

# Development and practice of food bioengineering technology in the context of the big health industry

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**Abstract.** With the in-depth implementation of the "Healthy China" strategy, the big health industry has become a key driver of national economic growth. As a core domain of modern food science, food bioengineering technology is encountering unprecedented opportunities for advancement within this context. This paper systematically elaborates on the conceptual framework of food bioengineering technology and its strategic positioning in the big health industry. It further provides an in-depth analysis of the research progress and practical applications of key technologies—such as glyco-bioengineering, fermentation engineering, enzyme engineering, and genetic engineering—in areas including functional food development, green food production, and food safety control. The findings indicate that food bioengineering technology supports the development of the big health industry through multiple pathways, including improving the nutritional value of foods, enhancing food safety, developing functional food components, and promoting the green transformation of the food industry. In response to existing challenges—such as immature core technologies, incomplete industry standards, and insufficient integration of industry, academia, and research—this paper proposes several countermeasures, including strengthening fundamental research, improving the standardization system, promoting collaborative innovation, and cultivating interdisciplinary talent. These efforts aim to provide theoretical references for the innovative development of food bioengineering technology in the context of the big health industry.

**Keywords:** big health industry, food bioengineering, Glyco-bioengineering, functional foods, green production

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## 1. Introduction

The big health industry refers to a comprehensive industrial system aimed at maintaining, improving, and promoting human health, encompassing multiple sectors such as medical products, healthcare supplies, nutritional foods, and health management. The report of the 19th National Congress of the Communist Party of China explicitly called for the implementation of the "Healthy China" strategy, elevating public health to the level of a national priority. According to relevant statistics, the scale of China's big health industry has exceeded the trillion-yuan threshold, emerging as a new growth engine for the national economy. Within this strategic context, the food industry—an essential sector closely tied to public health—is undergoing a

transformation from merely meeting basic nutritional needs to delivering health-promoting and disease-preventive functions.

Food bioengineering technology refers to the application of biotechnology in the field of food, encompassing subfields such as genetic engineering, fermentation engineering, enzyme engineering, protein engineering, and glyco-bioengineering. By leveraging biological systems and processes, this technology enables the modification of food raw materials, optimization of food processing techniques, development of functional food components, and enhancement of food safety control. In recent years, with breakthroughs in frontier disciplines such as glycobiology and synthetic biology, food bioengineering technology has demonstrated significant potential in functional food development, green food production, and food safety assurance, becoming a key driver of high-quality development in the food industry.

Against the backdrop of the rapid expansion of the big health industry, how to fully leverage the advantages of food bioengineering technology to promote the transformation of the food industry toward enhanced nutrition, functionality, and sustainability—and to meet the growing health demands of the population—has become a focal issue for both academia and industry. Building on a review of the current state of development in food bioengineering technology, this paper systematically analyzes its practical applications within the context of the big health industry, examines the existing problems and challenges, and proposes corresponding policy recommendations, with a view to providing a reference for the innovative development of food bioengineering technology in China.

## **2. Overview of food bioengineering technology and the needs of the big health industry**

### **2.1. Concept and classification of food bioengineering technology**

Food bioengineering technology refers to a technological system grounded in biological principles and implemented through engineering approaches to design, modify, and optimize food raw materials, processing procedures, and final products. Its core lies in harnessing the functions of biological systems—such as microorganisms, plants, and animal cells—or their components, including enzymes, genes, and antibodies, to achieve precise control over food processing, improve food quality, and develop new resources.

In terms of its technical scope, food bioengineering technology mainly encompasses several key subfields. First, fermentation engineering utilizes the metabolic activities of microorganisms to produce foods or food additives, such as yogurt, alcoholic beverages, and condiments. Second, enzyme engineering applies enzymatic catalysis to improve food processing techniques, as exemplified by the use of amylase in glucose production. Third, genetic engineering employs recombinant DNA technology to modify the traits of food raw materials, such as genetically modified soybeans and insect-resistant rice. Fourth, protein engineering optimizes the functional properties of foods by altering protein structures. Fifth, glyco-bioengineering investigates the structure–function relationships of carbohydrates and their applications in food, including the development of functional oligosaccharides and polysaccharides [1].

