BIOTECHINTELLECT, 2026, 3(1) e23 (1-13)
https://jbiotechintel.com/index.php/biotechintel

Policy Report

eISSN: 3115-7920

OPEN ACCESS

Nutritional Reformulation to Functional Food Innovation: An Evidence-Informed Framework for the Development of Synbiotic Cereal-based Snacks

Mohammad Mahdi Fadavi[1,2], Samira Hosseini[3], Ghasem Fadavi[4], Fatemeh Mohammadi-Nasrabadi[5*], Fatemeh Esfarjani[5,6*]

[1] Diabetes Research Center, Endocrinology and Metabolism Clinical Sciences Institute, Tehran University of Medical Sciences, Tehran, Iran
[2] School of Medicine, Tehran University of Medical Sciences, Tehran, Iran
[3] Ph.D. Candidate in Food and Nutrition Policy, Faculty of Nutrition and Food Sciences, Tabriz University of Medical Sciences, Tabriz, Iran
[4] Food, Halal and Agricultural Products Research Group, Research Center of Food Technology and Agricultural Products, Standard Research Institute, Karaj, Alborz, Iran
[5] Food and Nutrition Policy and Planning Research Department, National Nutrition and Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[6] Iranian Scientific Association for Health, Food and Nutrition, Tehran, Iran.

Article history:
Received 02 Aug 2026
Revised 03 Oct 2026
Accepted 06 Oct 2026
Published online 08 Oct 2026

Keywords: lipid quality, prebiotic, probiotic, snack reformulation, symbiotic, dietary fibre, whole grain.

How to cite this article:
Fadavi MM, Hosseini S, Fadavi G, Mohammadi-Nasrabadi F. Esfarjani F. Nutritional reformula-tion to functional food innovation: an evidence informed frame work for the development of synbiotic cereal-based snacks. BiotechIntellect, 2026; 3(1): e23, 1-13. https://doi.org/10.66224/BiotechIntellect.3.1.62

*corresponding author's
Fatemeh Mohammadi Nasrabadi
f.mohammadinasrabadi@sbmu.ac.ir
Fatemeh Esfarjani
f.esfarjani@sbmu.ac.ir

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ABSTRACT

Background: Commercial snack foods are widely consumed but may be high in saturated and trans fatty acids, refined carbohydrates, and energy while contributing limited dietary fiber. This study aimed to develop a health-oriented synbiotic cereal-based snack integrating nutritional reformulation with probiotic-prebiotic functionality.

Material and Methods: An evidence-informed conceptual framework was developed by synthesizing scientific and regulatory evidence across seven domains: dietary fat quality, carbohydrate quality, probiotics, prebiotics, synbiotics, food-matrix and processing considerations, and health-claim substantiation. Evidence was translated into sequential product-development and validation stages addressing lipid quality, whole grains and dietary fiber, strain-specific probiotic selection, prebiotic functionality, synbiotic integration, and probiotic protection and stability.

Results and Conclusion: The framework establishes a progressive evidence hierarchy: nutritional reformulation → functional-ingredient characterization → product stability and safety → demonstrated synbiotic functionality → substantiated health benefit. Required validation includes strain-level identification and safety, probiotic viability throughout processing and storage, prebiotic selective utilization, physicochemical stability, sensory acceptance, microbiological safety, and appropriate human evidence when health benefits are claimed. The framework emphasizes that prebiotic co-incorporation alone is insufficient to demonstrate synbiotic functionality. A synbiotic cereal-based snack provides a practical research development model for integrating nutritional improvement with functional-food innovation. The proposed framework offers a translational pathway for evidence-based functional snack development while supporting scientifically appropriate product characterization, regulatory evaluation, and substantiation of synbiotic and health claims.

What is "already known":

- Commercial snack foods provide may be high in saturated and trans fatty acids, refined carbohydrates, and energy while contributing limited dietary fiber.
- Incorporating whole grains and dietary fiber into cereal-based snacks may improve nutritional profile, although enrichment may adversely affect sensory.
- Synbiotic cereal-based snack can provide a practical research development model for integrating nutritional improvement with functional-food innovation.

What this article adds:	• An evidence-informed conceptual framework was developed across 7 domains: dietary fat quality, carbohydrate quality, probiotics, prebiotics, synbiotics, food-matrix and processing considerations, and health-claim substantiation • The framework establishes a progressive evidence hierarchy: nutritional reformulation → functional-ingredient characterization → product stability and safety → demonstrated synbiotic functionality → substantiated health benefit. • Required validation includes strain-level identification and safety, probiotic viability throughout processing and storage, prebiotic selective utilization, physicochemical stability, sensory acceptance, microbiological safety, and appropriate human evidence when health benefits are claimed.

1. INTRODUCTION

Commercial snack foods are widely consumed because of their convenience, accessibility, palatability, and suitability for rapid consumption. However, many snack products can provide relatively high amounts of saturated fat, trans fat, refined carbohydrates, and energy while contributing limited dietary fiber. Consequently, snack reformulation represents an opportunity to improve the nutritional quality of frequently consumed foods.

