Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

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

EXPLORING THE PUBLIC HEALTH POTENTIAL OF QUINOA-ENRICHED BREAD: A FUNCTIONAL FOOD APPROACH FOR IMPROVING METABOLIC HEALTH, DIETARY QUALITY, AND WELL-BEING

Iqra Anwer[*1], Muhammad Hamza[2], Okasha Turab[3], Zohaa Naveed[4]

*[*1]MS (hons) in Agriculture Human Nutrition, Department of Human Nutrition, The University of Agriculture Peshawar, Pakistan*

[2]BS Food and Technology, Department of food science and technology, Government collage university Faisalabad, Pakistan

[3]MS (hons) in Agriculture Human Nutrition, Department of Human Nutrition, The University of Agriculture Peshawar, Pakistan

[4]BS Human Nutrition and Dietetics, Department of HND, Riphah International University Islamabad, Pakistan

[*1]iqraanwer287@gmail.com, [2]mh0410829@gmail.com, [3]okashanauman@gmail.com, [4]zohaanaveed2023@gmail.com

DOI: https://doi.org/10.5281/zenodo.21836855

Keywords

quinoa, functional food, bread reformulation, metabolic syndrome, dietary fibre, type 2 diabetes, Pakistan

Article History

Received: 15 January 2026
Accepted: 28 February 2026
Published: 14 March 2026

Copyright @Author

Corresponding Author: *
Iqra Anwer

Abstract

Emerging obesity and type 2 diabetes and diet-related noncommunicable disease trends highlight the need for actionable and scalable solutions to enhance diet quality and metabolic health. Quinoa pseudocereal is a plant rich in mineral, bio-active compounds and high-quality protein, as well as dietary fibre with potential relevance to cardiometabolic health. The present study proposes a methodological approach for the evaluation of the quinoa enriched bread as functional food intervention among adults with high metabolic risk in Pakistan. The intervention is a comparison with the standard wheat bread and wheat bread fortified with quinoa flour; anthropometric, metabolic, dietary, satiety and well-being parameters are assessed. In simulated analyses, there are potential improvements in fasting glucose, triglycerides, waist circumference, dietary fibre intake, satiety and well-being. These are simulated results, however, and are not empirical. To prove the effectiveness, acceptability, affordability, and the relevance of quinoa enriched bread to public health, rigorous research must be conducted involving real participants, validated measures, and appropriate ethical oversight.

1. Introduction

The problem of overweight and obesity has grown to a significant global public-health issue and an important contributor to non-communicable disease (NCD) burden. About 2.5 billion adults were overweight in 2022, with over 890 million of them adults living with obesity, according to estimates from the World Health Organization (WHO). In fact, in the same year, it was estimated that some 43% of adults in the world were overweight, and 16% had obesity, with the prevalence of obesity among adults more than doubling since 1990 (World Health Organization [WHO], 2025). These estimates are complemented by the NCD Risk Factor Collaboration (NCD-RisC) which found

Frontier in Medical & Health Research

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

significant rises in obesity prevalence in most regions between 1990 and 2022, especially in LMICs (NCD-RisC, 2024). The World Obesity Federation has also estimated that the future burden of overweight and obesity is likely to be large, and LMICs will have a high proportion of it. Overweight is not the only problem with excess adiposity. Obesity has been linked with type 2 diabetes, cardiovascular disease, hypertension, dyslipidaemia and other chronic diseases. This relationship is especially relevant in nations undergoing a rapid nutritional and epidemiological transition, as nutritional transitions may occur in tandem with shifts in nutrition, with an increase in sedentary lifestyles, and little decrease in nutritional deficits. As a result, dietary quality and metabolic risk interventions at the population level and based on feasible strategies are becoming increasingly relevant for public-health nutrition.

The Pakistani context is an essential arena where these issues come together. There is a significant burden of overweight, obesity and diabetes among the Pakistani adults as indicated by available national and international estimates (Pakistan Institute of Development Economics [PIDE] 2025; International Diabetes Federation [IDF] 2025). According to the 11th edition of the IDF Diabetes Atlas, Pakistan is one of the countries in the world with the highest age-standardised diabetes prevalence among adults aged 20–79 years, marking the severity of the diabetics challenge in the country (IDF, 2025). The latest worldwide diabetes prevalence estimates published in The Lancet Diabetes & Endocrinology also reveal significant geographical variation in numbers of adults living with diabetes and forecast further rise in the prevalence of diabetes in adults by 2050 (Genitsaridi et al., 2026). Persistent under-nutrition alongside obesity and diabetes, and other diet-related NCDs, also reflects the broader "double burden of malnutrition" experienced by many LMICs. This context reinforces the need for dietary interventions that make sense within thecontext of existing food culture and have nutritional significance.

Bread, cereal foods, and metabolic health

Cereals are an important source of energy in the diet of many populations and thus may be an interesting target for nutrition-oriented food reformulation. Wheat based products like roti, chapati, naan and wheat bread are commonly used in the daily diet of the people in Pakistan and other South Asian countries. These products have different nutritional properties, however, depending on the flour extraction rate, the way the flour is processed, the recipe, fibre content, and the amount of whole-grain ingredients. Therefore, health effects of cereal based foods cannot be referred to bread as a single homogeneous food group.