These technological branches are highly interconnected and mutually reinforcing, collectively forming a comprehensive system of modern food bioengineering. Among them, glyco-bioengineering, as an emerging frontier field, has developed particularly rapidly in recent years and demonstrates broad application prospects in areas such as functional food development and green agriculture [2].

## 2.2. Connotation and development trends of the big health industry

The big health industry is a comprehensive system characterized by broad coverage and an extended industrial chain. From the perspective of the industrial chain, it includes upstream health management, midstream medical services, and downstream rehabilitation and healthcare. From the product perspective, it encompasses pharmaceuticals, medical devices, health foods, functional foods, and health-related products. Compared with the traditional medical industry, the big health industry places greater emphasis on preventive care and health maintenance, advocating the concept of "preventive treatment of disease" and reflecting a shift from disease-centered treatment to health-centered promotion.

At present, China's big health industry exhibits several notable development trends. First, the overall scale continues to expand. With the acceleration of population aging and the rising awareness of health among residents, demand for health-related consumption is steadily increasing, and the industry is projected to reach a scale of 16 trillion yuan by 2030. Second, the product structure is undergoing continuous optimization. The focus is shifting from traditional pharmaceuticals and health supplements toward functional foods and personalized nutrition solutions, with growing consumer demand for natural, green, and functional food products. Third, technological innovation is accelerating. The deep integration of biotechnology, information technology, and artificial intelligence with the health industry is giving rise to new formats such as precision nutrition and intelligent health management. Fourth, the policy environment continues to improve. The release of the "Healthy China 2030" Planning Outline has provided strong policy support for the development of the health industry [3].

## 2.3. Strategic positioning of food bioengineering in the big health industry

Within the framework of the big health industry, food bioengineering technology occupies a distinctive strategic position. On the one hand, food is fundamental to sustaining human life, and foods improved through bioengineering can enhance nutritional health at the source. On the other hand, as an important component of the big health industry, the development and production of functional foods rely heavily on bioengineering technologies.

More specifically, the strategic value of food bioengineering technology in the big health industry is reflected in several dimensions. First, it serves as a key engine for the transformation and upgrading of the food industry. Traditional food processing largely depends on physical and chemical methods, which often involve high energy consumption, low efficiency, and product homogeneity. The introduction of bioengineering technologies enables greener, more precise, and more efficient processing, thereby promoting high-quality development of the food industry [4]. Second, it provides core technological support for the development of functional foods. The extraction, purification, stabilization, and targeted delivery of functional components all depend on advances in bioengineering. Third, it constitutes a critical means of ensuring food safety. Applications of bioengineering in the detection of harmful substances, control of pathogenic microorganisms, and degradation of pesticide residues offer effective tools for safeguarding food safety [5]. Fourth, it facilitates the efficient utilization of resources. Through biotransformation technologies, by-products from agricultural and sideline processing can be converted into high-value functional ingredients, enabling the recycling and efficient use of resources.

### 3. Key technologies in food bioengineering and their applications in the big health industry

#### 3.1. Glyco-bioengineering technology and the development of functional foods

Glyco-bioengineering is a technological field that focuses on the biological functions of carbohydrates and their engineering applications. In living organisms, carbohydrates not only serve as sources of energy and structural components but also play critical roles in cellular recognition, signal transduction, and immune regulation. In recent years, with advances in glycan analysis technologies and glycobiology research, a wide range of carbohydrate substances with specific biological functions have been isolated and identified, providing new resources for the development of functional foods.

The application of glyco-bioengineering in functional food development is mainly reflected in the following aspects:

First, the development and application of functional oligosaccharides. Functional oligosaccharides are carbohydrates that are not digested by human enzymes but can be utilized by beneficial intestinal microbiota. They exhibit physiological functions such as regulating gut flora, enhancing immune function, and promoting mineral absorption. Significant progress has been made in this field in China, with products such as fructooligosaccharides, isomaltooligosaccharides, xylo-oligosaccharides, and soybean oligosaccharides already developed and widely used in dairy products, beverages, and health foods. For instance, fructooligosaccharides can be extracted from Jerusalem artichoke and chicory through fermentation processes, and their ability to promote the proliferation of bifidobacteria has been confirmed by numerous clinical studies.

