Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

DEVELOPMENT OF FUNCTIONAL AND NUTRACEUTICAL FOODS FROM INDIGENOUS CROPS FOR PREVENTION OF NON-COMMUNICABLE DISEASES IN PAKISTAN

Wajid Hussain[*1], Bushra Zafar Khan[2]

*[*1]Ph.D Scholar, Department of Agriculture and Food Technology, Karakoram International University Gilgit, Pakistan*

[2]Student, National Institute of Food Science and Technology, University of Agriculture Faisalabad

[*1]aliwajid88@gmail.com, [2]bushrazafarkhan08@gmail.com

DOI: https://doi.org/10.5281/zenodo.22227009

Keywords
Indigenous crops; Functional foods; Nutraceuticals; Non-communicable diseases; Antioxidant activity; Pakistan

Article History
Received: 25 January 2026
Accepted: 11 March 2026
Published: 25 March 2026

Corresponding Author: *
Wajid Hussain

Abstract
Non-communicable diseases (NCDs) represent an important public-health challenge in Pakistan, creating a need for affordable, culturally appropriate, and nutritionally improved foods. This study proposes the development and evaluation of functional and nutraceutical foods using selected indigenous crops as sources of protein, dietary fibre, minerals, phytochemicals, and other bioactive compounds. A quantitative experimental food-development design was structured around five formulations: one conventional control and four indigenous-crop formulations, each produced in three independent batches. A sensory population of 1,200 eligible adult consumers was defined, from which a sample of 100 adults was selected for sensory evaluation. The dataset indicates progressive improvements in protein, dietary fibre, phenolic content, and antioxidant activity across selected formulations, with the optimized formulation achieving the strongest overall balance between nutritional functionality and sensory acceptability. One-way ANOVA and Tukey HSD are proposed for group comparisons, with α = .05. Because the numerical results are simulated for demonstration, they should be replaced by actual laboratory and sensory observations before submission as empirical findings. The study provides a structured framework for subsequent product development, validation, commercialization, and public-health research.

1. Introduction
Diet-related NCDs, including cardiovascular disease, diabetes, cancer, and chronic respiratory disease, are strongly influenced by modifiable dietary and lifestyle factors. Diets high in refined carbohydrates, free sugars, sodium, unhealthy fats, and highly processed foods may increase risk, whereas diets rich in whole grains, pulses, fruits, vegetables, fibre, and plant bioactives support healthier dietary patterns. Functional foods provide physiological benefits beyond basic nutrition, while nutraceuticals broadly refer to food-derived substances or products associated with health-promoting effects.

Indigenous and underutilized crops—including millets, sorghum, amaranth, buckwheat, legumes, seeds, fruits, and vegetables—provide opportunities to improve dietary diversity and agricultural resilience. Their functional value depends on processing, formulation, bioavailability, safety, stability, and consumer acceptance. Pakistan's agricultural diversity therefore provides a strong basis for developing locally sourced functional foods. The supplied manuscript similarly identifies the need to integrate crop characterization, formulation, processing optimization, laboratory functionality, physicochemical quality, and sensory acceptability. filecite turn0file0 L38-L42

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ISSN: (e) 3007-1607 (p) 3007-1593

2. Problem Statement

Pakistan faces a growing burden of diet-related NCDs alongside undernutrition and micronutrient deficiencies. Although many indigenous crops contain valuable nutrients and bioactive compounds, their systematic transformation into standardized, acceptable, and scientifically evaluated functional foods remains limited. Existing research frequently emphasizes raw-crop composition or isolated phytochemicals without integrating formulation, processing, laboratory functionality, physicochemical quality, and sensory acceptability. The central research gap is therefore the absence of an integrated Pakistan-specific approach linking indigenous-crop selection, food formulation, processing optimization, nutritional and phytochemical characterization, consumer acceptance, and NCD-related functional indicators.

3. Research Questions

- Which indigenous crops have the greatest nutritional, phytochemical, and functional potential for food development?
- What are the nutritional, mineral, fibre, antioxidant, and bioactive profiles of selected crops?
- How do processing and formulation affect nutritional, functional, physicochemical, and bioactive properties?
- Which formulation provides the best balance of nutritional quality, functionality, stability, and sensory acceptability?
- To what extent do developed foods demonstrate characteristics relevant to dietary NCD risk reduction?
- What factors may influence adoption and commercialization in Pakistan?

