ORIGINAL ARTICLE

Formulation and Optimization of Quinoa Chickpea Apple Pomace-Based Protein Bar for Protein Energy Malnutrition

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Abstract

Aim: Protein-energy malnutrition (PEM) remains a primary global health concern due to limited access to balanced diets in vulnerable populations. The development of protein-rich functional foods offers a sustainable approach to addressing this challenge. Quinoa is a pseudocereal rich in essential amino acids. **Materials and Methods:** In the presented study, a combination of chickpea and quinoa was utilized to formulate a protein-enriched functional bar. Apple pomace, an agro-industrial by-product, was incorporated to enhance nutritional value and promote waste valorization. Response surface methodology was employed to optimize the formulation, resulting in 11 experimental trials based on protein content and sensory acceptability. **Results and Discussion:** The optimized bar provided 15.8 g protein and 307.71 kcal/100 g, satisfying both nutritional adequacy and sensory quality parameters. The formulated protein bar has potential in fulfilling daily protein requirements by approximately 25–30% of body weight, depending on the individual's body weight, thereby contributing to the management of PEM. **Conclusion:** Future research should focus on clinical and consumer-based trials to evaluate acceptance, efficacy, and long-term health benefits of the developed product.

Key words: Functional food, health, population, protein bar, protein-energy malnutrition

INTRODUCTION

Malnutrition in all its forms is a serious problem worldwide and a significant barrier to achieving the SDG goal of zero hunger by 2030. This problem is prevalent in areas where poverty, contaminated water, food insecurity, and various waterborne diseases are prevalent. Protein-energy malnutrition (PEM) is often described as a silent emergency in the world and the main reason for various deficiencies, such as stunting, wasting, underweight, and child death. In the growing age, there is a high demand for protein energy, and they have a deficiency in these nutrients in their diet.[1]

The global fruit and vegetable processing market reached a substantial value of approximately 314 billion U.S. dollars in 2023. India stands as the second-largest fruit and vegetable producer globally, with a current production volume of around 319 million tons. Approximately 7.4 million tons of this production undergo processing. Fruit cultivation encompasses approximately 7.05 million hectares, whereas vegetable cultivation spans 11.35 million hectares. The processing of fruits generates significant waste materials, including pomace, peels, and seeds, accounting for nearly 1.83 million tons.[1]

The residual material left after juice extraction is known as pomace, and its disposal often poses environmental and legal challenges. It is essential to recognize that these unconventional resources, such as pomace and other waste products, can be a valuable repository of nutrients, dietary fibres, colorants, antioxidant compounds, and other substances beneficial for human health.[2] According to

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Gajera *et al*.,[3] fruit by-products have many properties, such as antimicrobial, antibacterial, anti-diabetic, antiviral, cardiovascular disease (CVD) protective, and many more. In addition, they possess a good water-binding capacity that can be utilized in the food industry for the textural, binding, and rheological properties of food products.[4]

Pulses are often consumed with cereals; this combination is a staple diet in many developing countries. This dietary pairing is crucial for maintaining the balance of essential amino acids.[5] In the evolving landscape of the future food market, the focus has shifted toward exploration of ensuring food security, safety, and sustainable protein sources. With a significant portion of the population transitioning to vegan diets, there is a growing emphasis on exploring plant-based protein sources. Highly nutritious snacks are developed using dried fruits, cereals, pulses, millet, pseudocereals, and nuts. These products cater to the dietary needs of school-going children, working individuals, and athletes who require a daily intake of high protein with fewer calories.[6]

In addition, some individuals who are managing their weight may opt for high-protein bars as meal replacements, believing that this approach can assist in weight control.[7] Legumes are renowned for their rich protein content, while pseudocereals, especially Quinoa, have the advantage of having all essential amino acids. Chickpeas, as a notable example, represent a valuable source of protein and unsaturated fatty acids, such as linoleic and oleic acids. Chickpeas additionally contain essential bioactive compounds, including isoflavones and carotenoids. These remarkable attributes collectively contribute to a range of potential health benefits, such as the prevention of CVD, muscle building, the reduction of cholesterol levels, the promotion of anti-diabetic effects, the potential for anticancer properties, and the capacity to mitigate inflammation.