Second, the isolation, purification, and application of bioactive polysaccharides. Bioactive polysaccharides are polysaccharide compounds with physiological activities such as immune regulation, antitumor effects, and hypoglycemic properties. They are primarily derived from edible fungi, traditional Chinese medicinal materials, and marine algae. China possesses abundant resources of such polysaccharides, including lentinan, ganoderma polysaccharides, goji polysaccharides, and kelp polysaccharides. Through modern separation and purification technologies, high-purity bioactive polysaccharide components can be obtained for the development of immune-regulating functional foods. Studies have shown that lentinan exhibits significant immunoenhancing effects and can be used as an adjunct dietary component for cancer patients.

Third, the development of glycan-based plant vaccines. These are carbohydrate substances capable of inducing disease resistance in plants, thereby reducing the use of chemical pesticides and ensuring the safety of agricultural products at the source. For example, oligosaccharides can activate plant defense responses and enhance resistance to pathogens. This technology is of great significance for the development of green agriculture and the production of safe, high-quality agricultural products.

The industrial prospects of glyco-bioengineering are highly promising. According to statistics, the annual output value of glyco-bioengineering products applied in food, pharmaceutical, and agricultural sectors in China has reached approximately 80 billion yuan and continues to grow rapidly. With further advances in glycan function research and preparation technologies, glyco-bioengineering is expected to play an increasingly important role in functional food development, green agriculture, and healthy aquaculture.

#### 3.2. Fermentation engineering and green food production

Fermentation engineering is a traditional strength within food bioengineering and refers to the process of converting raw materials into target products through the growth and metabolic activities of microorganisms.

In the context of the big health industry, its application value in green food production and the preparation of functional components has become increasingly prominent.

First, the application of fermentation engineering in dairy production. Lactic acid bacteria fermentation is a core technology in dairy processing. By selecting strains of lactic acid bacteria with specific functional properties, fermented dairy products with probiotic benefits can be produced. For example, the use of lactococci as starter cultures in the production of butter, sour cream, and both hard and soft cheeses can significantly improve fermentation efficiency. Studies indicate that when concentrated starter cultures are used, 360 mL of concentrated bacterial solution can inoculate 2,273 kg of raw milk for the production of hard Cheddar cheese, whereas at least 21 kg of conventional starter culture would be required to achieve the same output. This approach not only enhances fermentation quality but also substantially reduces production costs [6].

Second, the application of fermentation engineering in the preparation of functional components. Microbial fermentation enables the conversion of low-cost raw materials into high-value functional ingredients. For instance, functional compounds such as  $\gamma$ -aminobutyric acid (GABA), Monascus pigments, and nattokinase have been successfully produced at an industrial scale through microbial fermentation. These compounds are widely used in health foods and functional foods. Taking red yeast rice as an example, Monacolin K produced by Monascus fermentation exhibits lipid-lowering effects and has become an important ingredient in functional food formulations.

Third, the application of fermentation engineering in the development of plant-based foods. With the rapid expansion of the plant-based food market, the role of fermentation engineering in protein modification and flavor improvement has attracted increasing attention. Fermentation with lactic acid bacteria or molds can effectively remove the beany flavor of soybean protein, improve protein digestibility, and enhance the textural properties of products. This technology provides critical support for the development of novel plant-based foods such as plant-based meat and plant-based milk. Research on the application of modern biotechnology in food engineering indicates that fermentation engineering offers unique advantages in improving the quality of plant-based food products [7].

### 3.3. Applications of genetic engineering and enzyme engineering in food nutritional enhancement

Genetic engineering and enzyme engineering constitute essential technological pillars of food bioengineering, playing a critical role in improving the nutritional value of foods and developing functional food components.

