Advanced Protein Source Development Technologies: Current Applications and Future Prospects

Mengli Ni [1*], Yi Zhou [2]
[1] Shandong Provincial Center for Agricultural Exchanges and Cooperation, Jinan 250100, Shandong, China
[2] Shandong Business Institute, Yantai Key Laboratory of Food Processing Technology, Shandong Engineering Research Center of Healthy Food Innovation Technology Application, Yantai 264000, Shandong, China

* Corresponding Author: **Mengli Ni**

Article Info

ISSN (online): 3049-0588
Volume: 03
Issue: 05
Received: 21-06-2026
Accepted: 23-07-2026
Published: 25-08-2026
Page No: 01-05

Abstract
With global population growth, escalating ecological pressures, and evolving consumer demands for health-conscious products, traditional animal and plant protein supply models face numerous challenges-including resource scarcity, high carbon emissions, and limited nutritional diversity. The development and application of novel protein sources have become a research focus in biomanufacturing, food science, and biopharmaceuticals. These novel protein sources encompass microbial proteins, plant-based proteins, algal proteins, cell-cultured proteins, and AI-designed artificial proteins, offering advantages such as environmental sustainability, low carbon footprint, and customizable functionality that overcome the limitations of conventional protein production. This article systematically reviews the resource characteristics, development processes, and core technological frameworks of various novel protein sources. It highlights the application of cutting-edge technologies-including AI-based de novo design, precision fermentation, bioextraction, and cell culture-in protein development, analyzes current applications in food, feed, and biopharmaceutical sectors, identifies technical barriers, safety regulations, and industrialization costs, and proposes future research directions. The study aims to provide theoretical insights and technical support for the industrial-scale, high-quality development of novel protein sources.

DOI: https://doi.org/10.54660/GARJ.2026.3.5.01-05

Keywords: Novel protein prototype, Biomanufacturing, AI-driven protein design, Sustainable utilization, Industrial-scale development

1. Introduction

Proteins serve as the essential nutrients for growth, development, and metabolism in living organisms, and are also core raw materials for the food, feed, and pharmaceutical industries. According to data from the United Nations Food and Agriculture Organization (FAO), global protein demand continues to rise annually. The traditional protein production model, which relies heavily on large-scale livestock farming and crop cultivation, suffers from significant shortcomings, including high land resource consumption, water waste, excessive greenhouse gas emissions, and elevated risks of pests and diseases. These limitations make it inadequate for meeting the protein supply demands driven by global sustainable development strategies and population growth. Additionally, conventional proteins generally exhibit limited functionality, high allergenicity, and poor digestibility and absorption rates, failing to meet the application requirements of sophisticated scenarios such as premium foods, foods for special medical purposes, and biologics.

Novel protein sources represent a distinct category of protein resources compared to traditional livestock, poultry, and cereal proteins. These functional protein materials are artificially cultivated, designed, and engineered through modern biotechnology, synthetic biology, and artificial intelligence technologies. Their core characteristics include industrial-scale production, diversified resource origins, customizable functional properties, and environmentally friendly manufacturing processes. In recent years, advancements in synthetic biology, high-throughput sequencing, AI-driven structural prediction, and precision fermentation have enabled leapfrog progress in novel protein source development-from natural resource screening to precise artificial design, and from crude extraction to refined functional modification. They have gradually become the cornerstone for replacing conventional proteins and establishing a sustainable green protein supply system. This article provides a comprehensive review of the classification, key development technologies, and industrial applications of novel protein sources, identifies current industry challenges, and outlines future trends, offering insights for technological innovation and industrial implementation.

2. Main Types and Resource Characteristics of Novel Proteinogens

Based on their raw material sources, production methods, and structural characteristics, the current mainstream novel protein sources can be classified into five major categories. Each category exhibits distinct features in terms of nutritional composition, functional properties, production advantages, and application scenarios, collectively forming a diversified system of novel protein resources.