Legumes and pseudocereal bars have been gaining popularity as they are packed with essential nutrients, amino acids, and many functional components. For example, pseudocereal bars with added iron, Vitamin A, Vitamin E, and fiber are considered healthy and come under the category of functional foods because of the high concentration of nutrients present in them.[8] Fruit and vegetable byproducts offer an excellent opportunity for enhancing the value and functional properties of bars.[9] Snack bars are not only convenient but also highly appealing to school-going children, teenagers, and persons seeking high-energy cereal protein bars and food products. These are rich in nutrients and play an essential role in promoting both mental and physical development.

However, the choices available for children to access wholesome and nourishing food products remain quite limited. There is an increasing demand for functional food that is rich in protein as well as good sensory attributes. Bridging this gap necessitates the development of products that align with the evolving trends of nutraceuticals and functional foods. Combining chickpea and quinoa with fruit pomace holds the potential to develop highly nutritious bars suitable for a broad spectrum of individuals. Considering the nutritional and bioactive potential of quinoa, chickpea, and apple pomace, the present study aimed to optimize the formulation of protein bars. By utilizing fruit by-products and incorporating the nutrient-rich attributes of pseudocereals and legumes, the study seeks to develop sustainable and appealing food options that address food waste challenges while enhancing nutritional value.

MATERIALS AND METHODS

Raw materials and sample collection

The cleaned, sorted, and dried quinoa and chickpeas of Indian origin were procured from the local market in Hisar, branded as Organic India Private Limited. Apple pomace was dried at home in the sun, whereas jaggery powder was purchased from the local market from Organic India.

Standardization of ingredients for bars

The primary ingredients employed in the development of the protein bar were chickpea, quinoa, and apple pomace. Chickpea constituted the primary component, incorporated at levels ranging from 70% to 80% across different formulations. Quinoa and apple pomace were each included within the range of 5–15%. To provide sweetness and act as a binding agent, jaggery syrup (10 g) was added to the formulation. The standardized proportions of the individual ingredients used for preparing a 110 g protein bar, including chickpea (75–85 g), quinoa (5–15 g), apple pomace (5–15 g), and jaggery (10 g).

Bar preparation

The protein bars were prepared using chickpea, quinoa, apple pomace powder, and jaggery syrup as the binding agent [Figure 1]. Chickpea, quinoa, and apple pomace powder were initially subjected to dry roasting at 120–150°C for 1–2 min to enhance flavor, improve digestibility, and reduce moisture content. The binding agent was prepared using jaggery syrup, which was heated to 118–122°C (soft ball stage) until the total soluble solids reached approximately 78–80°Brix. The roasted dry ingredients were immediately mixed with the hot jaggery syrup at 80–90°C, followed by continuous stirring to ensure uniform coating and proper binding. The mixture was then transferred into a buttered moulding tray at 70–80°C and lightly pressed to achieve a uniform thickness. After cooling to ambient temperature (25–30°C), the product was cut into standardized pieces and packed. Finally, the packaged bars were stored at ambient temperature for further evaluation.

Experimental design and formulation of protein bar

This study employed an I-optimal Coordinate Exchange design with three components – chickpea, quinoa, and apple pomace powder – on sensory attributes, including appearance, taste, texture, mouthfeel, overall acceptability, and protein content. Based on preliminary trials, the total weight of the bar was fixed at 110 g/sample. The proportions of quinoa, chickpea, and apple pomace powder were constrained within the ranges of 5–15 g, 75–85 g, and 5–15 g, respectively. The experimental design resulted in 11 experiment designs as presented in Table 1.