Applications of genetic engineering in improving crop nutritional quality. Through genetic modification techniques, specific functional genes can be introduced into crops to achieve targeted improvements in nutritional traits. For example, by introducing key fructan-synthesizing enzymes such as 1-SST and related genes into crops like maize, sugar beet, and rice, it is possible to increase fructan content and produce agricultural products enriched with fructans. Fructans are dietary fibers beneficial to human health, contributing to gut regulation and enhanced mineral absorption.

In terms of protein nutrition enhancement, the introduction of exogenous genes encoding methionine and lysine into cereal crops can increase the content of these limiting amino acids in seeds, thereby improving the overall nutritional quality of cereal proteins. Studies have shown that the relatively low levels of methionine and lysine in cereal grains are key constraints on protein synthesis, and genetic engineering provides an effective solution to this limitation.

Regarding the improvement of lipid quality, gene cloning techniques can be used to introduce genes encoding enzymes involved in saturated fatty acid biosynthesis into crops, thereby modifying the fatty acid

composition of plant seeds. For instance, biosynthetic enzyme genes extracted from engineered yeast can be transferred into crops, enabling the production of plant-derived oils with more desirable nutritional profiles.

Applications of enzyme engineering in food processing. Enzyme engineering utilizes the catalytic properties of enzymes to achieve precise control over food processing and optimize product quality. In starch processing, enzymes such as  $\alpha$ -amylase and glucoamylase are widely used in the production of starch sugars. In lipid processing, lipases are applied in fat modification and interesterification reactions. In protein processing, proteases are used for protein hydrolysis and the preparation of functional peptides.

Particularly noteworthy is the application of enzyme engineering in the production of functional peptides. Through enzymatic hydrolysis of animal and plant proteins, bioactive peptides with antihypertensive, antioxidant, and immunomodulatory functions can be obtained. For example, peptides derived from whey protein hydrolysis have demonstrated blood pressure-lowering effects and have already been applied in the development of functional foods. Advances in modern biotechnology in food engineering indicate that enzyme engineering holds broad prospects in the field of functional food development [8].

### 3.4. Biological sterilization technology and food safety assurance

Food safety is a fundamental requirement for public health and a critical prerequisite for the development of the big health industry. Biological sterilization technology refers to methods that utilize biological organisms or their metabolic products to eliminate or inhibit harmful microorganisms, and it holds significant application value in green food production.

Principles and classification of biological sterilization. Biological sterilization is primarily based on microbial death kinetics, employing physical, chemical, or biological approaches to induce protein denaturation and thereby cause microbial death. Common sterilization methods include flame sterilization, dry heat sterilization, moist heat sterilization, and filtration. The rate of sterilization depends on factors such as microbial species, size, temperature, and heat resistance; under identical temperature conditions, longer exposure generally leads to more effective sterilization. For heat-resistant microbial spores, higher sterilization intensity is required to meet industrial sterility standards.

Applications in food processing. Incorporating bioengineering-based sterilization techniques into food processing can reduce reliance on chemical preservatives. Protein engineering technologies, for instance, can be used to design novel proteins that enhance enzyme stability in foods, thereby extending shelf life while minimizing the use of chemical additives.

Applications of air sterilization in agricultural production. In crop production, air sterilization technologies can be applied to control pests and diseases, reducing the use of chemical pesticides. Based on microbial aerobic fermentation mechanisms, anaerobic sterilization facilities can be installed in areas with high microbial concentrations to effectively regulate the levels of bacteria and fungal spores within specific environments, thereby preventing plant diseases. The design of such sterilization systems must be tailored to local climatic conditions, microbial composition, and environmental parameters such as temperature and humidity.

### 3.5. Nitrogen fixation and conversion technology and sustainable development of green agriculture

Nitrogen fixation and conversion technology refers to the process of transforming atmospheric nitrogen into bioavailable forms such as ammonia or nitrate, playing a crucial role in promoting crop growth and reducing the use of chemical fertilizers. Nitrogen is an essential nutrient for plant growth; however, atmospheric nitrogen in its elemental form cannot be directly utilized by crops. Through nitrogen fixation technology,

nitrogen-fixing bacteria are introduced into plant root systems, enabling the conversion of atmospheric nitrogen into forms that can be assimilated by plants, thereby promoting growth.