2.1. Microbial Single-Cell Protein

Microbial single-cell proteins are protein resources obtained through fermentation cultivation using microbial cells such as yeast, bacteria, and fungi, representing one of the most industrially mature novel protein sources. Their core advantages include a short production cycle, independence from seasonal and climatic constraints, and extremely high land utilization efficiency. These proteins can be produced at scale using inexpensive substrates such as industrial wastewater and agricultural waste, facilitating resource recycling. Microbial proteins exhibit a balanced amino acid profile, rich in essential amino acids, vitamins, and minerals, with crude protein content ranging from 40% to 70%. They are cholesterol-free, exhibit low allergenicity, and combine nutritional value with safety. Commonly used production strains include Candida, Saccharomyces cerevisiae, and Aspergillus, and these proteins find widespread applications in feed processing and conventional food additives.

2.2. Novel Plant-Based Protein

Unlike traditional soybean or wheat proteins, the novel plant-based proteins are prepared from specialty coarse grains and aquatic plants such as peas, mung beans, quinoa, flaxseeds, water hyacinth, and broad beans through precise extraction and modified processing techniques. These proteins offer broad availability, environmental safety, and high consumer acceptance, while avoiding the allergenic and gas-producing drawbacks associated with traditional soybean proteins. Additionally, physical and biological modification technologies enhance their solubility, emulsifying properties, and gel-forming capabilities, making them suitable for various food applications-including plant-based meat products, meal replacements, and protein beverages. Currently, they represent the most widely used novel protein source in the consumer food sector.

2.3. Algal Protein

Algal protein is derived from microalgae and large marine algae, primarily including resources such as spirulina, chlorella, and Haematococcus pluvialis. Algae exhibit high photosynthetic efficiency and rapid growth rates, allowing cultivation in seawater or saline-alkali soils without occupying arable land, thereby offering significant ecological benefits. Their protein content ranges from 50% to 65%, and they are rich in bioactive compounds such as phycobiliproteins, unsaturated fatty acids, and polysaccharides, conferring both nutritional and health-promoting properties along with biological activities like antioxidant and immunomodulatory effects. Compared to other protein sources, algal protein is hypoallergenic and easily digestible, making it suitable for applications in premium nutritional foods, health supplements, and specialized dietary products.

2.4. Cell Culture Proteins

The cell-cultured protein utilizes animal cell in vitro culture technology to isolate muscle stem cells from livestock, poultry, and aquatic animals. It is prepared through serum-free culture medium acclimation, large-scale cell proliferation, and differentiation processes, resulting in a novel protein prototype that fully replicates the structure and taste of animal proteins. This protein prototype perfectly retains the nutritional advantages of traditional animal proteins, contains no antibiotic or hormone residues, mitigates disease risks associated with livestock farming, and significantly reduces carbon emissions and land consumption during production. It represents a core direction for green alternatives to meat proteins and has currently progressed from laboratory research to pilot-scale industrialization.

2.5. AI-Designed Proteins

AI-designed proteins are newly engineered structural and functional protein prototypes created de novo based on the sequence-structure-function correlation principles of proteins, leveraging artificial intelligence technologies such as deep learning and diffusion models (RFdiffusion). These proteins do not rely on natural protein templates, thereby overcoming the functional limitations of natural proteins. Such protein prototypes can be precisely customized to meet specific application requirements in terms of stability, catalytic activity, and binding specificity, offering advantages such as resistance to extreme temperatures, acid/alkali conditions, and high activity. They are primarily applied in advanced fields such as biomedicine, biocatalysis, and high-end enzyme preparations, representing a cutting-edge direction in current protein prototype development.

3. Novel Proteinogen Core Development Technology System

The efficient development and functional optimization of novel protein candidates were achieved through a multidisciplinary technological framework, encompassing four core technical modules: resource screening, large-scale preparation, functional modification, and precision design. This approach enabled comprehensive technological breakthroughs spanning the entire process from resource discovery to final product fabrication.