Current World Health Organization guidance emphasizes both the amount and quality of dietary fat and recommends limiting saturated and trans fatty acid intake while favoring appropriate replacement nutrients, particularly unsaturated fatty acids [1]. Therefore, reformulation should not simply aim to reduce total fat; it should improve the quality of the lipid fraction while maintaining technological functionality and acceptable sensory characteristics.

Carbohydrate quality provides a second opportunity for improvement. Greater whole-grain consumption has been associated with more favorable cardiovascular and mortality outcomes, while higher dietary fiber intake is associated with beneficial health outcomes across several chronic disease endpoints [2, 3]. Incorporating whole grains and dietary fiber into cereal-based snacks may therefore improve their nutritional profile, although excessive enrichment may adversely affect texture, moisture, flavor, and consumer acceptance.

The concept of a synbiotic requires an additional level of evidence. The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus defines a synbiotic as a mixture containing live microorganisms and substrate(s) selectively utilized by host microorganisms that confer a health benefit. The consensus further distinguishes complementary synbiotics from synergistic synbiotics, with the latter specifically designed to promote utilization of the substrate by the co-administered microorganism [4]. The development of synbiotic cereal-based snacks, including biscuits, cookies, corn- and legume-based snacks, and breakfast cereals, is an emerging approach in the production of functional foods. By combining live probiotic microorganisms with prebiotic compounds, these products may provide a convenient means of incorporating such ingredients into the diet. Whole grains, oats, resistant starch, inulin, and oligosaccharides are particularly relevant to the formulation of synbiotic products because of their potential functional properties. However, the simultaneous presence of a probiotic and a prebiotic in a product does not, by itself, demonstrate a synbiotic effect. Evidence should also address microbial viability, the utilization of the prebiotic component, stability during storage, and, when health benefits are claimed, appropriate biological outcomes.

The review by Yazici et al. [5] discusses the potential application of synbiotic combinations in solid cereal-based foods, including biscuits, cakes, pasta, and breakfast cereals. Various Lactobacillus species and ingredients such as inulin, guar gum, and maltodextrin have been investigated in these products. More recent studies have also examined probiotic-coated snacks enriched with legume flour. Nevertheless, baked foods create a particular challenge for probiotic delivery because processing conditions, oxygen, moisture, water activity, storage, and interactions among food components can affect microbial survival and functionality [6, 7]. Protection and encapsulation technologies may provide additional opportunities to improve probiotic survival, although their success depends on the microorganism, carrier material, processing conditions, and food matrix [8, 9].

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Accordingly, the present article proposes an evidence-informed model for developing a synbiotic cereal-based snack as a health-oriented snack model. The framework integrates nutritional reformulation with probiotic-prebiotic functionality and health claim substantiation.

2. METHODS

2.1. Study design

This study used an evidence-informed conceptual framework approach to develop a translational pathway for the design of a health-oriented synbiotic cereal-based snack. The objective was to integrate relevant evidence from nutrition, food science, microbiology, probiotic and prebiotic research, and health-claim substantiation into a coherent product-development framework. The methodological approach was structured around the principle that development of a functional snack should simultaneously address nutritional quality, food-matrix characteristics, probiotic and prebiotic functionality, product stability, safety, sensory acceptability, and the level of evidence required to support health-related claims.

2.2. Rapid review

A rapid literature search was conducted to identify reports published up to 2026. The search strategy combined keywords including “synbiotic”, “prebiotic”, “probiotic,” and “cereal,” using Boolean operators “AND” and “OR.” Electronic databases searched included PubMed, Scopus, Web of Science, Science Direct, and Google Scholar. To ensure comprehensive coverage, additional sources such as reference lists of relevant articles, project reports, conference abstracts, dissertations, and reviews were examined as gray literature. After initial screening of titles and abstracts for relevance, full texts of potentially eligible articles were assessed. Duplicate records were removed following importation into EndNote X7 (Thomson Research Soft, Philadelphia, PA).

Data extraction and quality assessment were performed independently by two reviewers, with discrepancies resolved through discussion or consultation with a third reviewer. Extracted information included study characteristics (first author, year of publication, and study design) and primary outcomes. Discrepancies between reviewers were resolved through discussion and consensus.

2.3. Evidence domains

Evidence was organized into seven predefined domains:

1. **Dietary fat quality:** saturated and trans fatty acids, appropriate replacement of less desirable fat sources, and implications for food formulation [1].
2. **Carbohydrate quality:** whole grains and dietary fiber and their relevance to healthy dietary patterns [2, 3].
3. **Probiotics:** strain-specific identity, safety, documented health effects, technological suitability, and viability in food matrices [6, 7].
4. **Prebiotics:** definition, selective utilization, and evidence requirements for demonstrating prebiotic functionality [10].
5. **Synbiotic:** complementary and synergistic synbiotic concepts and the requirement for demonstrated functionality and health benefit [4].
6. **Food-matrix and processing considerations:** effects of processing, moisture, water activity, oxygen, storage, packaging, and protective technologies on probiotic survival [6, 7, 9].
7. **Health-claim substantiation:** scientific evidence required to support nutrition and health claims associated with functional foods [8].