4. Objectives

General objective: To develop and scientifically evaluate functional and nutraceutical food products from selected indigenous crops in Pakistan with potential relevance to dietary NCD prevention.

- Select indigenous crops with strong nutritional, phytochemical, and functional potential.
- Determine proximate composition, dietary fibre, minerals, antioxidant capacity, and selected bioactive compounds.
- Develop and optimize indigenous-crop-based food formulations.
- Assess nutritional, physicochemical, functional, and bioactive changes caused by processing and formulation.
- Evaluate sensory characteristics and consumer acceptability.
- Compare optimized products with conventional control formulations.
- Assess selected in-vitro indicators such as antioxidant activity and glycemic-related characteristics.
- Identify the formulation most suitable for further clinical, commercial, and public-health development.

5. Significance of the Study

The study integrates food science, nutrition, functional-food research, preventive nutrition, and agricultural biodiversity. It may support healthier locally sourced foods, increase utilization of underused crops, create value-added agricultural opportunities, and provide evidence relevant to nutrition-sensitive NCD prevention. For industry, the findings can support formulation standardization and product innovation; for policymakers, they may inform dietary diversification, food innovation, food safety, and evidence-based health claims.

6. Literature Review

6.1 Functional Foods and NCD Prevention

Functional foods may influence pathways associated with oxidative stress, inflammation, glucose regulation, lipid metabolism, satiety, and gut microbial activity. However, laboratory antioxidant activity or the presence of a bioactive compound does not establish clinical disease prevention. Evidence should progress from food composition and in-vitro functionality to bioavailability and controlled human outcomes.

6.2 Indigenous and Underutilized Crops

Underutilized crops can improve dietary diversity, nutritional security, agricultural resilience, and food-system sustainability. Millets, sorghum, amaranth, buckwheat, and legumes are particularly relevant because of their fibre, protein, mineral, and phytochemical profiles. Their conversion into value-added foods is promising, but commercialization,

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ISSN: (e) 3007-1607 (p) 3007-1593

consumer awareness, supply chains, and product standardization remain important barriers.

6.3 Cereals, Pseudocereals, and Legumes

Millets provide fibre, minerals, plant protein, and phytochemicals. Sorghum processing can alter nutritional, bioactive, and technological characteristics, demonstrating the importance of process optimization. Legumes such as chickpea, lentil, and mung bean provide protein, complex carbohydrates, fibre, minerals, and phytochemicals and may contribute to favourable cardiometabolic dietary patterns.

6.4 Bioactive Compounds, Processing, and Fibre

Polyphenols, flavonoids, carotenoids, and related compounds contribute to the functional potential of plant foods. Processing may preserve, degrade, transform, or increase the availability of these compounds. Dietary fibre may influence satiety, glucose absorption, lipid metabolism, and gut fermentation. Functional-food optimization should therefore evaluate several outcomes simultaneously.

6.5 Sensory Acceptability and Research Gap

Nutritional superiority alone does not guarantee consumer adoption. Higher inclusion of indigenous ingredients may alter colour, aroma, taste, texture, or mouthfeel. The literature therefore supports a moderate-optimization strategy in which nutritional and functional improvements are achieved without unacceptable sensory changes. This is consistent with the source manuscript's emphasis on balancing functionality and sensory acceptance. filecite turn0file0 L108-L113

7. Underpinning Theory

The study is underpinned by the Functional Food Concept, which proposes that foods can provide physiological benefits beyond basic nutrient supply through bioactive components and food-matrix characteristics.

Conceptual pathway: Indigenous crop characteristics → processing/formulation → nutritional and bioactive composition → functional properties → potential NCD-related benefits.

The framework establishes an important boundary: functional potential measured in laboratory settings is not equivalent to clinically proven NCD prevention. filecite turn0file0 L114-L122

8. Hypotheses

- H1: Selected indigenous crops will demonstrate higher nutritional and/or bioactive potential than conventional comparators.
- H2: Indigenous-crop incorporation will improve the nutritional quality of developed products.
- H3: Higher bioactive content will be associated with greater in-vitro antioxidant activity.
- H4: Processing and formulation optimization will improve functional characteristics.
- H5: Higher dietary fibre will be associated with lower estimated glycemic potential or starch digestibility.
- H6: Optimized formulations will demonstrate greater NCD-related functional potential than controls.
- H7: Excessive indigenous-crop inclusion will reduce sensory acceptability.
- H8: Optimized formulations will show greater overall acceptability than non-optimized formulations.
- H9: Processing method will influence bioactive retention and antioxidant activity.
- H10: The optimized formulation will provide the most favourable overall balance of nutritional, functional, physicochemical, and sensory characteristics.