3.1. High-Throughput Resource Screening and Identification Techniques

Leveraging metagenomics, integrated multi-omics analysis, and high-throughput screening technologies, high-quality protein-coding genes, high-yield bacterial strains, and raw material lines can be rapidly identified from natural microorganisms, specialty plants, and algal resources. Through techniques such as gene sequencing, protein structure prediction, and activity assays, the amino acid composition, allergenicity, stability, and functional characteristics of protein precursors can be swiftly characterized. This approach overcomes the limitations of traditional screening methods, which are often characterized by low efficiency and poor targeting specificity, providing precise data support for the selection of optimal raw materials for novel protein precursors and significantly reducing the resource discovery cycle.

3.2. Green and Efficient Preparation and Extraction Technologies

For the raw material characteristics of different types of protein precursors, the industry has established mature green preparation processes. Plant and algae proteins primarily employ technologies such as low-temperature ultrasonic extraction, membrane separation, and supercritical extraction to replace traditional high-temperature acid-base extraction methods, effectively preserving the natural biological activity and nutritional components of proteins while reducing wastewater pollution. Microbial proteins are produced through precision fermentation and high-density fermentation techniques, with optimized fermentation temperature, pH, and dissolved oxygen parameters to enhance protein yield and purity. Cell culture proteins utilize serum-free suspension culture and bioreactor-scale amplification technologies to lower cultivation costs and improve cell proliferation efficiency. These green preparation technologies effectively address the issues of high processing losses, nutrient depletion, and severe contamination associated with conventional protein processing methods.

3.3. Protein Functional Modification Technology

Natural novel protein precursors generally exhibit defects such as poor solubility, insufficient gel strength, and limited functionality, necessitating modification techniques to optimize their application performance. Current mainstream modification technologies fall into three categories: physical modification (high-temperature extrusion, ultra-high pressure, ultrasonic treatment), biological modification (enzymatic hydrolysis, microbial fermentation), and chemical modification (mild cross-linking). Modification enables precise regulation of the spatial structure of proteins, enhancing their emulsifying properties, foaming capacity, solubility, and digestibility/absorption rates while reducing allergenicity. This approach accommodates the functional requirements of diverse processing scenarios, significantly elevating the practical value of novel protein precursors.

3.4. AI De novo Design and Directed Modification Technology

The integration of artificial intelligence and synthetic biology has ushered in a new era of precise protein design. AI models centered around RFdiffusion and AlphaFold2 enable accurate prediction of protein three-dimensional structures, elucidation of the correlation mechanisms between sequences and functions, de novo design of novel protein molecules tailored to specific requirements, or targeted mutation and directional modification of natural proteins. Compared to traditional modification techniques, AI-driven design overcomes the structural limitations of natural proteins by precisely optimizing core metrics such as stability, activity, and specificity, significantly reducing R&D costs and shortening development cycles. This represents the core technological foundation for the development of advanced functional protein constructs.

4. Application Fields of Novel Proteinogens

4.1. Food Industry Sector

The food industry represents the most extensive application scenario for novel protein sources. Novel plant-based proteins, microbial proteins, and algae-derived proteins can replace traditional livestock and poultry proteins in the production of plant-based meat products, protein beverages, meal replacement foods, and baked goods, addressing issues associated with conventional foods such as high fat content, elevated cholesterol levels, and potential allergenicity. Modified proteins, characterized by low allergenicity and high digestibility, are suitable for infant complementary foods and foods for special medical purposes, meeting the nutritional requirements of specific populations. AI-designed functional proteins serve as food preservatives and antioxidants, replacing chemical additives to enhance food safety and extend shelf life. Currently, novel protein-based foods have become a core growth driver in the health food industry, with their market size continuing to expand rapidly.

4.2. Feed Industry Sector

Traditional feed relies on fish meal and soybean meal, which face challenges such as resource scarcity and significant price fluctuations. Novel protein sources represent the optimal alternative to conventional feed proteins. Microbial single-cell proteins, algal proteins, and insect proteins can be directly used as feed ingredients to replace traditional soybean meal and fish meal. These proteins not only exhibit high protein content and balanced nutritional profiles but also enhance the immunity and growth performance of livestock and aquatic animals. Moreover, these protein sources can be produced from agricultural waste, significantly reducing feed production costs, alleviating pressure on the feed raw material supply chain, and facilitating the green and low-carbon transformation of the livestock farming industry.