These domains were selected to reflect the major components required for translation of nutritional reformulation into a functional food product.

2.4. Evidence identification & synthesis

Relevant scientific and regulatory evidence was identified from the literature and authoritative guidance documents addressing dietary fat quality, whole grains, dietary fiber, probiotics, prebiotics, synbiotics, food matrices, probiotic stability, encapsulation and protection strategies, and nutrition and health claims. Priority was given to authoritative guidelines, international consensus documents, systematic reviews and meta-analyses, and relevant peer-reviewed reviews addressing food-technology and

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probiotic applications. The identified evidence was not quantitatively pooled because the purpose of the study was conceptual framework development rather than estimation of a common effect size.

Evidence was subsequently synthesized according to the predefined domains. For each domain, the following questions were considered: 1) What nutritional or functional characteristic should be addressed? 2) What evidence is required to support the proposed ingredient or intervention? 3) What technological constraints may affect implementation? 4) What product-level validation is required? And 5) what evidence is necessary before a functional or health claim can be made? This process enabled the integration of nutritional and functional considerations into a sequential product-development pathway.

2.5. Framework development

The framework was developed by translating the synthesized evidence into sequential but interconnected stages of product development. The framework comprised five principal components: 1) lipid-quality optimization, including reduction of saturated fatty acids (SFA) and trans fatty acids (TFA)-rich fat sources and their appropriate replacement; 2) whole-grain and dietary-fiber enrichment, while considering technological and sensory consequences; 3) strain-specific probiotic selection, based on identity, safety, documented efficacy, technological compatibility, and stability; 4) evidence-based prebiotic selection and synbiotic integration, with explicit consideration of selective substrate utilization and the distinction between complementary and synergistic synbiotics; and 5) food-matrix and probiotic-protection strategy, considering processing, packaging, storage, and technologies such as protective carriers and encapsulation. The framework was then extended to include product-level validation requirements, including viable-cell counts, stability, selective substrate utilization, physicochemical characteristics, sensory acceptance, microbiological safety, and relevant health outcomes.

2.6. Evidence hierarchy for product development

An evidence hierarchy was incorporated into the framework to distinguish different levels of product development. Improvement in nutritional composition was considered a distinct level of evidence from the presence of functional ingredients, demonstrated probiotic viability, demonstrated synbiotic functionality, and demonstrated health benefit. Accordingly, the framework follows the sequence:

Nutritional reformulation → functional-ingredient characterization → product stability and safety → demonstrated synbiotic functionality → substantiated health benefit.

This distinction was incorporated to avoid interpreting the incorporation of probiotic and prebiotic ingredients as sufficient evidence of synbiotic functionality. In accordance with the ISAPP consensus, a synbiotic requires evidence that the combined components meet the relevant definition and confer a health benefit [4].

2.7. Validation criteria

Because the proposed Cereal-Based Snack represents a research-development model, the framework identifies validation criteria that should be addressed before a product is considered a scientifically validated synbiotic food. These criteria include strain-level identification and safety assessment; viable probiotic-cell counts during processing and storage; stability under relevant storage conditions; characterization and validation of the proposed prebiotic substrate; evidence of selective substrate utilization where required; physicochemical quality, including moisture, water activity, texture, lipid oxidation, and fatty-acid composition; sensory acceptance; microbiological safety; and appropriate human evidence when a health benefit or health claim is proposed. The resulting framework was therefore designed as a translational research and product-development model rather than as evidence that a specific synbiotic cereal-based snack has already been developed or demonstrated to provide a health benefit. Table 1 indicates the core components and validation requirements.

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Table 1. Key Components and Validation Requirements for an evidence-based framework for the development of cereal-based synbiotic snacks

Component	Development objective	Principal consideration	Required evidence
Lipid fraction	Improve SFA/TFA† profile	Appropriate unsaturated lipid replacement	Fatty-acid profile; oxidative stability
Grain base	Increase nutritional quality	Whole-grain incorporation	Nutrient composition; texture
Dietary fiber	Increase fiber density	Technological compatibility	Fiber content; water activity; sensory quality
Probiotic	Provide a documented microorganism	Strain-specific evidence	Identity; safety; viable count
Prebiotic	Provide a selectively utilized substrate	Compatibility with probiotic	Selective utilization; functionality
Synbiotic combination	Integrate probiotic and substrate	Complementary or synergistic design	Functional and health evidence
Food matrix	Preserve product and microbial quality	Processing and storage effects	Shelf-life and viability testing
Final product	Balance nutrition and functionality	Consumer acceptability	Physicochemical, microbiological and sensory validation

† saturated fatty acids (SFA) & trans fatty acids (TFA)

3. RESULTS AND DISCUSSION

3.1. Narrative review

Research in this field varies in terms of its objectives and methodologies. Some studies have directly developed synbiotic cereal-based snacks, whereas others have investigated probiotic survival in Cereal-Based Snacks or the fermentation potential of dietary fiber incorporated into Cereal-Based Snack formulations. Additional studies have focused on the development of cereal-based snacks. For accurate interpretation, it is essential to distinguish between studies of synbiotic products, probiotic products, and products containing ingredients with potential prebiotic properties (Table 2).