9. Methodology

9.1 Research Design

A quantitative experimental food-development design was adopted for the empirical model. The structure follows the source manuscript: crop selection, raw-material characterization, product formulation, processing optimization, laboratory testing, sensory evaluation, and statistical comparison. The proposed design contains one conventional control (C) and four indigenous-crop formulations (F1–F4), with each formulation produced in three independent batches. This treatment structure is directly aligned with the source manuscript. filecite turn0file0 L138-L146

9.2 Population

The target population for the sensory component was defined as adult consumers in Faisalabad who regularly consume the relevant food category and who would potentially be consumers of a locally developed functional food. For demonstration purposes, an accessible population of 1,200 eligible adults was assumed after screening for age, regular consumption, willingness to participate, and absence of known allergy or intolerance to the ingredients.

Population component	Number
Eligible adult consumers in accessible population	1,200
Excluded during screening	200
Eligible sampling frame	1,000
Selected sensory participants	100
Response/completion rate	100%

9.3 Sampling and Sample Size

A sample of 100 adult sensory evaluators was used for the dataset. The sample was treated as a purposive/eligibility-based sensory panel because participants needed to regularly consume the relevant food category and have no known allergy or intolerance to the ingredients. The original manuscript also targeted approximately 100 adult sensory evaluators, subject to final power analysis and ethical approval. □filecite□turn0file0□L143-L146□

Sample characteristic	value
Total sensory sample	100 adults
Age range	18–55 years
Mean age (years)	31.8
Female	52 (52%)
Male	48 (48%)
Regular consumers of relevant food category	100 (100%)
Informed consent	100 (100%)

9.4 Experimental Treatments and Production Sample

Treatment	Description	Independent batches	production units
C	Conventional control formulation	3	3
F1	Low indigenous-crop incorporation	3	3
F2	Moderate indigenous-crop incorporation	3	3
F3	High indigenous-crop incorporation	3	3
F4	Optimized indigenous-crop formulation	3	3
Total	5 treatments	15	15

The laboratory assessment included moisture, protein, fat, ash, fibre, carbohydrate, selected minerals, total phenolics, flavonoids, antioxidant activity (e.g., DPPH/ABTS/FRAP), glycemic-related characteristics where feasible, and physicochemical properties. Sensory assessment used a coded 9-point hedonic scale covering colour, aroma, taste, texture, mouthfeel, aftertaste, and overall acceptability. These measures follow the source methodology. □filecite□turn0file0□L147-L158□

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Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

9.5 Data Collection and Statistical Analysis

The dataset was structured to demonstrate descriptive analysis, one-way ANOVA, Tukey HSD post-hoc comparisons, and Pearson correlation. Statistical significance was set at $\alpha = .05$. Means, standard deviations, p-values, and effect-oriented interpretation were used to demonstrate the expected reporting format. The source manuscript specifies these analytical procedures and cautions that actual numerical values must be replaced after analysis of the real dataset. filecite turn0file0 L159-L167

10. Data Analysis and Results

The following tables contain simulated values prepared solely to demonstrate the empirical structure of the paper. They should not be reported as actual experimental findings unless they are replaced by verified laboratory and sensory observations.

10.1 Proximate Composition

Treatment	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	Carbohydrate (%)
C	6.8	8.9	7.1	1.7	3.4	72.1
F1	6.7	9.8	7.0	1.9	5.1	69.5
F2	6.6	10.7	7.0	2.1	6.7	66.9
F3	6.5	11.5	6.9	2.3	8.1	64.7
F4	6.4	11.2	6.8	2.2	8.4	64.9

Protein increased from 8.9% in the control to 11.2% in F4, while dietary fibre increased from 3.4% to 8.4%. These patterns demonstrate the expected nutritional improvement associated with indigenous-crop incorporation. F3 had the highest protein concentration, whereas F4 provided the highest fibre concentration and was subsequently treated as the optimized formulation because optimization considers multiple criteria rather than a single nutrient.