4.3. Biopharmaceutical Sector

Artificially designed proteins and functionally modified proteins by AI possess irreplaceable advantages in the biomedical field. Highly specific binding proteins and enzyme proteins obtained through precise design can be utilized for the preparation of antibody drugs, diagnostic reagents, and biocatalysts. Novel proteins with optimized stability serve as drug carriers or core ingredients for sustained-release formulations, enhancing drug utilization efficiency and safety. Low-allergenicity, high-activity proteins can also be applied in medical nutritional formulations and postoperative rehabilitation diets, providing innovative solutions for clinical nutritional support. With the maturation of protein design technologies, novel medical protein sources have become a pivotal breakthrough in biomedical innovation.

4.4. Other Industrial Fields

The novel protein derivatives can also be applied in fields such as biomaterials and the environmental protection industry. Modified plant proteins and microbial proteins can be utilized to produce biodegradable protein films, bio-adhesives, and packaging materials, serving as alternatives to traditional plastic materials and contributing to the development of the environmental protection sector. Functional proteins can act as biological flocculants and heavy metal adsorbents, finding applications in wastewater treatment for achieving environmentally friendly management, with broad cross-sectoral application prospects.

5. Existing Issues and Challenges in the Development of Novel Protein Progenins

5.1. Core technologies face bottlenecks

Current developments in novel protein candidates still face numerous technical limitations. At the industrial production level, large-scale manufacturing processes for cell-cultured proteins and AI-generated proteins remain immature, characterized by low bioreactor efficiency and poor mass production stability, hindering large-scale production. Protein modification technologies lack sufficient precision, often leading to loss of protein activity during modification, with inadequate fine-tuning of functional modifications. AI-driven protein design still exhibits structural prediction biases, exhibits low efficiency in activity validation for entirely novel functional proteins, and demonstrates insufficient integration between design and industrial application.

5.2. High industrialization costs

Compared to traditional proteins, the production costs of most novel protein sources remain significantly higher. The use of serum-free culture media for cell cultivation and advanced bioreactor equipment entails substantial investments; AI-driven protein design requires prolonged R&D cycles and high technical barriers; moreover, the energy consumption and substrate utilization efficiency in large-scale fermentation of microbial and algal proteins require optimization. Consequently, the overall production costs far exceed those of traditional soybean or livestock proteins, resulting in insufficient market competitiveness and hindering large-scale industrial adoption.

5.3. Incomplete safety evaluation and standard system

Novel protein sources represent emerging biological resources, yet China has not yet established a unified and comprehensive system for quality testing, safety evaluation, and industry standards. Research data on the allergenicity, toxicity, and long-term consumption safety of various novel protein sources remain insufficient, particularly regarding the lack of biosafety assessment systems for artificially designed proteins and cell-cultured proteins. Additionally, inadequate industry regulations governing production processes, product quality, and additive usage result in inconsistent product quality across the market, hindering the standardized development of the industry.

5.4. Insufficient Market Awareness and Acceptance

The market penetration of certain novel protein sources (insect-derived proteins, cell-cultured proteins, and artificially designed proteins) remains relatively low. Consumers harbor misconceptions regarding their safety, taste, and nutritional value. Additionally, the taste and flavor of some novel protein products still fall short compared to traditional animal proteins, and their processing compatibility requires improvement, further hindering their market promotion and consumer acceptance.

6. Prospects for the Development of Novel Proteinogens

6.1. Integrated and Precision-Oriented Technological Development

The future development of novel protein precursors will advance toward the integration of multiple technologies and precision regulation. This involves promoting the deep integration of synthetic biology, AI deep learning, and multi-omics technologies to establish an integrated technical system encompassing "design-screening-preparation-modification-validation," thereby enhancing the accuracy of protein precursor design, the efficiency of preparation, and the targeting precision of modifications. Key breakthroughs will be achieved in core industrialization technologies such as large-scale cell culture, low-cost fermentation, and precise retention of protein activity, addressing the challenges of poor mass-production stability and high costs, and facilitating the widespread industrial application of advanced novel protein precursors.