3.2. Evidence-Informed Product Development

Lipid-quality optimization: The first component is improvement of the lipid fraction. SFA- and TFA-rich fat sources should be reduced where technically feasible and replaced with appropriate sources of unsaturated fatty acids [1]. The replacement strategy should consider not only nutritional composition but also oxidative stability, flavor, baking performance, texture, cost, and shelf life.

Whole-grain and dietary-fiber enrichment: The second component is improvement of carbohydrate quality through whole-grain ingredients and dietary fiber. Whole grains contain fiber and a range of associated nutrients and bioactive compounds, and epidemiological evidence supports their inclusion in healthy dietary patterns [2]. Higher dietary fiber intake has likewise been associated with favorable health outcomes. In a Cereal-Based Snack, however, increasing whole-grain or fiber content can modify dough properties, hardness, spread, color, flavor, water activity, and consumer acceptance. The appropriate formulation should therefore balance nutritional improvement with technological feasibility [3].

Probiotic selection: The probiotic component should be selected at the strain level. The term probiotic requires documented evidence of a health benefit under defined conditions. Candidate strains should therefore be considered according to identity, safety, documented efficacy, technological compatibility, tolerance to processing stresses, and ability to maintain viability during storage [6, 7].

Synbiotic integration: The probiotic and prebiotic components should be evaluated as a functional system. Under the ISAPP definition, simultaneous incorporation of a probiotic and a prebiotic is insufficient to establish synbiotic functionality [4]. A complementary synbiotic may combine independently supported probiotic and prebiotic components, whereas a synergistic synbiotic is designed so that the substrate is selectively utilized by the co-administered microorganism. Therefore, product development should explicitly define:

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Table 2. Selected studies included in the review on evidence-informed framework for the development of synbiotic cereal-based snacks

Author(s) and year	Study method	Sample Product and main ingredients	Main findings
Arepally et al. (2023)(12)	Production of millet biscuits; comparison of free and encapsulated probiotic cells; evaluation of inactivation kinetics at different baking temperatures and times.	Millet-based biscuits containing probiotics encapsulated with maltodextrin and gum arabic.	Encapsulation improved probiotic survival under certain baking conditions. A logarithmic model was suitable for describing microbial inactivation. A viable count of approximately 5 log CFU/g was achievable under the reported conditions.
Liu et al. (2023)(14)	In vitro digestion and fermentation of polysaccharide-containing biscuits using fecal microbiota from healthy individuals and individuals with diabetes.	Biscuits containing xanthan gum, konjacglucomannan, or arabinogalactan; no direct addition of live probiotics was reported in the formulation.	Fermentation resulted in a decrease in pH, an increase in short-chain fatty acids, and changes in microbial composition. Arabinogalactan produced a greater increase in the relative abundance of Bifidobacterium and Lactobacillus than the other tested ingredients.
Yazici et al. (2023)	Review of studies investigating synbiotic combinations in solid cereal-based foods.	Studies involving cream-filled biscuits, gluten-free cookies, crackers, cakes, pasta, and breakfast cereals.	Inulin, guar gum, maltodextrin, and coating materials were among the investigated ingredients. In probiotic cream-filled biscuits, a guar gum–inulin combination was associated with better probiotic survival and higher sensory acceptability than a xanthan gum–maltodextrin combination.
Pereira et al. (2019)(18)	Development of cereal bars with edible coatings; evaluation of microbiological, physicochemical, and sensory properties and stability over 90 days of storage.	Cereal bars containing *Bifidobacterium animalis* subsp. lactis BB-12 and inulin, coated with whey protein isolate or alginate.	The whey protein coating preserved probiotic viability more effectively than the alginate coating during storage and simulated digestion. Physicochemical properties remained stable, and sensory acceptance was satisfactory.
Zhang et al. (2015)(23)	Solid-state fermentation of whole-oat flour; assessment of physicochemical properties, bacterial counts, and changes in food components.	Fermented whole-oat flour containing *Lactiplantibacillus plantarum* TK9 and *Bifidobacterium animalis* subsp. lactis V9.	Final counts of CFU/g for strain TK9 and CFU/g for strain V9 were reported. The study demonstrated the potential of fermented oats as a food matrix rich in lactic acid bacteria.
Castillo-Escandón et al. (2023)(19)	Development of a corn- and legume-based snack; application of an edible coating containing probiotic and prebiotic components; assessment of nutritional composition and bacterial survival.	Corn- and legume-based snacks containing *Lactobacillus acidophilus* and agave fructans in an alginate coating.	Agave fructans reduced probiotic viability losses during drying and storage. The addition of legumes increased the protein content without substantially reducing overall product acceptability.
Roudbaneh et al. (2025)(13)	Optimization of a gluten-free cookie formulation by partially replacing oil with inulin and sugar with stevia; evaluation of viability and physicochemical properties.	Low-calorie gluten-free cookies containing *Lactobacillus acidophilus* encapsulated with alginate, starch, and a chitosan coating.	A formulation replacing 50% of the sugar with stevia and 50% of the oil with inulin showed desirable properties. A probiotic count of approximately 6.8 log CFU/g was reported after baking in the optimized formulation. The findings support the protective role of encapsulation but do not independently establish that the product is synbiotic.
Suo et al. (2026)(20)	Development of legume- and fiber-enriched cookies coated with dark chocolate containing probiotics; evaluation of nutritional composition, prebiotic potential, sensory acceptance, and stability.	Chickpea- or red-lentil-based cookies coated with chocolate containing the multistrain probiotic formulation SLAB51, with selected fibers used to modify nutritional composition.	Compared with the wheat-based control, the legume-based products had higher fiber and protein contents and lower sugar and saturated fat contents. Probiotic survival after six months was 88% at 4°C and 41.7% at 25°C. The study also investigated prebiotic potential and product stability.