Quality evaluation of the prepared bar

Sensory evaluation of the protein bar

Sensory evaluation of the prepared protein bar samples was conducted by a semi-trained panel comprising 50 members, including faculty and students from FC College for Women, Hisar, Haryana. The panelists were first instructed on the method to be used for evaluating the sensory attributes. The samples were served to the panellists on white plates. The panellists were instructed to cleanse their mouths with a swish of distilled water and rinse them out with tap water. Between each session, there should be a minimum of 2 min of rest. The sensory attributes and proteins were analyzed.[13]

Proximate composition

The proximate composition of the formulated protein bar was evaluated to determine its nutritional profile. Moisture content, crude protein, crude fat, crude fiber, and total ash were estimated using standard analytical procedures recommended by the Association of Official Analytical Chemists (AOAC, 2023).[8] The carbohydrate content was not measured directly but was calculated by difference, i.e., by subtracting the combined percentage of moisture, crude protein, crude fat, and total ash from 100%. This approach provides an indirect but reliable estimation of the total carbohydrate fraction present in the product. The caloric value (energy content) of the protein bar was calculated based on the proximate composition using the Atwater conversion factors, which are widely applied for nutritional energy estimation. Accordingly, protein and carbohydrate contents were multiplied by a factor of 4 kcal/g each, while crude fat was multiplied by 9 kcal/g. The total energy value was then expressed as kilocalories per 100 g of the product.[10]

RESULTS AND DISCUSSION

Effect of ingredient proportions on sensory attributes and protein quantity and optimization of bar formulation

The formulation of composite food products such as protein bars requires an intricate balance between nutritional enhancement and sensory acceptability. In this study, a three-component mixture consisting of chickpea flour (A), quinoa flour (B), and apple pomace powder (C) was investigated for its effects on sensory attributes – appearance, taste, texture, mouth feel, and overall acceptability – alongside protein content. Table 2 represents the response models summarizing analysis of variance statistics, fit statistics, and equations in terms of the coded component. Ternary mixture design [Figure 2] and response surface methodology (RSM) were employed to identify the optimal proportions of ingredients to maximize desirability. The results reveal significant trends that reflect the interplay between protein-rich ingredients (chickpea and quinoa) and fiber-rich apple pomace powder, with important implications for optimizing food products.

Protein content

Protein content was strongly influenced by the proportion of chickpea flour, followed by quinoa flour. At the same time, apple pomace powder contributed minimally to protein enhancement due to its higher fibre and lower protein

Table 1: Experimental runs and quality attributes

Chickpea (g)	Quinoa (g)	Apple pomace powder (g)	Appearance	Taste	Texture	Mouth feel	Overall acceptability	Protein content (%)
85	9.63	5.37	7.4	8.1	7.4	7.8	7.68	15.26
81.88	11.66	6.46	7	7.1	7.2	7.1	7.1	15
78.06	13.52	8.42	7.1	6.5	7.3	6.6	6.88	14.63
75	11.22	13.78	6.4	6.7	6.8	6.8	6.68	13.88
77.09	7.91	15	7.3	8.1	6.5	8.1	7.5	13.83
80.08	5	14.92	7.9	8	6.7	7.8	7.6	13.97
83.39	8.02	8.59	7.3	7.7	7.3	7.8	7.53	14.83
80.11	10.2	9.69	7.8	7.6	7	7.4	7.45	14.56
83.3	5	11.7	7.4	8.2	6.9	8.4	7.73	14.47
75	14.19	10.81	6.8	6.3	7.1	6.3	6.63	14.2
80	15	5	6.7	6.2	7.6	6	6.63	15.08

Table 2: The proximate composition of optimized protein bar

Nutrient	Content
Moisture (g/100g)	9.14±0.06
Protein (g/100g)	17.01±0.15
Fat (g/100g)	5.53±0.09
Ash (g/100g)	2.34±0.04
Fiber (g/100g)	18.73±0.12
Carbohydrate (g/100g)	65.98±0.22
Calories (kcal/100 g)	307.71±1.34

Note: Values are expressed as mean±standard deviation of triplicate determinations (*n*=3)

