filled with approximately 9 milliliters of diluents (distilled water). A 250 ml conical flask was filled with a known amount of

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nutritional agar. The nutritional agar was chilled to 45°C before being poured onto petri dishes after the contents of the 250ml conical flask were swirled and autoclaved for 15 minutes at 121°C. After measuring and adding about 1 milliliter of the extrudate sample to the first tube, a serial dilution was created. Following the dilution, 1 milliliter was measured and added to the appropriate petri dishes. The agar was then allowed to harden. The incubation period was 18–24 hours at 37°C. A computerized colony counter was used to count the amount of colonies (cfu/g).

The method outlined by (30) was used to count the mould. A 250 ml conical flask was filled with a known amount of potato dextrose agar. After gently swirling the contents of the 250 ml conical flask, it was autoclaved for 15 minutes at 121 degrees Celsius to sterilize it. Before adding the potato dextrose agar to the petri dishes, it was allowed to cool to 45°C. In order to prevent the growth of microorganisms other than molds, 10% tartaric acid was added to the agar during the cooling phase.

Sensory evaluation: The formulated breakfast cereals were evaluated for sensory properties of taste, colour, flavour, texture, mouthfeel including general acceptability on a 9-point hedonic scale (strongly dislike, strongly like) as described by (31). 50 untrained panelists were presented with the same samples and assigned scores on a hedonic scale of nine points. In order to prevent the panelists from transferring their knowledge from one sample to the next, they were given water to rinse their mouths in between.

Design Expert 13.0 software was then used to statistically analyze the results. Table 4 displays the optimisation constraints used in the second optimisation.

Table 4: Limitations for the Second Optimisation of the Developed Breakfast Cereal

Title		Target	Lower Bound	Upper Bound	Minimum Weight	Maximum Weight	Significance
Malted Finger Millet Flour		is in range	37.7	46.9	1	1	3
Malted, Baked Bambara Groundnut Flour		is in range	25	40	1	1	3
Date Palm Fruit Powder		is in range	5	20	1	1	3
Turmeric Powder		is in range	5.9	15	1	1	3
Screw Rate		is in range	70	150	1	1	3
Barrel Heat		is in range	94	126	1	1	3
Total Protein		target = 6.75	4.56	6.75	1	10	5
Carbohydrate		is in range	72.9	77.04	1	1	3
Moisture Content		is in range	4.55	9.5	1	1	3
Ash		maximize	2.9	3.75	1	1	3
Total fibre		is in range	0.2	1.12	1	1	3
Total Fat		minimize	6.2	9.84	1	1	3
Total energy		Target of action = 414.6	379.9	414.6	1	10	5
Retinol		Increase	1.61	2.02	1	1	3
Vitamin B complex		Increase	2.03	2.96	1	1	3
Vitamin D		Increase	0.55	0.82	1	1	3
Vitamin E		Increase	0.10	0.250	1	1	3
Free Fatty Acids		minimize	1.75	1.965	1	1	3
Power of Hydrogen		minimize	6.8	8.03	1	1	3
Peroxide value		minimize	1.57	1.97	1	1	3
Water activity		minimize	0.65	0.7	1	1	3

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Apparent density	minimize	0.45	0.722	1	1	3
Oil Retention Capacity	Increase	16	21	1	1	3
Water Retention capacity	Increase	6	16	1	1	3
Water Solubility index	maximize	48	66	1	1	3
Swelling Power	maximize	148	157	1	1	5
Solidification Temperature	is in range	78	88	1	1	3
Sodium(Na)	is in range	43.22	60.56	1	1	3
Potassium(K)	is in range	144.56	204.71	1	1	3
Calcium(C)	maximize	146.45	192.3	1	1	3
Magnesium(Mn)	maximize	88.75	133.62	1	1	3
Iron(Fe)	maximize	9.58	12.98	1	1	3
Zinc(Zn)	maximize	0.9085	1.3625	1	1	3
Phosphorus(P)	is in range	3.1935	4.8685	1	1	3
Bacteria load	minimize	2	21	1	1	5
Mould	minimize	1	9	1	1	5
Toughness	is in range	65.523	218.5	1	1	3
Chewiness	is in range	6.697	45.36	1	1	3
Expansion rate	maximize	1.3906	2.1166	1	1	3
Taste	maximize	4.64	5.3	1	1	3
Colour	is in range	3.92	4.8	1	1	3
Savour	maximize	5.36	5.7	1	1	3
Texture	maximize	5.82	6.46	1	1	3
Mouth feel	is in range	4.16	4.96	1	1	3
General acceptability	maximize	4.82	5.22	1	1	3

3.0Results,Discussionsand Recommendation

3.1Experimental Results of the Developed Breakfast Cereal's Proximate Composition

Table 5 displays the average values of the proximate qualities of the prepared morning cereal.