10.2 Mineral and Bioactive Results

Treatment	Iron (mg/100g)	Calcium (mg/100g)	Phenolics (mg GAE/100g)	Flavonoids (mg QE/100g)	DPPH inhibition (%)
C	2.8	42.0	118	46	41.2
F1	3.2	48.0	145	55	46.8
F2	3.7	53.0	171	66	52.7
F3	4.1	58.0	198	76	59.4
F4	4.0	57.0	205	79	61.1

The results show a progressive increase in iron, calcium, phenolic compounds, flavonoids, and DPPH antioxidant activity across the formulations. F4 produced the highest phenolic concentration and antioxidant activity, supporting its selection as the optimized formulation. These values are simulated and do not constitute laboratory observations.

10.3 Physicochemical and Glycemic-Related Indicators

Treatment	pH	Water activity	Estimated starch digestibility (%)	Estimated glycemic potential index
C	6.2	0.42	78.4	72.5
F1	6.18	0.41	74.1	68.7
F2	6.15	0.4	69.8	64.3
F3	6.12	0.39	65.2	60.1
F4	6.14	0.39	63.8	58.9

The pattern suggests that higher fibre and indigenous-crop incorporation were associated with lower estimated starch digestibility and glycemic potential. This is consistent with H5 at the conceptual level; however, in-vitro or estimated glycemic indicators should not be interpreted as clinical evidence of diabetes prevention.

10.4 Sensory Evaluation

Treatment	Colour M(SD)	Aroma M(SD)	Taste M(SD)	Texture M(SD)	Overall acceptability M(SD)
C	7.5 (0.9)	7.4 (0.9)	7.6 (0.8)	7.5 (0.9)	7.6 (0.8)
F1	7.6 (0.8)	7.5 (0.9)	7.7 (0.8)	7.6 (0.8)	7.7 (0.8)
F2	7.7 (0.8)	7.6 (0.8)	7.8 (0.8)	7.7 (0.8)	7.8 (0.7)
F3	7.1 (1.0)	7.0 (1.0)	6.8 (1.1)	7.0 (1.0)	6.9 (1.0)
F4	8.1 (0.7)	8.0 (0.7)	8.2 (0.6)	8.1 (0.7)	8.2 (0.6)

The sensory data demonstrate the expected non-linear relationship between inclusion and acceptability. F3, representing a relatively high inclusion level, showed reduced taste and overall acceptability, whereas F4 achieved the highest overall acceptance. This pattern illustrates why optimization should balance nutritional improvement with consumer acceptance.

10.5 ANOVA Results

Outcome	F-statistic	p-value	Interpretation
Protein	18.42	< .001	Significant differences among formulations
Dietary fibre	31.76	< .001	Significant differences among formulations
Total phenolics	27.13	< .001	Significant differences among formulations
DPPH antioxidant activity	24.88	< .001	Significant differences among formulations
Overall sensory acceptability	7.64	< .001	Significant differences among formulations

one-way ANOVA indicated statistically significant differences among the five treatments for all major outcomes. Tukey HSD comparisons would subsequently be used to identify the specific treatment pairs responsible for the differences. Because the underlying values are simulated, these statistics are examples of reporting format rather than evidence of actual significance.

10.6 Correlation Analysis

Variables	r	p-value	Interpretation
Fibre and estimated starch digestibility	−0.91	< .001	Strong negative association
Phenolics and DPPH activity	0.96	< .001	Very strong positive association
Flavonoids and DPPH activity	0.94	< .001	Very strong positive association
Fibre and overall acceptability	0.31	.041	Weak positive association
High inclusion level	−0.52	.003	Moderate negative

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ISSN: (e) 3007-1607 (p) 3007-1593

and overall acceptability			association

The correlations support the proposed relationships between bioactive compounds and antioxidant activity and between fibre and estimated starch digestibility. The results also demonstrate that nutritional enhancement alone does not guarantee sensory acceptance.

10.7 Hypothesis Testing

Hypothesis	Decision	Basis
H1	Supported	Indigenous formulations showed higher selected nutritional/bioactive values than control.
H2	Supported	Protein and fibre improved across selected formulations.
H3	Supported	Phenolics/flavonoids were strongly positively associated with DPPH activity.
H4	Supported	Optimized F4 showed favourable functional characteristics.
H5	Supported	Higher fibre was associated with lower estimated starch digestibility.
H6	Supported	F4 showed the strongest combined functional indicators.
H7	Supported	High-inclusion F3 showed lower sensory acceptance.
H8	Supported	F4 achieved the highest overall acceptability.
H9	Supported	treatment differences indicated processing/formulation effects.
H10	Supported	F4 provided the best multi-criteria balance in the dataset.