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Probiotic strain → prebiotic substrate → intended interaction → evidence of functionality.

Food-matrix and probiotic-protection strategy: The food matrix should be considered an active determinant of probiotic performance. Proteins, carbohydrates, water activity, oxygen, packaging, processing conditions, and storage can affect probiotic viability and functionality [6, 7]. Baking presents a particular challenge because high temperatures can substantially reduce microbial viability. Possible approaches include strain selection, incorporation at a later processing stage where feasible, protective carriers, or encapsulation technologies [8, 9]. However, protection technology should be treated as a formulation variable requiring validation rather than as an assumed solution.

3.3. Validation Requirements

The proposed Cereal-Based Snack should be considered a research-development concept until experimental evidence establishes its functionality. First, the selected microorganism should be identified at the strain level and evaluated for safety and technological suitability. Viable-cell counts should be determined during storage because probiotic cells may experience substantial losses during processing and shelf life [6]. Second, the selected substrate should demonstrate the characteristics required for prebiotic functionality, including selective utilization and an associated health benefit [10]. Third, the final food should undergo physicochemical assessment, including moisture, water activity, texture, lipid oxidation, and fatty-acid composition. These parameters are essential because nutritional reformulation may influence both food quality and stability. Fourth, sensory acceptance should be established. A nutritionally improved product that is poorly accepted by consumers may have limited practical value. Finally, microbiological safety and, where a health benefit is proposed, appropriate human evidence should be generated. Health claims should be supported by a sufficient and scientifically sound evidence base and should not imply benefits that have not been demonstrated [11]. Figure 1 indicated the evidence-based product-development framework for synbiotic cereal-based snacks.

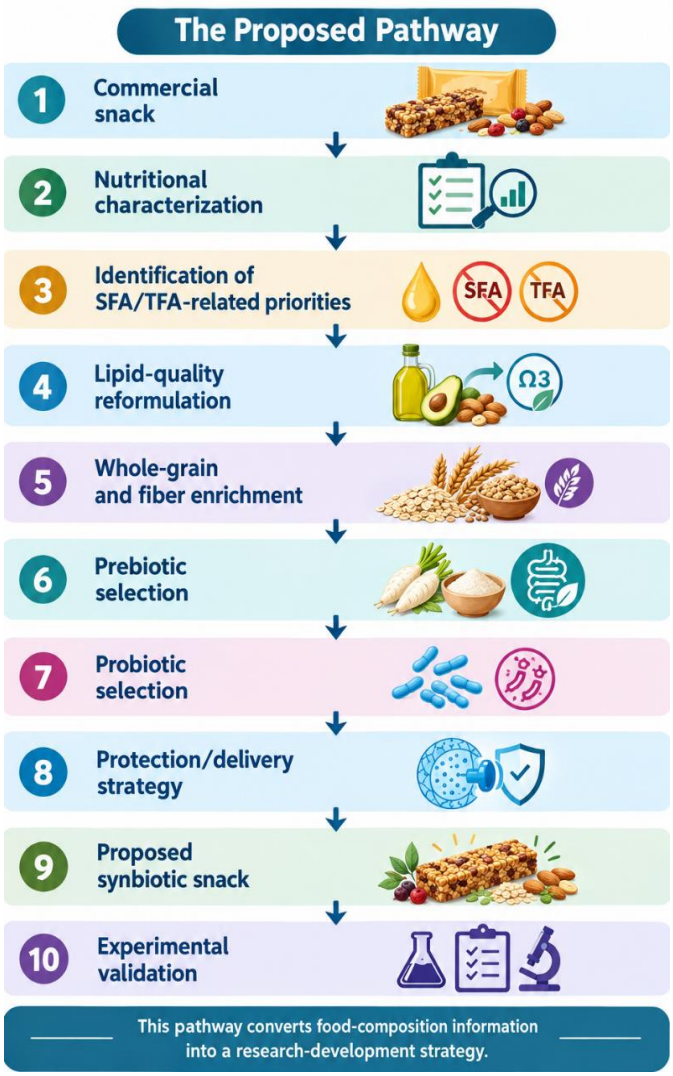


Figure 1. Evidence-based product-development framework for synbiotic cereal-based snacks.