Table 5: Result of Proximate Composition for the Developed Functional Morning Cereal.

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Run	y_{cp}	y_{fat}	y_{fibre}	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
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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

$y_{cp} = Crude\ Protein$, $y_{fat} = Crude\ Fat$, $y_{fibre} = Crude\ Fibre$,
$y_{mc} = Moisture\ Content$, $y_{ac} = Ash\ Content$, $y_{cho} = Carbohydrate$

3.2 Statistical Analysis of the Experimental Results: Table 6 displays the summary of the regression analysis showing only terms that are significant of the proximate characteristics of the prepared morning cereal.

Table 6: The Regression Analysis's Summary Statistics of the Developed Breakfast Cereal Proximate Properties (indicating only significant terms)

Response	**Origin**	**p-value**	**F-value**	**R^2**	**Adjusted R^2**	**Predicted R^2**	**C.V. (%)**	**Signal-to-noise Ratio**
γ_{cp}	Model L/Mixture $\chi_1\chi_3\chi_5$	<0.0001 0.0104 0.0200	3.17 3.55 5.65	0.5039	0.3452	0.0716	33.11	7.1343
γ_{fat}	Model L/Mixture	0.0205 0.0205	3.05 3.05	0.1139	0.0766	0.0175	37.04	5.4169
γ_{fibre} γ_{mc}	Model χ_7 χ_7^2 Model L/Mixture $\chi_2\chi_8^2$ $\chi_5\chi_7^2$	0.0243 0.0450 0.0052 0.1580 0.7317 0.0024 0.0040	2.27 4.13 8.20 1.34 0.5056 9.91 8.87	0.1850 0.3576	0.1035 0.0915	0.0032 -0.3279	31.00 16.00	9.6324 4.9321
γ_{ac}	Model L/Mixture	0.0177 0.6377	1.99 0.6368	0.3214	0.1602	-0.1558	7.02	8.2621
γ_{cho}	Model L/Mixture	0.0105 0.0138	2.04 3.36	0.3945	0.2008	-0.0667	6.09	7.1935

γ_{CP}= Total protein, γ_{fat}= Total fat, γ_{fibre}= Total fibre, γ_{mc}= Moisture, γ_{ac}= Ash, γ_{cho}= Carbohydrate

Crude protein model: The results of statistical analysis of crude protein showed that crude protein model and ingredient proportions (Linear Mixture) are significant (p ≤ 0.05). The interactive effect of malted finger millet, date fruit and turmeric proportions ($\chi_1\chi_3\chi_5$) has a p-value of 0.02, making it significant. The causes of variations account for 50.39% of the changes in the crude protein, according to the R^2 value of 0.5039. The Adjusted R^2 of 0.3452 (difference more than 0.2) and the Predicted R^2 of 0.0716 do not

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match, indicating that the model may be overfitting the analyzed data and cannot be utilized to interpolate crude protein consistently. A sufficient signal is indicated by the signal-to-noise ratio of 7.134. This implies that the breakfast cereal can be predicted and the design space can be navigated using the crude protein model.

Total fat model: Results of analysis of crude fat content showed that the crude fat model is significant and crude fat with Linear Mixture p-value of 0.0205, implies the amounts of ingredients has a significant impact on the prepared breakfast cereal at the 5% level of significance. The causes of variation account for 11.39% of the variation in crude fat, according to the R^2 value of 0.1139. The Adjusted R^2 of 0.0766 and the Predicted R^2 of 0.0175 agree (difference less than 0.2). This suggests that the model is not overly sensitive to the analysed data and can be employed for interpolation. Adequate Precision ratio of 5.417 indicates an adequate signal. The model can be used to navigate the design space and be used to make predictions about the crude fat content for given levels of each factor of the breakfast cereal.

Total fibre model: From the results of analysis of crude fibre, with p-values less than 0.05, the crude fibre model and the proportions of the ingredients (linear mixture) are significant. The first and second order of screw speed (x_7 and x_7^2) are additional important parameters. This implies that the screw speed at first and second order substantially affected the breakfast cereal's crude fat at 5% significance levels. The sources of variation account for 18.50% of the differences in crude fiber, according to the R^2 of 0.1850. The Adjusted R^2 of 0.1035 and the Predicted R^2 of 0.0032 agree (difference less than 0.2). This implies that the model can be used for interpolation. A sufficient signal is indicated by an appropriate precision ratio of 9.634. This implies that the crude fiber model can be used to forecast the breakfast cereal's crude fiber content and navigate the design space.