The decisions above are strictly. Actual hypothesis decisions must be based on the final verified dataset, statistical assumptions, effect sizes, confidence intervals, and the pre-specified analytical plan.

11. Discussion

The findings demonstrate how indigenous-crop incorporation could improve the nutritional and functional profile of developed foods while also highlighting the importance of sensory optimization. Protein, fibre, mineral, phenolic, flavonoid, and antioxidant values were modelled to increase across formulations, while excessive inclusion was modelled to reduce sensory acceptance. This pattern is consistent with the study's conceptual expectation that functional-food development requires a balance between nutritional enhancement and product acceptability.

The association between phenolic compounds and antioxidant activity also demonstrates the analytical logic of H3. Similarly, the negative relationship between fibre and estimated starch digestibility provides a plausible mechanism for H5. Nevertheless, these laboratory indicators should be interpreted as functional potential rather than proof of disease prevention. The source manuscript explicitly distinguishes in-vitro functionality from clinically established NCD prevention. filecite turn0file0 L180-L183

The selection of F4 as the optimized formulation reflects a multi-criteria decision

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ISSN: (e) 3007-1607 (p) 3007-1593

rather than the maximization of one variable. Although F3 had slightly higher protein in the dataset, F4 achieved the strongest overall combination of fibre, phenolics, antioxidant activity, physicochemical stability, and sensory acceptability. This approach is consistent with the source manuscript's recommendation that the final formulation be selected using nutritional, functional, physicochemical, and sensory criteria together. filecite turn0file0 L165-L167

12. Conclusion

The study demonstrates a structured approach for developing functional and nutraceutical foods from indigenous crops in Pakistan. In the dataset, indigenous-crop formulations showed improved nutritional and functional characteristics compared with the conventional control, while the optimized F4 formulation achieved the most favourable overall balance. The sensory results further demonstrate that excessive incorporation may reduce consumer acceptance and that optimization is therefore preferable to maximizing indigenous-crop inclusion. These conclusions are demonstrative only and must be validated through actual laboratory, sensory, bioavailability, and ultimately controlled human studies before making health or NCD-prevention claims.

13. Implications

- Theoretical: Extends the Functional Food Concept by linking indigenous biodiversity, processing, formulation, bioactive characteristics, and consumer acceptability.
- Practical: Provides a framework for locally sourced functional foods in bakery products, snacks, beverages, porridges, and composite cereal-legume foods.
- Industrial: Supports product standardization, quality control, product innovation, and value-added use of underutilized crops.
- Public health: May contribute to healthier dietary patterns and NCD-risk reduction strategies when integrated with broader healthy-diet approaches.
- Policy: Supports research and development, university–industry collaboration, improved value chains, food-safety standards, nutrition education, and evidence-based health claims.

14. Recommendations

- Prioritize indigenous crops with strong nutritional, bioactive, and processing potential.
- Optimize rather than maximize crop inclusion to preserve sensory quality.
- Use validated analytical methods, replication, randomization, and quality-control procedures.
- Assess nutrient and bioactive bioavailability, not only concentration.
- Conduct randomized human trials using clinically relevant NCD biomarkers.
- Compare processing methods such as germination, fermentation, extrusion, roasting, and drying.
- Strengthen consumer, sensory, affordability, willingness-to-purchase, and market research.
- Develop food-safety and evidence-based regulations for functional-food claims.

15. Limitations and Future Research

The principal limitation of this revised version is that the numerical dataset is rather than empirical. Therefore, the statistical results and hypothesis decisions cannot be treated as observed findings. Additional limitations include variation in crop composition by cultivar and region, limited generalizability of sensory findings, and the absence of direct clinical outcomes, long-term shelf-life evidence, comprehensive bioavailability assessment, anti-nutritional-factor analysis, and microbiome-related evaluation.

Future research should replace the dataset with verified laboratory and sensory observations; conduct power analysis before final sampling; assess bioavailability and simulated digestion; undertake randomized controlled human trials; and evaluate affordability, market acceptance, scalability, agricultural sustainability, and long-term consumer adoption. These priorities are consistent with the future-research directions in the supplied manuscript. filecite turn0file0 L218-L226

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