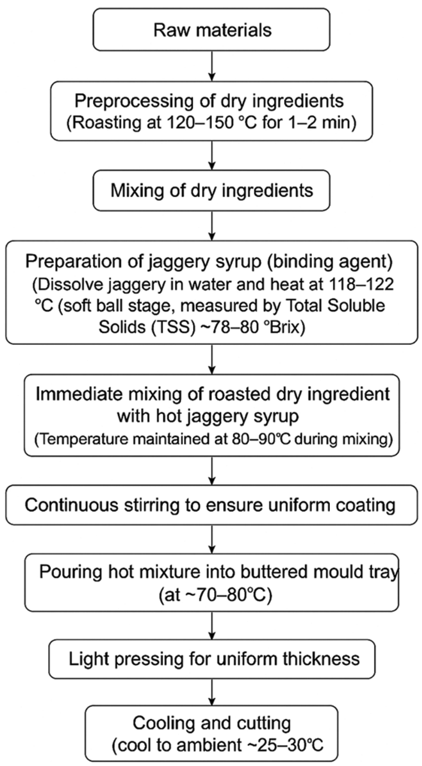

Figure 1: Procedure for preparation of protein bar

composition. As the ternary plots reveal, protein levels peaked (≈15.3%) when chickpea was present at higher proportions (>80 g), with a modest contribution from quinoa. Conversely, higher inclusion of apple pomace powder led to a dilution effect, reducing protein concentration to approximately 13.8–14.2%. This outcome aligns with the known nutritional profile of the ingredients: chickpea flour contains approximately 20–22% protein, quinoa about 14–16%, and apple pomace is largely dietary fiber with negligible protein. Thus, for a protein-enriched snack formulation, chickpea emerges as the dominant contributor, and its proportion must be carefully balanced with sensory quality considerations.

Appearance

The sensory attribute of appearance was most favorable when moderate levels of chickpea (≈approximately 80–83 g) were combined with low-to-moderate levels of apple pomace (≈approximately 8–12 g). The highest predicted appearance score (7.53) corresponded to such combinations. In contrast, higher levels of apple pomace (>15 g) tended to reduce appearance scores, likely due to darker coloration, coarse particle distribution, and potential visual heterogeneity imparted by pomace fibers. Quinoa, although a secondary contributor, influenced appearance positively when included at intermediate levels (10–12 g), likely enhancing visual uniformity without overwhelming the matrix. These findings highlight the importance of balancing functional fibers with protein-rich flours to maintain consumer-perceived visual appeal.

Taste

Taste scores reached their peak (7.6–7.7) when chickpea flour was maintained at high levels (≈83 g) alongside moderate apple pomace inclusion (≈8–10 g). Apple pomace contributed a subtle sweetness and fruity undertone, which complemented the otherwise beany or earthy flavors of chickpea and quinoa. However, excessive apple pomace (>13 g) negatively impacted the taste, resulting in reduced scores (~6.2–6.7). This reduction may be attributed to the presence of residual polyphenols and tannins in pomace, imparting bitterness or astringency at higher concentrations. Quinoa's contribution appeared neutral to slightly negative at higher levels (>14 g), likely due to the presence of saponins, which are associated with bitterness if not entirely removed during processing. Therefore, optimal taste required maximizing chickpea content while allowing limited but strategic inclusion of apple pomace to mask legume off-notes and improve palatability.

Texture

Texture was strongly affected by both chickpea and quinoa proportions, with the highest texture ratings (~7.4–7.5) observed when chickpea was predominant and quinoa maintained at intermediate levels (≈10–12 g). Apple pomace, although beneficial for fiber enrichment, harmed texture when present in high proportions. Excessive pomace inclusion led to coarse, crumbly, and less cohesive matrices, reducing panellist scores (~6.3–6.7). Conversely, moderate levels of pomace (~8–10 g) maintained acceptable textural properties by contributing bulk and binding through water-holding capacity. Thus, texture optimization required a delicate equilibrium between structural proteins from chickpea and quinoa, and dietary fiber from apple pomace.

Mouthfeel

Mouthfeel followed a similar trend to texture, with the highest scores (≈7.8–8.4) observed in formulations containing high chickpea levels and balanced proportions of quinoa and apple pomace. Apple pomace enhanced mouthfeel positively when included moderately (≈8–10 g), likely by providing juiciness and preventing dryness, but at higher levels, the fibrous sensation was perceived as undesirable. At intermediate levels, quinoa contributed positively to smoothness, but excess led