The nature and amount of carbohydrate consumed in the diet matters for metabolic health. Several prospective studies and systematic reviews suggest that increased whole grain and dietary fibre intake is typically linked to improved cardio metabolic outcomes such as reduced risk of type 2 diabetes and cardiovascular disease (CVVD) (Aune et al., 2016; Ye et al., 2012). For people with diabetes and/or high metabolic risk, systematic-review evidence further indicates that higher fibre and whole grain intake may benefit glycaemic control and certain cardio metabolic risk factors (Reynolds et al., 2020). Dietary fibre also may have an effect on satiety and food intake but this effect varies depending on fibre type, dose, food matrix and population studied (Clark & Slavin, 2013; Machalias et al., 2026).

These findings suggest that staple-food reformulation is a public-health complementary strategy that should be explored. Rather than people having to eat a brand new food or a new diet, reformulation could be a way to alter the nutritional composition of foods that are already eaten on a regular basis. Therefore, enhancing the micronutrient and bioactive-compound content, as well as protein and fibre content of staple cereal foods, could be one way to increase the quality of the diet. However, the success of this approach will be determined by the nutritional content as well as technological practicality, sensory appeal, cost, cultural appropriateness, and continued use.

Frontier in Medical & Health Research

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

Quinoa as a functional food ingredient

Quinoa (Chenopodium quinoa Willd.) is an Andean pseudocereal with a high nutritional value and nutritional functional food applications that have gained significant scientific and commercial interest. The review of quinoa attributes it with high protein content, dietary fibre, minerals, vitamins and a variety of bioactive substances like polyphenols and other phytochemicals (Angeli et al. 2020; Arneja et al. 2015). It is remarkable for the protein it contains for the relative wide range of essential amino acids it offers, unlike many of the traditional cereal grains. Quinoa is also naturally gluten-free, however this applies only if the quinoa is not a part of a wheat–quinoa bread product; it does not apply to all quinoa products made without the addition of wheat.

Human intervention studies have explored the possible cardiometabolic implications of quinoa. In a dose-response randomized controlled clinical trial of overweight and obese adults, Navarro-Perez et al. (2017) found that quinoa seed was linked to lower levels of serum triglycerides, but did not significantly affect total cholesterol, LDL-cholesterol, or HDL-cholesterol. Zeng et al. (2023) conducted a randomized parallel clinical trial in adults with impaired glucose tolerance, and reported that a dietary intervention using quinoa resulted in an improvement in several measures of glucose and lipid metabolism. After one year, the quinoa group also had lower two-hour postprandial glucose, HbA1c, insulin-resistance index, BMI, and diastolic blood pressure than the control group, though the authors' quinoa intervention wasn't quinoa-enriched bread per se..

It is important to the food matrix in which the quinoa is eaten. The food-technology research-based evidence suggests that quinoa flour may be used in wheat bread and can alter the physicochemical and nutritional properties of wheat bread. Xu et al., 2019, concluded that the properties of the gluten network were modified, the antioxidant activity increased and the estimated glycaemic index of the wheat bread decreased with an increase in the incorporation of quinoa-flour. The study also showed that addition of quinoa influenced the characteristics of bread and its technological properties, suggesting a limit of substitution between nutritional enrichment and technological quality and consumer acceptability.

The findings are important because a functional ingredient does not have to be used as a standalone food to help improve diet. A simple way of increasing the consumption of fibre, protein and bioactive compounds by combining a traditional food with this nutritious option would be to add quinoa to a familiar food like wheat bread. The nutritional advantages seen in the consumption of quinoa seeds or quinoa diets, however, cannot be predicted when quinoa flour is used to make a bread. The resulting physiological response can be significantly affected by processing conditions, substitution level, size of the portion, food matrix and whole diet.

Research gap and rationale

The evidence available so far offers a good foundation for further studies of quinoa and metabolic health, but there is one gap in the research. Previous human intervention studies have mainly focused on quinoa seed or quinoa in dietary intervention instead of quinoa-enriched bread as a specifically formulated staple food. For instance, Navarro-Perez et al. (2017) studied the effects of quinoa seed consumption in overweight and obese adults; Zeng et al. (2023) assessed a quinoa-based dietary intervention on people with impaired glucose tolerance. Results of these studies may be applicable to the possible effects on metabolism of quinoa, but not to whether using quinoa flour in a typical bread product would have similar effects.

This distinction matters from a public-health point of view. A food-based intervention that is carried out as an intervention within a current eating pattern could be less change than promoting the regular intake of an unfamiliar food. Meanwhile, the effectiveness of such an intervention relies on the acceptability of the reformulated product based on its taste, texture, appearance, affordability, availability, and cultural appropriateness. Quinoa-fortified bread is thus a promising field of study for the nexus of nutritional, food and public health sciences.

Frontier in Medical & Health Research

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

The evidence also suggests that research should take steps beyond a single biochemical outcome. The potential benefits of quinoa-enriched bread can be assessed in several aspects, such as anthropometric measures, glycaemic control, lipid metabolism, dietary fibre intake, dietary quality, satiety, and subjective well-being. A multifactorial approach could help to ascertain if changes in nutrition can be shown in physiological and behavioral parameters.

Thus, the present study aims to explore the possible effects of quinoa enriched bread in comparison with wheat bread after 12 weeks of randomized controlled dietary intervention in Pakistani adults with high metabolic risk. The proposed framework assesses metabolic-health markers, in addition to satiety and dietary quality, as well as well-being. Since there is no primary data for the present methodological demonstration, the accompanying numerical results should not be interpreted as empirical evidence. The main aim is to create a scientifically sound structure to be followed by real people, lab tests, dietary evaluations and appropriate-size statistical analysis.