3.4. Product development

The major strength of the proposed framework is its multidimensional nature. Traditional snack reformulation frequently focuses on reducing an undesirable nutrient. Although this remains important, a broader strategy can simultaneously address lipid quality, carbohydrate quality, dietary fiber, and functional-food characteristics. The lipid component is particularly important because replacing saturated or trans fats with another fat source does not automatically guarantee nutritional improvement. The replacement lipid must also be compatible with the processing and storage characteristics of the product [1]. Similarly, whole-grain and fiber enrichment should

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not be pursued independently of technological considerations. Changes in fiber concentration may influence texture, moisture, flavor, and consumer acceptance. Product development should therefore optimize nutritional composition rather than simply maximize the concentration of individual components.

The probiotic and prebiotic components introduce a more stringent evidence requirement. The probiotic concept is strain-specific, while prebiotic functionality depends on selective utilization and demonstrated benefit [10]. Consequently, the term "synbiotic" should be reserved for formulations meeting the scientific criteria established by the ISAPP consensus [4]. The Cereal-Based Snack matrix also illustrates the importance of integrating food technology with microbiology. Probiotic survival depends on processing and matrix characteristics, and the use of protection or encapsulation technologies may be necessary in some applications [6-9]. The framework may also be transferable beyond biscuits to cereal bars, crackers, breakfast products, and other shelf-stable snacks. The same principle applies: nutritional reformulation should be integrated with food-matrix design and rigorous functional validation.

The technological aspects of cereal-based snack development require further consideration. Relevant factors include water activity, moisture content, oxygen exposure, packaging characteristics, oxidative stability, thermal processing, storage conditions, and shelf-life performance. Moreover, the incorporation of whole grains, legumes, and functional ingredients may influence texture, flavor, structural integrity, sensory acceptance, and consumer compliance. The potential challenges associated with industrial-scale production and formulation reproducibility should also be considered.

3.5. Encapsulation, adding whole grain or legumes, and stability

Effect of encapsulation on probiotic survival in biscuits: One of the main challenges in producing Synbiotic Cereal-Based Snacks is the sensitivity of probiotic bacteria to high baking temperatures, moisture loss, and unfavorable storage conditions. Arepally et al. [12] reported that encapsulating *Lactobacillus acidophilus* using maltodextrin and gum arabic improved cell survival under certain baking conditions compared with free cells. A count of 5.38 log CFU/g was reported at 200°C after 360 seconds under the specified experimental conditions. These findings are consistent with those of Roudbaneh et al. [13], who developed gluten-free cookies and demonstrated that encapsulation with sodium alginate and a chitosan coating enabled probiotic counts of approximately 6.8 log CFU/g after baking. In contrast, the viability of unencapsulated cells was very low. However, the count in the encapsulated samples decreased to 4.5 log CFU/g after 72 hours of storage, highlighting the importance of evaluating product stability after processing. Taken together, these studies suggest that encapsulation is an effective strategy for protecting probiotics against thermal stress. Nevertheless, its effectiveness depends on the encapsulating material, microbial strain, baking conditions, and storage environment. Therefore, the selection of an appropriate coating should consider microbial survival, texture, sensory characteristics, and production costs. Moreover, these studies primarily investigated probiotic Cereal-Based Snacks. To establish a synbiotic effect, the specific contribution of the prebiotic component must also be evaluated.

Role of prebiotic ingredients in the functional properties of Cereal-Based Snacks: Inulin, fructooligosaccharides, and certain non-digestible polysaccharides are of interest in the development of functional Cereal-Based Snacks. In addition to their potential role in supporting intestinal microbiota, these ingredients may influence physicochemical properties such as hardness, moisture content, texture, and fat replacement. In the study by Roudbaneh et al. [13], inulin was used to replace part of the oil in a gluten-free cookie formulation to reduce its caloric content. The optimized formulation, which involved replacing 50% of the oil with inulin and 50% of the sugar with stevia, demonstrated the importance of balancing nutritional quality, probiotic survival, and sensory properties. Liu et al. [14], in contrast, investigated the effects of xanthan gum, konjac glucomannan, and arabinogalactan in Cereal-Based Snacks. During in vitro fermentation of digested Cereal-Based Snack samples using fecal microbiota, increased short-chain fatty acid production and changes in microbial composition were observed.

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Among the tested ingredients, arabinogalactan produced a greater increase in the relative abundance of Bifidobacterium and Lactobacillus [15-17]. These findings support the importance of selecting appropriate fiber ingredients when designing functional Cereal-Based Snacks. However, in vitro fermentation outcomes cannot be directly equated with clinical benefits in humans. Furthermore, xanthan gum and konjac glucomannan should not automatically be classified as established prebiotics solely because they can be fermented; such classification requires sufficient evidence of selective utilization and associated health benefits.