6.2. Industrial Scale-up and Low-Cost Upgrade

Leveraging advancements in industrial biotechnology, we optimize the production process for novel protein precursors, develop low-cost culture media and high-efficiency bioreactors, enhance raw material utilization and production efficiency, and reduce industrialization costs. Simultaneously, we extend the industrial chain by promoting the resource utilization of agricultural waste and industrial by-products, establishing a circular economy production model. This further lowers production costs and strengthens the market competitiveness of novel protein precursors compared to traditional proteins, enabling large-scale substitution applications in the food and feed sectors.

6.3. Standard System: Standardization and Improvement

Accelerate the establishment of a comprehensive industry standard system covering safety evaluation, quality testing, production specifications, and product labeling for novel protein preparations. Conduct systematic toxicological, allergenicity, and long-term safety trials for various types of novel protein preparations, and enhance the foundational database. Develop standardized production control and quality testing systems to regulate industry practices, ensure product quality and safety, and provide institutional support for the market-oriented and standardized development of novel protein preparations.

6.4. Product Diversification and Scenarios Refinement Expansion

Based on the requirements of diverse application scenarios, we develop novel protein source products that are diversified and feature refined functionalities. For various sectors-including general foods, functional foods, special diets, biopharmaceuticals, and feed-we customize protein products with differentiated nutritional profiles and functional characteristics. We optimize protein processing compatibility, enhance product texture and flavor, and improve consumer acceptance. Additionally, we explore the bioactive value of these novel protein sources, expanding their applications in high-end fields such as biopharmaceuticals, biomaterials, and environmental protection to maximize industrial value.

7. Conclusion

As a green and sustainable novel biological resource, novel protein precursors have overcome the resource and environmental constraints of traditional protein production, combining nutritional value, functionality, environmental friendliness, and economic viability. They represent the core direction for upgrading the global protein supply system. Leveraging cutting-edge technologies such as AI-driven protein design, precision fermentation, green extraction, and biomanagement, various novel protein precursors have demonstrated broad application prospects in food, feed, and biomedical fields. However, the industry still faces challenges including technological bottlenecks, high costs, lack of standardized protocols, and insufficient market recognition. Future efforts should focus on overcoming these core limitations through technological innovation, optimizing industrial processes, refining industry standards, and expanding application scenarios. This will drive the development of the novel protein precursor industry toward scale, premium quality, standardization, and sustainability, providing crucial support for ensuring global protein supply security, advancing the sustainable development of the biotechnology sector, and achieving carbon peaking and neutrality goals.

References

1. China Society for Biotechnology. Novel quality proteins: opportunities and challenges. Acta Bioeng. 2025;41(5):225-240.
2. Yang W, Li DG, *et al*. Ten years of progress and future prospects in de novo protein design. Nat Rev. 2026;3(2):18-32.
3. Zhang M, Li J. Processing technologies, functional characteristics and research progress of novel alternative protein resources. Food Sci. 2025;46(8):350-358.
4. Smith J, Deck S, *et al*. Novel proteins for future foods: current status, challenges, and perspectives. Foods. 2026;15(6):1289.
5. Wang H, Liu Y. Industrial development and application of microbial single-cell proteins driven by synthetic biology. Feed Ind. 2025;46(10):1-6.
6. Chen Y, Zhou M. Advances in AI-driven novel protein design technologies and their applications. Biotechnol Bull. 2025;31(4):98-107.

How to Cite This Article

Ni M, Zhou Y. Advanced protein source development technologies: current applications and future prospects. Global Agronomy Research Journal. 2026;3(5):1-5. doi:10.54660/GARJ.2026.3.5.01-05.

Creative Commons (CC) License