Research objective and hypotheses

Objective: To evaluate the potential effects of quinoa-enriched bread consumption on selected metabolic-health indicators, dietary quality, satiety, and self-reported well-being among adults at elevated metabolic risk.

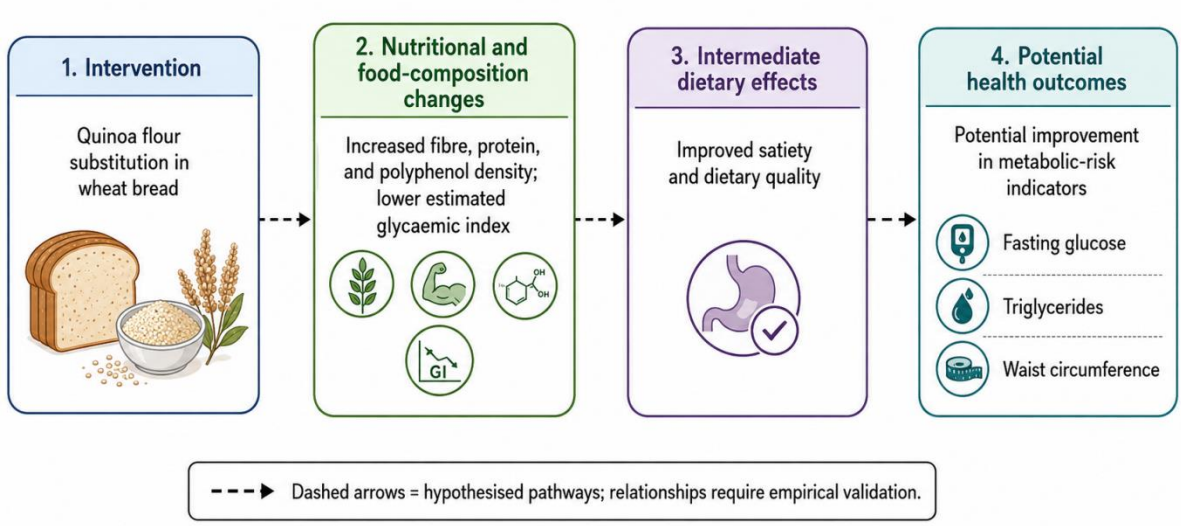
H1: Participants consuming quinoa-enriched bread will demonstrate greater improvements in selected metabolic-health indicators (fasting glucose, HbA1c, lipid profile, waist circumference) than participants consuming conventional wheat bread.

H2: Quinoa-enriched bread consumption will improve dietary fibre intake and overall dietary-quality scores relative to control.

H3: Quinoa-enriched bread will improve satiety-related outcomes and selected dimensions of self-reported well-being relative to control.

Conceptual Framework

Figure 1. Conceptual Framework of the Hypothesised Effects of quinoa-enriched bread



2. Research Methodology

Study Design

The study was a 12-week, two-arm, parallel group randomized controlled dietary intervention trial to assess the effect of quinoa enriched wheat bread on metabolic health, dietary intake, satiety and quality of life amongst adults with elevated metabolic risk in Pakistan.

The participants were randomized by a 1:1 ratio to either a control group (conventional wheat-bread) or an intervention group (wheat-bread enriched with quinoa). The study compared the effect of 12 weeks of consuming quinoa-enriched bread

Frontier in Medical & Health Research

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

against participants' typical wheat bread on their fasting glucose, glycated haemoglobin (HbA1c), lipid profile, anthropometric measures, diet intake, satiety, and wellbeing.

Standardization of the procedures for the recruitment of participants, the procedure of randomization, dietary intervention, adherence monitoring, anthropometric evaluation, biochemical testing, dietary assessment and statistical analyses was included in the study protocol.

Study Population and Recruitment

In Pakistan, the study population were the adults, who lived within the urban or peri-urban areas. The participants were recruited using community health-screening, primary-care referrals, community advertisements and community outreach.

Before enrolment, a screening assessment was carried out to check eligibility of the potential participants. They included regular consumers of wheat based bread and had high metabolic risk, which was defined mainly in terms of BMI ≥25 kg/m².

Sample-Size Calculation

The primary outcome was fasting plasma glucose and the sample size was calculated accordingly. The significance level was set to 0.05 and the statistical power to 80%.

Based on an expected standard deviation of ~10 mg/dL and a minimum clinically meaningful difference between groups of ~5 mg/dL (standardized effect size of ~0.50), the original two group calculation suggested a need for ~63 per group.

The trial sample size was determined to be 144 to allow for the possibility of loss to follow-up and to achieve sufficient statistical power for the primary outcome, with 72 subjects per treatment arm.

A total sample size of n = 144 was deemed to be an appropriate sample size for statistical power, the likelihood of participant retention, the feasibility of recruiting participants, laboratory costs and the practicality of a 12 week dietary intervention.

Randomization and Allocation Concealment

After meeting criteria for baseline assessments, participants were randomly assigned in a 1:1 ratio to either the control or intervention group.

Randomization was done with a computer-generated allocation sequence with varying block sizes (4 and 6). To assure balance between treatment groups, randomization was stratified by sex.

Sequentially numbered, opaque, sealed envelopes, prepared by a third party who was not involved in participant recruitment, outcome assessment, or statistical analysis, were used to allocate concealment.