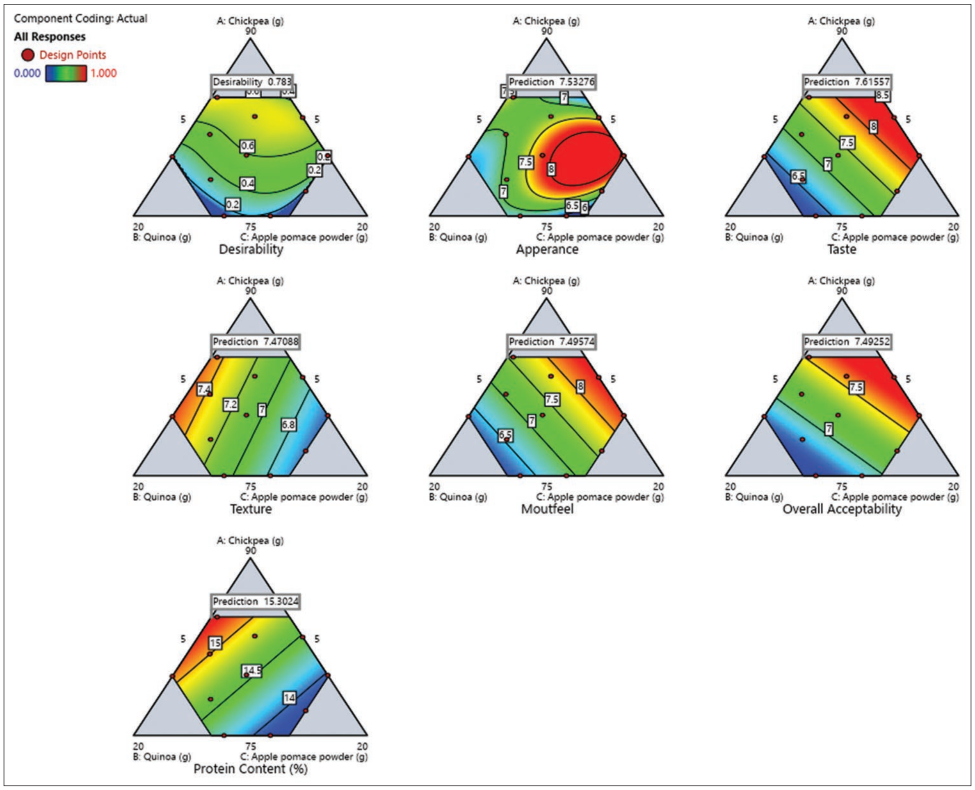

Figure 2: Ternary contour plots showing the effect of chickpea (A), quinoa (B), and apple pomace powder (C) on the predicted responses of protein bar formulation. The plots represent (a) overall desirability, (b) appearance, (c) taste, (d) texture, (e) mouthfeel, (f) overall acceptability, and (g) protein content.

to grittiness. Significantly, the highest mouthfeel score (8.4) corresponded to a formulation with 83.3 g of chickpea, 5 g of quinoa, and 11.7 g of apple pomace, suggesting that limited quinoa and moderate pomace synergise with chickpea to optimize consumer-perceived textural smoothness.

Overall acceptability

Overall acceptability scores reflected a composite measure of all sensory attributes. The highest values (≈7.7–7.8) were associated with formulations containing high chickpea (80–85 g), low-to-moderate quinoa (5–10 g), and balanced apple pomace (8–12 g). These results indicate that while protein content is maximized by high chickpea inclusion, consumer preference is optimized by incorporating sufficient apple pomace to enhance sweetness, flavor masking, and mouthfeel. However, when apple pomace exceeded 13 g, overall acceptability declined due to compromised texture, appearance, and bitterness. Thus, the data reveal that optimal formulations require prioritizing chickpea as the protein base while leveraging moderate amounts of apple pomace for sensory improvement.

Scientific and practical implications

The study demonstrates the critical role of ingredient interactions in determining both nutritional and sensory quality of functional food products. Chickpea flour, with its high protein content, is indispensable for achieving nutritional targets but risks introducing beany flavors and dense textures if used alone. Quinoa provides complementary proteins and enhances textural properties, but its contribution must be carefully moderated to avoid bitterness. Apple pomace serves as a functional fiber source with added sensory benefits, particularly in terms of taste and mouth feel; however, excessive inclusion compromises product quality due to textural coarseness and astringency. From a product development standpoint, the findings suggest that a chickpea-dominant formulation with controlled additions of quinoa and apple pomace achieves the best compromise between healthfulness and consumer appeal. The incorporation of apple pomace also provides a sustainability advantage, valorising fruit by-products into value-added functional ingredients.