Comparison of methods for incorporating probiotics and prebiotics: Three main approaches can be distinguished in the development of cereal-based snacks:1. Incorporation of probiotics into the dough before baking. This approach is relatively straightforward from a manufacturing perspective, but probiotic cells are exposed to thermal stress. The findings of Arepally et al. [12] suggest that encapsulation can partially mitigate this challenge. 2. Addition of probiotics to a coating or cream layer after baking. This approach reduces direct exposure to high oven temperatures and may be suitable for cream-filled biscuits and chocolate-coated cookies.3. Application of an edible coating containing both probiotics and prebiotics. This strategy may protect microbial cells while enabling their combination with dietary fiber ingredients. In this context, Pereira et al. [18] developed cereal bars containing *Bifidobacterium animalis* subsp. lactis BB-12 and inulin, using whey protein isolate or alginate as the coating material. The whey protein coating preserved probiotic viability more effectively during 90 days of storage and simulated digestion. Sensory acceptance was also satisfactory. Together, these findings suggest that the location and method of probiotic incorporation are as important as strain selection and coating material. However, the superiority of one approach cannot be generalized across all products without direct comparisons using the same formulation and storage conditions.

Contribution of whole grains and legumes to nutritional quality: The incorporation of whole grains and legumes can increase the dietary fiber and protein content of snacks while providing a suitable matrix for functional ingredients. In the study by Castillo-Escandón et al. [19], a corn- and legume-based snack containing agave fructans and *Lactobacillus acidophilus* was developed. The results indicated that agave fructans reduced probiotic viability losses during drying and storage, while the addition of legumes increased the product's protein content. The more recent study by Suo et al. [20]extended this approach to cookies prepared with chickpea and red lentil flour. The cookies were coated with dark chocolate containing a probiotic formulation. Compared with the wheat-based control, the legume-based products had higher fiber and protein contents and lower sugar and saturated fat contents. Probiotic survival after six months of storage was 88% at 4°C and 41.7% at 25°C. Comparison of these studies suggests that combining fiber-rich raw materials with probiotic-containing coatings is a promising strategy for developing functional snacks [21]. Nevertheless, the actual synbiotic effect must be established by determining whether the selected fiber is selectively utilized by the probiotic strain and whether the interaction remains evident under simulated gastrointestinal conditions or in human studies.

Storage stability and sensory acceptability: Probiotic viability immediately after production is insufficient to establish product quality because moisture content, water activity, storage temperature, coating composition, and packaging can affect microbial survival over time. Pereira et al. [18] found that a whey protein coating preserved probiotic viability in cereal bars more effectively than an alginate coating. Meanwhile, the review by Yazici et al. [5, 12] reported that, in cream-filled biscuits, a guar gum–inulin combination was associated with better probiotic survival and sensory acceptance than a xanthan gum–maltodextrin combination. These differences indicate that the performance of a coating material depends on the food matrix and that no single material can be considered optimal for all products. Future studies should therefore assess probiotic counts immediately after baking, at multiple storage intervals, and after simulated gastrointestinal digestion. These measurements should be accompanied by sensory evaluation, texture analysis, and water activity measurements.

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3.6. Policy Action

The proposed framework has implications for food policy, product regulation, industry practice, consumer information, and research priorities. Policy actions should support progressive nutritional improvement while ensuring that functional-food claims remain proportional to the available scientific evidence. In policy-making, considerations must include food labeling requirements, the substantiation of health claims, the standardization of ingredients, microbial safety, quality control procedures, regulatory variations across different jurisdictions, and the commercial feasibility of cereal-based synbiotic snacks.

Government and regulatory authorities: National food and nutrition policies should encourage the reformulation of frequently consumed snack foods toward improved lipid quality, greater whole-grain and dietary-fiber content, and reduced reliance on nutritionally undesirable fat sources. Reformulation policies should emphasize appropriate replacement of saturated and trans fatty acids rather than simple reduction of total fat, consistent with current World Health Organization (WHO) guidance [1]. Regulatory authorities should establish or strengthen clear requirements for the identification, safety, viability, and labeling of probiotic strains and for the characterization of prebiotic ingredients. Where synbiotic products are marketed, regulatory frameworks should distinguish between the presence of probiotic and prebiotic components and demonstrated synbiotic functionality [4, 10]. The use of nutrition and health claims should be based on a sufficient scientific evidence base and should provide truthful and non-misleading information to consumers [11]. Public-sector research and regulatory programs could further support standardized approaches for evaluating probiotic viability throughout processing and shelf life, food-matrix compatibility, selective substrate utilization, and product safety. Such measures would facilitate evidence-based development of functional foods while reducing the risk of unsupported health claims [22].

Food industry: Food manufacturers should adopt a stepwise reformulation strategy that integrates nutritional quality with technological feasibility. Priority should be given to replacing SFA- and TFA-rich fat sources with nutritionally appropriate and technologically suitable alternatives, followed by optimization of whole-grain and dietary-fiber incorporation. The selection of probiotic strains and prebiotic substrates should be based on strain-specific evidence, safety, technological compatibility, and documented functionality rather than on the presence of these ingredients alone. Because baking and storage may compromise probiotic viability, manufacturers should evaluate appropriate processing, packaging, protective matrices, and encapsulation strategies on a product-specific basis. Before commercial claims are made, proposed synbiotic products should undergo systematic validation covering strain identity, viable-cell counts during shelf life, physicochemical stability, selective substrate utilization, microbiological safety, sensory acceptance, and, where applicable, evidence of a relevant health benefit [22].