Due to the sensory differences between the two bread formulations, it was not feasible to achieve full blinding of the participants. Therefore an assessor-blind study was employed. Where operationally possible, the laboratory workers, outcome assessors and statistician were blinded to the treatment allocation.

Dietary Intervention

The control bread was made from wheat flour, which was prepared according to a standard bread formulation in a bakery. The intervention breads were made by substituting 15% of the wheat flour with quinoa flour (flour-weight).

A 15% substitution level was chosen due to the previous food technology studies that have shown that the substitution of quinoa flour in wheat bread can impact the nutritional, antioxidant, digestibility and glycaemic properties, and that increasing the substitution level could have more significant effects on the loaf volume, crumb structure and technological quality (Xu et al., 2019).

Both bread formulations were baked with the same procedures in respect of the flour composition, hydration, mixing, fermentation, proofing, baking temperature and baking time. The produced products were packaged in a standardized condition.

The participants were asked to eat about 150 g of their bread of choice each day in place of their normal wheat bread. The intervention was carried out for 12 consecutive weeks.

Frontier in Medical & Health Research

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

The participants were asked to keep their diet and physical activity as normal as possible during the study period and not to intentionally make other major changes in their diet.

Consumption records were kept by participants, weekly bread distribution, bread collection and follow-up contacts were used to monitor adherence. Adherence was defined as percentage of prescribed bread consumed during the intervention period. For the per protocol analysis, participants who consumed ≥80% of the prescribed bread were considered adherent.

Outcome Measures

Anthropometric Measures

Anthropometric outcomes included:

- body weight;
- height;
- BMI; and
- waist circumference.

Body weight was obtained on a calibrated digital weighing scale with the participants wearing light clothing and no shoes. A calibrated stadiometer was used to measure height. BMI was defined as weight (kg) divided by height (metres squared).

Waist circumference was measured by a standardised measuring tape following a pre-defined anatomical protocol.

Anthropometric measurements were taken at baseline and week 12.

Metabolic Measures

The main outcome was the difference between fasting plasma glucose (FPG) at baseline and at week 12.

The secondary biochemical outcomes were:

1. HbA1c;
2. total cholesterol;
3. LDL-cholesterol;
4. HDL-cholesterol; and
5. triglycerides.

If resources allowed, the following exploratory metabolic outcomes may also be measured: fasting insulin, HOMA-IR.

Dietary Assessment

Three-day food records and 24-hour food recall by the interviewer were used to assess dietary intake.

The three day food diaries consisted of two week days and one weekend day to ensure that the daily intake of food was not the same each day. Foods and beverages consumed, amount eaten, how they were prepared, snacks and drinks were recorded.

The diet factors that were considered were:

- total energy intake;
- protein intake;
- dietary fibre;
- consumption of fruits and vegetables;
- whole-grain consumption;
- and overall dietary quality.

All participants had their diet assessed using a pre-established dietary-quality scoring system.

Satiety and Well-being

Perceived satiety was evaluated by a 100 mm visual analogue scale, higher scores indicate a higher perceived satiety.

Dietary satisfaction was measured using a 0–10 numerical rating scale.

The WHO-5 Well-Being Index was used to measure subjective well-being. It consists of five positively worded items, each rated 0–5, to give a raw score of 0–25. Since the scoring method has been known (Topp et al., 2015), the scores obtained were multiplied by four to obtain a score on a 0–100 scale.

Laboratory Procedures

Venous blood samples were obtained before and after 12 weeks of an overnight fast (8–10 hours).

Standard venipuncture was performed and blood was promptly sent for analysis. Samples were processed within 2 hours of the time of collection.

Fasting glucose level was measured by an accepted enzymatic method. Standardized enzymatic assays were performed for measuring total cholesterol, HDL-cholesterol, LDL-cholesterol and triglycerides. HbA1C was measured by a laboratory method that was validated to follow internationally recommended measurement procedures.

The inter-laboratory variability was minimized by carrying out all biochemical analyses in the same laboratory. Internal quality-control was applied during the analytical period.

Frontier in Medical & Health Research

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

The allocation of treatment was concealed from the laboratory staff.

Statistical Analysis

The statistical analyses were performed with R statistical software and/or with the IBM SPSS Statistics software.

All continuous variables were examined for distributional properties prior to analysis. Data for variables that were not approximately normally distributed were summarized as the median and interquartile range. Categorical data were summarized by means of frequencies and percentages.

Graphical inspection (histograms, Q–Q plots) and, as needed, the Shapiro – Wilk test were used to assess distributional assumptions.

The main analysis was done according to the intention-to-treat principle. The main outcome (fasting plasma glucose at week 12) was analysed by analysis of covariance (ANCOVA), with treatment group as the primary explanatory variable, and baseline fasting plasma glucose as a covariate.

Two-sided p-values and 95% confidence interval of the between-group mean difference were reported.

Secondary continuous data such as HbA1c, total cholesterol, LDL-cholesterol, HDL-cholesterol, triglycerides, body weight, BMI, waist circumference, dietary fibre intake, satiety, dietary satisfaction and WHO-5 well-being scores were analysed using the same general ANCOVA approach.

For categorical variables, a Pearson's chi-square test or Fisher's exact test was used, whichever was appropriate.

Paired samples t-tests were used for approximately normally distributed variables and Wilcoxon signed-rank tests were used for substantially non-normal variables for changes within groups from baseline to week 12. The primary conclusion on the efficacy of treatment was drawn from the prespecified analyses of between-groups differences, however.