Prediction of optimized bar formulation and its confirmation

Numerical optimization was performed using RSM to predict the optimal formulation of the protein bar within the specified experimental constraints. The model suggested an optimized blend consisting of 85% chickpea flour, 10% quinoa, and 5% apple pomace powder. At this composition, the predicted response values for sensory attributes were appearance (7.53), taste (7.62), texture (7.47), mouth feel (7.50), and overall acceptability (7.49), all of which fell within the desirable range. Furthermore, the formulation was predicted to yield a protein content of 15.30%, thereby meeting the nutritional target. The composite desirability score of 0.783 indicates that the selected formulation provides a satisfactory balance between sensory quality and nutritional enhancement, validating its suitability as a protein-rich functional bar.

The color gradient from blue (low) to red (high) indicates the magnitude of each response. Black dots represent design points used in the experimental design, and predicted values at the optimized formulation are displayed on each plot.

The optimized protein bar formulation was experimentally validated to confirm the adequacy of the predicted model. The confirmation trials showed a close agreement between predicted and observed values for both sensory and nutritional responses. For taste, the predicted mean was 7.53, while the experimental mean was slightly higher (7.71), both falling within the 95% prediction interval (7.35–8.16). Similarly, texture (predicted: 7.62; observed: 8.46), mouthfeel (predicted: 7.47; observed: 7.77), and appearance (predicted: 7.50; observed: 8.28) demonstrated higher actual values compared to the model predictions, indicating a positive deviation toward consumer preference. The overall acceptability also showed a favorable outcome, with the predicted mean of 7.49 and observed mean of 8.0 within the prediction interval (7.04–7.94). For protein content, the predicted value (15.30%) closely matched the experimental mean (14.51%), with only a minor deviation, confirming the nutritional adequacy of the formulation. These findings validate the reliability of the optimization model, with all experimental values lying within or close to the prediction intervals, thereby ensuring the robustness of the formulation. The positive shift in sensory responses suggests that the optimized protein bar not only meets nutritional targets but also exceeds expectations in terms of consumer acceptability.

Proximate composition of optimized bar

The formulated product (≈80% chickpea, 10% quinoa, 5% apple pomace, and ~10 g jaggery syrup per 100 g) shows a proximate profile of 17.01 g protein, 5.53 g fat, 65.98 g carbohydrate, and 18.73 g dietary fiber with 9.14% moisture and 2.34% ash; the energy value of 307.7 kcal/100 g is consistent with available carbohydrate (total carbohydrate minus fiber), yielding an energy distribution of ~22% from protein, ~16% from fat, and ~62% from carbohydrate [Tables 2 and 3]. This macronutrient pattern is pertinent to PEM: Relative to WHO specifications for ready-to-use therapeutic foods (520–550 kcal/100 g with 10–12% energy from protein and 45–60% from fat), the present mix is markedly lower in energy density and lipid content, indicating it is better suited as a supplementary/preventive food or as part of complementary feeding, rather than as a stand-alone therapeutic product for severe acute malnutrition (SAM). The protein content is comparatively high for a plant-based blend and is supported by the protein quality of the ingredients: Chickpea proteins typically show PDCAAS values ~0.75–0.84 depending on processing (cooked/baked/extruded),

Table 3: Response models summarize analysis of variance statistics, fit statistics, and equations in terms of the coded component

Response	Equation	Model type	F-value (P-value)	CV%	R^2	Adj-R^2	Pred-R^2	Adeq precision	Press
Taste	Y=8.80A+5.24B+8.00C	Linear	26.92 (0.0003)	4.28	0.8706	0.8383	0.8398	13.0536	1.61
Texture	Y=+7.98A+9.94B+2.75C-6.15AB+6.32AC +4.12BC+ 1.85ABC+1.61AB (A-B)-11.96AC (A-C)-13.82BC (B-C)	Texture	39.19 (0.0458)	1.58	0.9074	0.8842	0.8398	15.5916	0.1733
Mouth feel	Y=8.66A+5.16B+8.10C	Linear	32.13 (0.0002)	3.98	0.8893	0.8616	0.75	13.05	1.48
Appearance	Y=7.29A+7.71B-1.66C-1.73AB+19.73AC +14.71BC-5.05ABC +6.57AB (A-B) -29.12AC (A-C)-14.43BC (B-C)	Cubic	2277.73 (0.0154)	0.1240	1.00	0.9996	0.9488	176.45	0.1048
Overall acceptability	Y=+8.20A+6.07B+7.43C	Linear	30.96 (0.0002)	9.31	0.8856	0.8570	0.7813	14.4296	2.32
Protein content	Y=+15.52A+14.87B+13.18C	Linera	23321.73 (<0.0001)	0.0504	0.9998	0.9998	0.9997	374.576	0.0008