Consumers and public nutrition education: Consumer information should focus on transparent communication of nutritional composition and scientifically substantiated functional properties. Nutrition education initiatives should improve consumers' ability to interpret information on saturated and trans fatty acids, dietary fiber, whole grains, and probiotic or prebiotic ingredients. The presence of a probiotic or prebiotic ingredient should not automatically be presented as evidence of a health benefit. Clear and standardized labeling may help consumers distinguish between nutritional improvement, the presence of functional ingredients, and health claims supported by scientific evidence.

Research and innovation priorities: Future research should prioritize integrated evaluation of reformulated snack products rather than assessment of individual ingredients in isolation. Research priorities include optimization of lipid replacement, whole-grain and fiber incorporation, strain–substrate compatibility, probiotic survival during processing and storage, food-matrix interactions, sensory acceptance, safety, and human evidence for relevant health outcomes. Particular attention should be given to the distinction between complementary and synergistic synbiotics, because the presence of a probiotic and a prebiotic alone does not establish synbiotic

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functionality. Evidence should demonstrate the relevant probiotic/prebiotic interaction and a health benefit before the product is described as a validated synbiotic. Overall, policy should encourage innovation while maintaining a clear evidence hierarchy:
Nutritional reformulation → functional-ingredient characterization → product stability and safety → demonstrated synbiotic functionality → substantiated health benefit.

This staged approach can support the development of nutritionally improved snack foods while avoiding the assumption that conceptual product design or the presence of probiotic and prebiotic ingredients alone constitutes validated synbiotic functionality.

4. LIMITATIONS

This article presents a conceptual and evidence-informed framework rather than experimental product-development research. The framework also does not prescribe a single probiotic strain, prebiotic substrate, lipid source, or protection technology. These choices should be determined by the intended product, target population, processing conditions, regulatory context, and quality of supporting evidence. Moreover, its principal contribution lies in integrating three interconnected dimensions: 1. Nutritional reformulation: Integrating strategies to improve the nutritional quality of cereal-based snacks, including dietary fiber enhancement, sugar and fat reduction, and the incorporation of nutritionally valuable ingredients. 2. Microbial functionality: Considering probiotic strain sel-ection, prebiotic substrate compatibility, encapsulation approaches, processing tolerance, microbial survival, and stability throughout product storage. 3. Translational product development and validation: Establishing a structured development pathway that connects ingredient selection and formulation optimization with technological characterization, microbial assessment, sensory evaluation, and the verification of potential synbiotic functionality. The lack of empirical validation for the proposed framework, the heterogeneity among the included studies, and the limited generalizability of laboratory and animal-based findings to human outcomes are among the most significant limitations of this study. Other limitations include the lack of economic evaluation and differences in regulatory requirements across countries.

5. CONCLUSION

A multidimensional approach to snack reformulation can integrate improved lipid quality, whole grains, dietary fiber, and scientifically supported probiotic–prebiotic functionality within a familiar food matrix. A synbiotic cereal-based snack provides a practical research-development model for connecting nutritional improvement with functional-food innovation.

The critical distinction is between conceptual formulation and demonstrated functionality. Reducing undesirable fatty acids and increasing fiber can improve nutritional composition, but the presence of a probiotic and prebiotic does not by itself establish synbiotic status. In light of the available evidence, demonstration of strain identity, viability, selective substrate utilization, stability, safety, sensory acceptance, and relevant health benefit is required before the product can be scientifically described as a validated synbiotic food or used to support a specific health claim.

6. DECLARATIONS

6.1. Acknowledgments

The authors acknowledge the support of the Research Council of the National Nutrition and Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Shahid Beheshti University of Medical Sciences, and thank all participants who contributed to the policy dialogue.

6.2. Conflicts of Interest

The authors declare no conflicts of interest.

6.3. Author Contributions

All authors contributed substantially to the conceptualization and design of the study, data collection, analysis and interpretation, manuscript preparation or critical revision, and final approval of the manuscript.

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6.4. Funding

The National Nutrition and Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Shahid Beheshti University of Medical Sciences, Tehran, Iran (Grant No. 43016375) supported this study.

6.5. Data Availability Statement

No new publicly available dataset was generated for this review. The evidence base consisted primarily of published literature and qualitative policy-dialogue information.

6.6. Ethics Declaration

The ethics approval of this study was coded as IR.SBMU.nnftri.Rec.1404.034.

6.7. Ethics Approval

Ethical approval was obtained from Shahid Beheshti University of Medical Sciences (IR.SBMU.nnftri.Rec.1404.034).

6.8. Use of Artificial Intelligence

During manuscript preparation, artificial intelligence-assisted tools were used for language and grammatical editing. The authors reviewed and edited the generated text and take full responsibility for the scientific content, interpretation, and final manuscript.

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