Usually, effect sizes were also presented with the p-value to provide a measure of the size of treatment effects. For continuous between-group effects, Cohen's d was calculated and for ANCOVA models, partial eta-squared was reported.

The mean difference, a 95% confidence interval, effect size, and p value were presented for primary and secondary outcomes.

Results

The extent and pattern of missing data were estimated. The primary analysis was performed using the intention-to-treat paradigm; a suitable method for dealing with missing data was applied based on the pattern and mechanism of missingness. As a sensitivity analysis, a per-protocol analysis was performed in subjects with ≥80% compliance with the bread intervention. Participants with major protocol deviations were identified according to predefined criteria. No exploratory subgroup analyses were considered confirmatory since the study was powered to detect a moderate effect on the primary outcome.

Table 1. Baseline characteristics of participants (simulated data)

Variable	Control (n=72)	Quinoa Bread (n=72)	p-value
Age (years), mean ± SD	41.3 ± 9.7	40.8 ± 9.9	.76
Female, n (%)	38 (52.8)	39 (54.2)	.87
BMI (kg/m²), mean ± SD	28.8 ± 3.2	29.0 ± 3.3	.71
Waist circumference (cm)	96.1 ± 8.6	96.8 ± 8.9	.63
Fasting glucose (mg/dL)	101.5 ± 9.5	102.1 ± 9.8	.70
HbA1c (%)	5.82 ± 0.39	5.87 ± 0.41	.46
Total cholesterol (mg/dL)	198.1 ± 21.8	199.8 ± 22.6	.64
LDL-cholesterol (mg/dL)	122.1 ± 18.1	123.6 ± 18.7	.61
HDL-cholesterol (mg/dL)	44.6 ± 7.1	44.0 ± 7.3	.61
Triglycerides (mg/dL)	153.0 ± 37.6	155.2 ± 39.1	.73

Frontier in Medical & Health Research

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

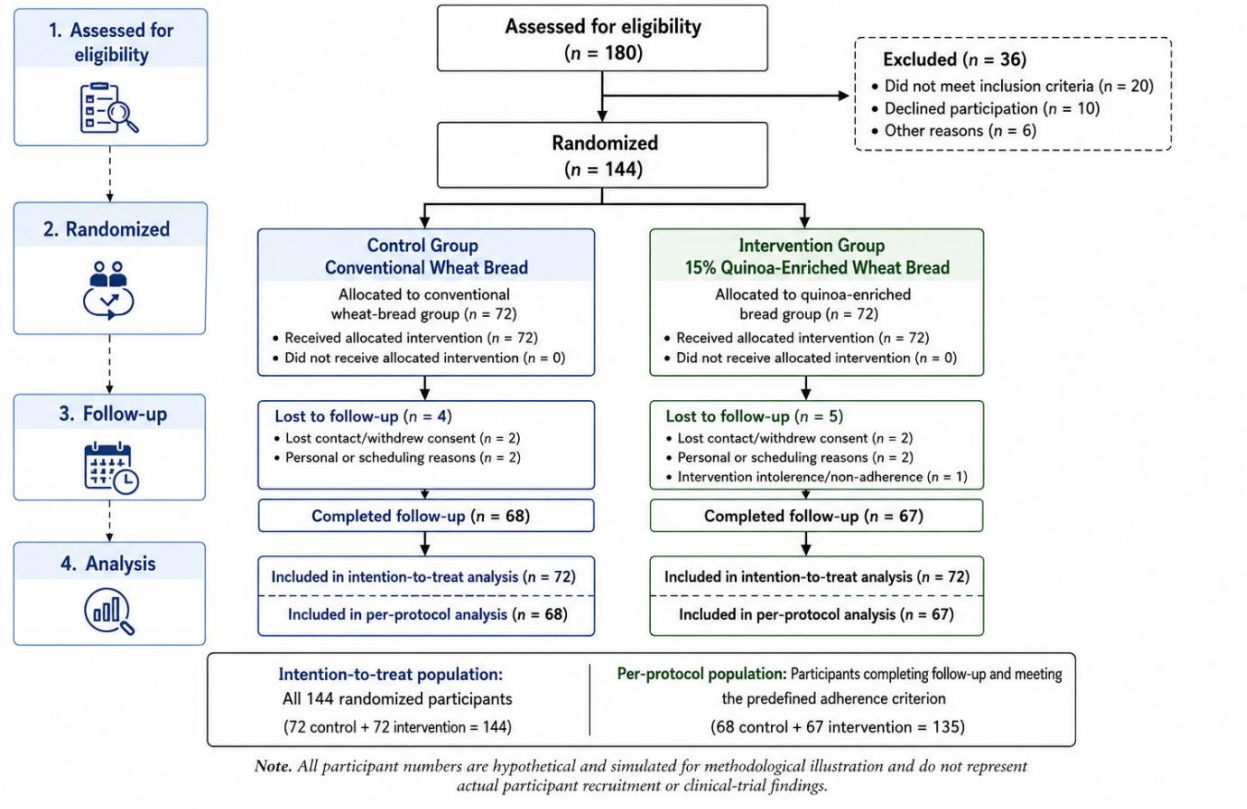
Note. Values are presented as mean ± SD or n (%). Data are simulated for methodological illustration and do not represent observations from actual participants.