and quinoa is notable for a balanced essential amino acid profile with relatively high lysine and sulfur amino acids, complementing pulse proteins and improving overall amino acid adequacy – features relevant when animal-source foods are scarce.[11,12] Processing choices also matter for PEM-oriented products: Common antinutritional factors in pulses and quinoa (phytate, tannins, trypsin inhibitors, and saponins) can depress protein and mineral bioavailability, but soaking, germination, thermal treatments, extrusion, and polishing/washing (for quinoa saponins) substantially reduce these compounds without compromising amino acid composition, thereby enhancing digestibility and potential micronutrient absorption.[13,14] The blend's high dietary fibre (~18.7 g/100 g) – partly contributed by apple pomace – adds functional benefits (satiety and gut health) yet may modestly attenuate mineral uptake in some contexts; evidence is mixed and fiber effects are type- and dose-dependent, underscoring the value of phytate-reducing processing and, where appropriate, mineral fortification for PEM-prone groups.[15-17] Apple pomace additionally provides polyphenols and other bioactives that can improve antioxidant status, a potential co-benefit in malnourished populations experiencing oxidative stress.[18] Jaggery syrup contributes carbohydrate energy and small but meaningful amounts of minerals (notably non-heme iron), which may help address anaemia risk when coupled with phytate-lowering preparation methods. However, jaggery alone is not a robust iron fortificant.[19] Finally, the low moisture (~9%) favors shelf stability in hot climates. The combination of pulses and pseudocereals aligns with WHO guidance emphasizing nutrient-dense complementary foods from pulses, seeds, fruits, and (where feasible) animal-source foods to prevent PEM; however, to meet therapeutic targets for SAM, the formula would require additional lipid (and micronutrient) fortification to raise energy density and fat-derived energy into the recommended range. Based on above findings, the optimized bar has chickpea 85%, quinoa 10%, and apple pomace 5%. It should be further confirmed by a two- sided test with 95% confidence.

CONCLUSION

The optimized protein bar developed in this study represents a nutritionally balanced and affordable product with the potential to address PEM, particularly in resource-limited settings. By incorporating a blend of macro- and micronutrients, the formulation provides an adequate supply of carbohydrates, dietary fiber, protein, and essential minerals, making it suitable for consumption across all age groups. The strategic use of protein sources ensures that the product contributes to meeting daily protein requirements, which is a pressing need in many developing nations. Importantly, the processing technique employed is simple, cost-effective, and easily adaptable for small-scale and cottage industries, thereby promoting widespread accessibility and commercial scalability. Beyond meeting basic nutritional needs, the protein bar can also be positioned as a functional food with added health benefits, supporting overall well-being and potentially reducing the risk of nutrition-related disorders.

Looking forward, several areas warrant further investigation to maximise the product's potential and consumer impact. Future studies should include comprehensive quality assessments focusing on sensory attributes such as flavor, texture, and mouthfeel, as these strongly influence consumer acceptance. Investigations into protein digestibility and bioavailability are equally important to ensure that the nutritional benefits are effectively delivered to the body. In addition, evaluating microbial safety and storage stability will be critical to determining the product's shelf life and ensuring long-term safety for consumers under different storage and distribution conditions. Expanding research into fortification with bioactive compounds or probiotics could further enhance the functional properties of the protein bar, opening avenues for targeted health benefits such as gut health, improved immunity, or glycemic control. Finally, conducting clinical trials and community-level intervention studies will help validate the product's efficacy in combating malnutrition and promoting health, thereby supporting its large-scale implementation as a sustainable, health-promoting dietary option.

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