Moisture content model: The results of analysis of moisture content showed that moisture content model is not significant with p-value above 0.05, and the moisture content of the developed morning cereal fails to significantly influence at 5% level of significance by the ingredient proportions considering the linear mixture p-value of 0.7317. The proportion of malted roasted Bambara groundnut with second order barrel temperature and the proportions of turmeric with second order screw speed ($x_2x_8^2$ and $x_5x_7^2$) were two interaction factors that had a substantial impact on the moisture content of the breakfast cereal. 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 signal-to-noise ratio of 4.9231. This implies that the moisture content of the breakfast cereal may be predicted using the moisture content model.

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 all the ingredients 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. A sufficient signal is indicated by a precision ratio of 8.2621. This implies that for certain values of each factor, the ash content model may be used to navigate the design space and estimate the breakfast cereal's ash content. The overall mean may be a more accurate predictor of ash content than the current fitted model, according to the negative Predicted R^2 of -0.1558. The model accounts for 32.14% of the variation in the ash content, according to the R^2 value of 0.3214.

Carbohydrate model: Carbohydrate content data results showed that the proportion of ingredients and the carbohydrate content model both have significant p-values of 0.0138 and 0.0105, respectively. The proportion of date fruit with turmeric and the proportion of malted finger millet, date fruit, and turmeric temperature (x_3x_5 and $x_1x_3x_5$) were two interaction factors that had a significant impact on the carbohydrate content of the prepared

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morning cereal. The overall mean may be a more accurate predictor of carbohydrates than the current fitted model, according to the negative Predicted R^2 of -0.0667. The model may be used to navigate the design space and forecast the carbohydrate content for specific quantities of each factor, and a sufficient precision ratio of 7.1935 indicates an adequate signal. To utilize the model for predictions, the ratio must be greater than 4.

3.3 Results of Optimizing the Developed Breakfast Cereal Numerically

Table 7 displays the 90 desirable solutions (component proportions and process factors) that were obtained from the first optimisation.

Table 7: Optimization Strategies for the Initial Optimisation of the Developed Breakfast Cereal

No	x_1	x_2	x_3	x_4	x_5	c_1	z_1	z_2	y_{cp}	y_{fat}	y_{fibre}	y_{mc}	y_{ac}	y_{cho}	D	
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	
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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	

χ_1 = *Malted Finger Millet*, $\chi_2 = Malted\ Baked\ Bambara\ Groundnut$, $\chi_3 = Date\ Palm\ Fruit$, $\chi_4 = Moringa\ oleifera\ Leaf$, $\chi_5 = Turmeric$, $C_1 = Salt$, $Z_1 = Screw\ Rate$, $Z_2 = Barrel\ Heat$

The results of second optimisation gave 84 desirability solutions which in Table 8 displays the ideal formulation conditions for the best-formulated morning cereal. Using the desirability function technique, the formulation (Solution 1) that yielded the best breakfast cereal with the highest desirability index of 0.5 was made with 42.71% malted finger millet, 40.0% malted roasted Bambara groundnut, 5% date fruit, 2% moringa powder, 10% turmeric, and 0.3% salt at a barrel temperature of 110 rpm and a screw speed of 110°C. Sensory scores and quality attributes of the best breakfast cereal as derived from the software are 7.28% crude fat, 7.43% moisture content, 75.58% carbohydrate, 5.79% protein, 3.40% ash content, 0.51% crude fibre, 391.039 k/cal gross energy, 2.48 mg/100g vitamin B, 1.83 mg/100g vitamin A, 0.69 µg/100g vitamin D, 0.16 mg/100g vitamin E, 9.8×10^3 (cfu/g) bacteria count, 4.6×10^3 (cfu/g) fungi count, 0.570 g/cm^3 bulk density, 82.4°C gelation temperature, 12.0% water absorption capacity, 151.32% swelling capacity 18.2% oil absorption capacity, 56.0 water solubility index, 82.4°C, 51 (mg/kg) sodium, 116.60 (mg/kg) magnesium, 167.7 (mg/kg) potassium, 170 (mg/kg) calcium, 3.71 (mg/l) phosphorus, 11.77 (mg/kg) iron, 1.13 (mg/l) zinc, 17.9 (N) hardness, 122.7 (N) chewiness, 0.68 water activity, 1.89 expansion rate, 5.5 flavour, 4.9 general acceptability, 4.9 taste, 4.2 colour, 4.8 mouthfeel, 6.1 texture. The desirability bar plot of the numerical solution in Figure 1 shows the highest desirability value. The study's findings demonstrated that the best-formulated morning cereal is of excellent quality.