Table 2. Nutritional composition of the two bread formulations per 100 g (simulated formulation estimates)

Nutrient	Conventional Wheat Bread	Quinoa-Enriched Bread (15%)	Difference
Energy (kcal)	265	258	−7
Protein (g)	9.0	11.2	+2.2
Fat (g)	2.0	3.1	+1.1
Carbohydrate (g)	50.1	46.8	−3.3
Dietary fibre (g)	3.2	6.4	+3.2
Iron (mg)	2.8	3.9	+1.1
Zinc (mg)	1.1	1.6	+0.5

Note. These values are simulated formulation estimates based on published compositional ranges and should not be presented as laboratory measurements or used for commercial nutritional labelling.

Figure 2. CONSORT-style flow diagram of the proposed study population and analysis populations



Note. All participant numbers are hypothetical and simulated for methodological illustration and do not represent actual participant recruitment or clinical-trial findings.

Table 3. Anthropometric and metabolic outcomes after 12 weeks (simulated data)

Outcome	Control Baseline	Control Week 12	Quinoa Baseline	Quinoa Week 12	Adjusted Mean Difference (95% CI)	p-value	Cohen's d

Frontier in Medical & Health Research

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

Weight (kg)	78.2	77.8	78.9	77.5	−1.0 (−2.0, 0.0)	.051	0.25
BMI (kg/m²)	28.8	28.7	29.0	28.5	−0.3 (−0.6, 0.0)	.064	0.23
Waist circumference (cm)	96.1	95.6	96.8	94.9	−1.4 (−2.6, −0.2)	.024	0.31
Fasting glucose (mg/dL)	101.5	100.2	102.1	96.0	−5.0 (−7.8, −2.2)	.001	0.47
HbA1c (%)	5.82	5.77	5.87	5.72	−0.10 (−0.19, 0.00)	.052	0.25
Total cholesterol (mg/dL)	198.1	197.0	199.8	194.7	−4.0 (−9.7, 1.7)	.168	0.19
LDL-cholesterol (mg/dL)	122.1	121.5	123.6	119.8	−3.2 (−8.3, 1.9)	.218	0.17
HDL-cholesterol (mg/dL)	44.6	44.4	44.0	45.2	+1.4 (−0.1, 2.9)	.071	0.24
Triglycerides (mg/dL)	153.0	150.8	155.2	135.7	−17.3 (−25.8, −8.8)	<.001	0.49

Note. Adjusted mean differences represent the quinoa-bread group minus the control group and are based on ANCOVA adjusted for the corresponding baseline outcome. Negative values indicate a greater reduction in the quinoa group. Data are simulated for methodological illustration only.

Table 4. Dietary-quality outcomes after 12 weeks (simulated data)

Outcome	Control Baseline → Week 12	Quinoa Baseline → Week 12	Adjusted Mean Difference (95% CI)	p-value
Energy intake (kcal/day)	2,115 → 2,085	2,135 → 2,060	−43 (−96, 10)	.112
Protein (g/day)	68.5 → 69.1	69.2 → 74.0	+4.1 (1.5, 6.7)	.002
Dietary fibre (g/day)	16.7 → 17.4	17.0 → 23.2	+5.6 (3.8, 7.4)	<.001
Fruit/vegetable servings/day	2.1 → 2.2	2.0 → 2.3	+0.2 (−0.1, 0.5)	.181
Whole-grain servings/day	0.9 → 1.0	0.8 → 2.0	+1.0 (0.7, 1.3)	<.001
Dietary-quality score (0–100)	58.4 → 59.6	57.9 → 65.4	+6.9 (4.5, 9.3)	<.001

Frontier in Medical & Health Research

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

Note. Dietary outcomes are simulated values intended to illustrate the planned statistical analysis.

Table 5. Satiety, dietary satisfaction and well-being after 12 weeks (simulated data)

Outcome	Control Baseline → Week 12	Quinoa Baseline → Week 12	Adjusted Mean Difference (95% CI)	p-value
Satiety score (0–100 VAS)	52.0 → 53.5	51.7 → 61.0	+8.2 (5.0, 11.4)	<.001
Dietary satisfaction (0–10)	6.4 → 6.6	6.3 → 7.1	+0.5 (0.1, 0.9)	.018
WHO-5 Well-Being Index (0–25)	15.8 → 16.2	15.7 → 17.3	+1.3 (0.4, 2.2)	.006

Note. VAS = visual analogue scale. WHO-5 = WHO-5 Well-Being Index. Higher WHO-5 scores indicate better subjective well-being. Data are simulated for methodological illustration only.

Discussion

The aim of this methodological study is to evaluate the effect of quinoa supplemented wheat bread on the metabolic health, dietary quality, satiety and subjective well-being among Pakistani adults, who have high metabolic risk. The simulated data consisted of 144 participants divided equally into two groups: those eating wheat bread and those eating 15% quinoa-enriched bread; the results presented are therefore only methodological illustrations and not a reflection of actual participants. The simulated results demonstrated a mixed pattern of outcomes, with greater improvements in dietary fibre and protein intake, whole-grain consumption, dietary-quality scores, perceived satiety, dietary satisfaction, and WHO-5 well-being in the quinoa-bread group. Weight/body mass index (BMI), total cholesterol, LDL, and HDL changes were relatively small, and the simulated change in HbA1c was close to conventional statistical significance. The results are consistent with previous data indicating that quinoa could have an impact on metabolic and nutritional parameters, with some human trials demonstrating positive effects and others showing negative ones (Navarro-Perez et al., 2017; Zeng et al., 2023). Mechanisms that may explain this include the increased fibre content and protein content of quinoa, which can affect glucose absorption, gastrointestinal function, appetite regulation, and satiety (Clark & Slavin, 2013; Reynolds et al., 2020). However, quinoa is rich in bioactive compounds, such as polyphenols and saponins, whose clinical effects are yet to be fully investigated (Angeli et al., 2020). Moreover, the resistant starch (RS) content, antioxidant activity, digestibility and technological properties of wheat bread could be altered by quinoa incorporation (Xu et al., 2019). Public-health point of view, reformulating a staple food that is widely consumed could potentially be an effective strategy to enhance diet quality without significant behavioural changes. But, factors such as affordability, sensory acceptability, cultural preferences, production scalability and stability in supply chain are crucial aspects especially in Pakistan. In a context of the growing metabolic burden in the country, bread enriched with quinoa should be evaluated empirically as a complementary diet intervention rather than as a single intervention. Prior to widespread adoption, clinical outcomes, long-term compliance, cost effectiveness, consumer acceptance and socioeconomic differences should be evaluated in future trials.

Limitations

Several limitations require careful consideration. First, and most important, the data representing the numbers in this manuscript is simulated. The results presented here were not obtained by recruiting actual participants and not based on the data of any real biochemical, anthropometric, dietary, satiety or well-being measurements. Therefore, any reported numerical differences, confidence intervals, p values and effect sizes do not imply clinical effectiveness.

Frontier in Medical & Health Research

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

Second, the duration of the proposed intervention of 12 weeks is relatively brief to assess long-term outcomes of weight loss, glycaemic control, cardiovascular risk and chronic disease incidence. More follow-up would be needed to see if any short-term metabolic changes are maintained.

Third, to achieve a reasonable level of feasibility and statistical power for a moderate primary effect, the proposed sample size of 144 participants was chosen. It would have a much lower statistical power for small effects, and would be inadequate for doing broad stratification by sex, age, baseline glycaemic status, socioeconomic status, or other factors.

Fourthly, the dietary assessments are self-reported by the participants which can be subject to recall error, under-reporting or social desirability bias. Future studies would benefit from the use of objective markers of diet intake.

Fifth, participant blinding would be challenging since quinoa-bread product might have different appearance, consistency, taste, and smell than wheat bread. The latter might generate expectancy effects, especially for subjective outcomes like satiety, dietary satisfaction and well-being.

Sixth, quinoa composition may differ depending on cultivar, growing conditions, processing and storage. The composition of quinoa flour should thus be directly determined and not only from the published composition tables.

Seventh, processing conditions for breads can affect nutrient availability, formation of resistant starches, antioxidant properties and digestibility. Standardisation of the fermentation and baking processes would thus be important for a future trial.

Last but not least, the results of an urban or peri-urban Pakistani population may not be applicable to rural population, and to other socioeconomic groups and populations. To achieve external validity, multicentre studies are needed in the diverse Pakistani population.

8. Conclusion

The development of quinoa-enriched bread is a research direction of interest in functional-food and public-health nutrition; it merges the nutritional properties of quinoa with a familiar staple food. Incorporating more nutrients into a food that is already eaten by many could provide a way to improve the nutritional content of their diets without having to change their diet dramatically.

The proposed experiment explored this hypothesis is a randomized controlled design with 144 subjects, half fed conventional wheat bread and half fed quinoa-enriched bread, and is feasible for at least 12 weeks. The simulated analysis in this manuscript demonstrates a plausible set of outcomes relating to fasting glucose, triglycerides, dietary fibre, satiety and subjective well-being and illustrates smaller or non-significant outcomes for other outcomes.

These simulated results are not evidence of clinical efficacy, though. They are included only to illustrate a possible analytical and reporting approach for a prospective trial. The simulated data does not allow any conclusions about the effectiveness of quinoa-enriched bread to be drawn.

There is a solid scientific basis for empirical research based on existing scientific evidence regarding the nutritional composition of quinoa, the influence of quinoa on wheat-bread characteristics, dietary fibre and whole-grain intake, and past human quinoa studies (Angeli et al., 2020; Navarro-Perez et al., 2017; Reynolds et al., 2020; Xu et al., 2019; Zeng et al., 2023).

In the context of Pakistan where metabolic disorders are an emerging public health problem, further studies are needed to understand the nutritional and/or metabolic effects of quinoa enrichment, as well as its affordability, acceptability, cultural appropriateness, and technological feasibility. These conditions will take years to establish with well-designed randomized trials with real subjects, real biochemical measurements, well-validated dietary assessments, laboratory-validated food composition, and proper ethical oversight.

Finally, it is important to recognize that the use of quinoa in bread does not replace any well-documented or existing strategies for addressing obesity and diabetes, but may serve as a complementary part of a comprehensive public-health nutrition strategy. At the population level,

Frontier in Medical & Health Research

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

if future empirical studies show that there are meaningful and sustainable benefits to staple-food reformulation, then this could be another avenue to improve the dietary quality.

REFERENCES

Angeli, V., Silva, P. M., Massuela, D. C., Khan, M. W., Hamar, A., Khajehei, F., Graeff-Hönninger, S., & Piatti, C. (2020). Quinoa (*Chenopodium quinoa* Willd.): An overview of the potentials of the "golden grain" and socio-economic and environmental aspects of its cultivation and marketization. *Foods, 9*(2), 216. https://doi.org/10.3390/foods9020216

Arneja, I., Tanwar, B., & Chauhan, A. (2015). Nutritional composition and health benefits of golden grain of 21st century, quinoa (*Chenopodium quinoa* Willd.): A review. *Pakistan Journal of Nutrition, 14*(12), 1034–1040.