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Table 8: Formulation Conditions for the Ideal Breakfast Cereal

	Malted Finger Millet Flour (%)	Malted, Roasted Bambara Groundnut Flour (%)	Date Palm Fruit (%)	Moringa oleifera Leaf (%)	Turmeric (%)	Salt (%)	Screw Rate (rpm)	Barrel Heat $\left({}^{0}C\right)$	Desirability	
1	**42.700**	**40.000**	**5.000**	**2.000**	**10.000**	**0.300**	**110.000**	**110.000**	**0.503**	**Selected**
2	46.800	40.000	5.000	2.000	5.900	0.300	110.000	110.000	0.503	
3	37.700	25.000	20.000	2.000	15.000	0.300	110.000	110.000	0.503	
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82	38.059	34.853	11.794	2.000	12.993	0.300	110.000	110.000	0.503	
83	44.956	26.231	19.589	2.000	6.925	0.300	110.000	110.000	0.503	
84	45.855	33.307	5.661	2.000	12.876	0.300	110.000	110.000	0.503	

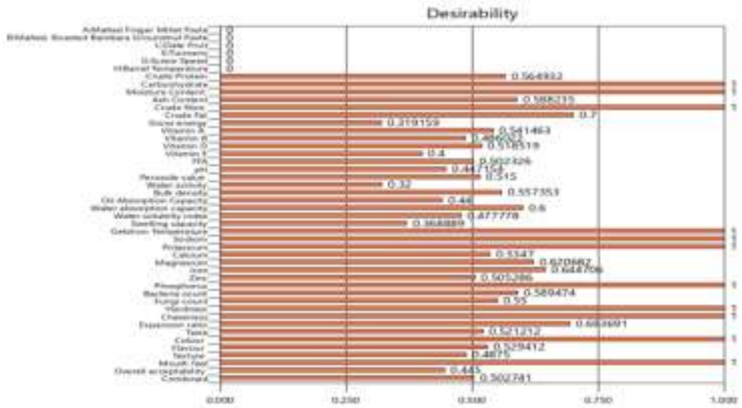

Figure 1: Desirability bar Plot of the Optimally Formulated Breakfast Cereal

4.0 Conclusion

In this study, a functional breakfast cereal was formulated from blends of locally available ingredients using constrained D-optimal mixture-process experimental design, characterised, and optimised using numerical optimisation via desirability function technique. The breakfast cereal provides novel choices for consumers in search of products with both improved nutritional and health benefits. The optimal breakfast cereal was formulated with 42.7% malted finger millet flour, 40.0% malted roasted Bambara groundnut flour, 5% date fruit powder, 2% moringa leaf powder and 10% turmeric powder, and yielded an optimal breakfast cereal with 5.79% protein, 75.58% carbohydrate, 7.43% moisture content, 3.40% ash content, 0.51% crude fibre, 7.28% crude fat, 391.039 k/cal gross energy, 1.83 mg/100g vitamin A, 2.48 mg/100g vitamin B, 0.69 µg/100g vitamin D, 0.16 mg/g vitamin E, 9.8×10^3 (cfu/g) bacteria count, 4.6×10^3 (cfu/g) fungi count, 0.68 water activity, 0.57 g/cm^3 bulk density, 18.2% oil absorption capacity, 12.0% water absorption capacity, 56.0 water solubility index, 151.32% swelling capacity, 82.4^{o}C gelation temperature, 51 (mg/kg) sodium, 167.76 (mg/kg) potassium, 170 (mg/kg) calcium, 116.6 (mg/kg) magnesium, 11.77 (mg/kg) iron, 1.13 (mg/l) zinc, 3.71 (mg/l) phosphorus, 122.7 (N) chewiness, 17.9 (N) hardness, 1.89 expansion ratio, taste (4.9), colour (4.2), flavour (5.5), texture (6.1), mouthfeel (4.8) and overall acceptability (4.9).

Mixture-process technology is also used to develop novel food products with specific functional ingredients and overall quality

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improvement which helps to solve the rising need to curb diet-related sicknesses all over the world. This study however, recommends that further study be carried out on the effect of more process variables in the formulation and optimisation of optimal breakfast cereals and the health attributes (antioxidants, phytochemicals,anti-inflammatory, antibacterial properties) of the breakfast cereal be evaluated and optimised.

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