Aune, D., Keum, N., Giovannucci, E., Fadnes, L. T., Boffetta, P., Greenwood, D. C., Tonstad, S., Vatten, L. J., Riboli, E., & Norat, T. (2016). Whole grain consumption and risk of cardiovascular disease, cancer, and all-cause and cause-specific mortality: Systematic review and https://doi.org/10.1136/bmj.i2716

Clark, M. J., & Slavin, J. L. (2013). The effect of fiber on satiety and food intake: A systematic review. *Journal of the American College of Nutrition, 32*(3), 200–211.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Genitsaridi, I., Salpea, P., Salim, A., Sajjadi, S. F., Tomic, D., James, S., Thirunavukkarasu, S., Issaka, A., Chen, L., Basit, A., Luk, A. O. Y., Ma, R. C. W., Mbanya, J.-C., Ramachandran, A., Wild, S. H., Duncan, B. B., Boyko, E. J., & Magliano, D. J. (2026). 11th edition of the IDF Diabetes Atlas: Global, regional, and national diabetes prevalence estimates for 2024 and projections for 2050. *The Lancet Diabetes & Endocrinology, 14*(2), 149–156. https://doi.org/10.1016/S2213-8587(25)00299-2

International Diabetes Federation. (2025). *Pakistan: IDF Diabetes Atlas, 11th edition, country profile*. https://idf.org/our-network/regions-and-members/middle-east-and-north-africa/members/pakistan/

Julious, S. A. (2005). Sample size of 12 per group rule of thumb for a pilot study. *Pharmaceutical Statistics, 4*(4), 287–291. https://doi.org/10.1002/pst.185

Machalias, A., Ferguson, J. J. A., Guy, T., & Beck, E. J. (2026). Cereal fibers and satiety: A systematic review. *Nutrition Reviews, 84*(1), 47–68. https://doi.org/10.1093/nutrit/nuaf083

Navarro-Perez, D., Radcliffe, J., Tierney, A., & Jois, M. (2017). Quinoa seed lowers serum triglycerides in overweight and obese subjects: A dose-response randomized controlled clinical trial. *Current Developments in Nutrition, 1*(9), e001321. https://doi.org/10.3945/cdn.117.001321

NCD Risk Factor Collaboration (NCD-RisC). (2024). Worldwide trends in underweight and obesity from 1990 to 2022: A pooled analysis of 3663 population-representative studies with 222 million children, adolescents, and adults. *The Lancet, 403*(10431), 1027–1050. https://doi.org/10.1016/S0140-6736(23)02750-2

Frontier in Medical & Health Research

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

Pakistan Institute of Development Economics. (2025). *Prevalence and determinants of overweight and obesity among adults in Pakistan*. https://pide.org.pk/research/prevalence-and-determinants-of-overweight-and-obesity-among-adults-in-pakistan/

Reynolds, A. N., Akerman, A. P., & Mann, J. (2020). Dietary fibre and whole grains in diabetes management: Systematic review and meta-analyses. *PLOS Medicine, 17*(3), e1003053. https://doi.org/10.1371/journal.pmed.1003053

dose–response meta-analysis of prospective studies. *BMJ, 353*, i2716.

The News International. (2025, April 8). Pakistan ranks first globally in diabetes prevalence. *The News International*. https://www.thenews.com.pk/print/1299445-pakistan-ranks-first-globally-in-diabetes-prevalence

Topp, C. W., Østergaard, S. D., Søndergaard, S., & Bech, P. (2015). The WHO-5 Well-Being Index: A systematic review of the literature. *Psychotherapy and Psychosomatics, 84*(3), 167–176. https://doi.org/10.1159/000376585

World Health Organization. (2000). *Obesity: Preventing and managing the global epidemic* (WHO Technical Report Series No. 894). World Health Organization.

World Health Organization. (2023). *Interventions to promote healthy diet: Technical brief on diet-related noncommunicable disease prevention*. https://cdn.who.int/media/docs/default-source/ncds/mnd/technical-brief-unhealthy-diet.pdf

World Health Organization. (2025). *Obesity and overweight*. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

World Obesity Federation. (2024). *World obesity atlas 2024*. https://www.worldobesity.org/news/world-obesity-atlas-2024

Xu, X., Luo, Z., Yang, Q., Xiao, Z., & Lu, X. (2019). Effect of quinoa flour on baking performance, antioxidant properties and digestibility of wheat bread. *Food Chemistry, 294*, 87–95. https://doi.org/10.1016/j.foodchem.2019.05.037

Ye, E. Q., Chacko, S. A., Chou, E. L., Kugizaki, M., & Liu, S. (2012). Greater whole-grain intake is associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. *The Journal of Nutrition, 142*(7), 1304–1313. https://doi.org/10.3945/jn.111.155325

Zeng, H., Cai, X., Qiu, Z., Liang, Y., & Huang, L. (2023). Glucolipid metabolism improvement in impaired glucose tolerance subjects consuming a quinoa-based diet: A randomized parallel clinical trial. *Frontiers in Physiology, 14*, 1179587. https://doi.org/10.3389/fphys.2023.1179587