However, many crops exhibit resistance to colonization by nitrogen-fixing bacteria, which limits the widespread application of this technology. The integration of biochemical engineering into nitrogen fixation systems can effectively overcome this limitation by facilitating compatibility between crops and nitrogen-fixing microorganisms, enabling a symbiotic relationship that enhances plant growth. This approach holds significant importance for the development of green agriculture, the reduction of chemical fertilizer use, and the assurance of agricultural product safety.

## **4. Practical pathways for the application of food bioengineering technology in the big health industry**

### **4.1. Functional food development and precision nutrition supply**

Functional foods refer to foods that possess specific health-promoting properties, are capable of regulating physiological functions, and can reduce the risk of disease. In the context of the big health industry, the development of functional foods has become a major direction for the food industry. The application of food bioengineering technology in this field is primarily reflected in the following aspects:

**Functional foods for gut microbiota regulation.** Through fermentation engineering, probiotic-rich fermented foods—such as yogurt and fermented fruit and vegetable juices—can be developed. Meanwhile, glyco-bioengineering enables the production of prebiotic functional oligosaccharides that promote the growth of beneficial intestinal microbiota. The synergistic use of probiotics and prebiotics (synbiotics) has demonstrated significant effects in regulating gut microbiota and enhancing immune function.

**Immunomodulatory functional foods.** Using glyco-bioengineering technologies, bioactive polysaccharides can be extracted from edible fungi and traditional Chinese medicinal materials to develop functional foods with immune-regulating properties. For example, polysaccharides derived from Ganoderma and shiitake mushrooms have been widely applied in health foods, with their immunoenhancing effects supported by extensive research.

**Functional foods for chronic disease prevention.** Through enzyme engineering, functional peptides can be produced and incorporated into foods with antihypertensive, hypoglycemic, and lipid-lowering effects. For instance, soybean peptides obtained via enzymatic hydrolysis exhibit lipid-lowering properties, while whey protein-derived peptides have demonstrated blood pressure-reducing effects.

With the growing adoption of the precision nutrition paradigm, functional food development is increasingly moving toward personalization and targeted design. By leveraging technologies such as genetic testing and metabolomics analysis, individual nutritional needs and health risks can be assessed, enabling the development of tailored functional foods. Food bioengineering technology provides critical support for precision nutrition by enabling precise control over the composition and dosage of functional ingredients to meet the diverse health needs of different population groups.

### **4.2. Bioengineering support for the intelligent transformation of the food industry**

The food industry is currently undergoing a transition from traditional manufacturing to intelligent production. Emerging technologies such as smart sensing, big data analytics, and the Internet of Things (IoT) are reshaping food production systems. In this transformation, food bioengineering technology serves as a key enabling foundation.

Application of biosensors in intelligent production. Biosensors are analytical devices that integrate biological recognition elements with signal transducers, enabling real-time monitoring of critical parameters in food processing. For example, enzyme-based sensors can detect glucose and lactic acid levels, while microbial sensors can monitor contamination. These technologies provide essential data for the intelligent control of food production processes.

Application of big data in optimizing biological processes. The optimization of biological processes, such as fermentation, depends on the analysis of large volumes of process parameters. Through big data analytics, variables such as fermentation temperature, pH, and dissolved oxygen can be comprehensively analyzed to establish models linking process parameters with product yield, thereby enabling intelligent optimization of fermentation processes.

Integration of intelligent equipment and biotechnology. The development of intelligent fermentation tanks and enzyme reactors provides the hardware foundation for automated control of biological processes. By integrating online monitoring, automated regulation, and data analytics, these systems enable intelligent operation, improving production efficiency and product consistency.

The advancement of food bioengineering technology and intelligent transformation is mutually reinforcing. On the one hand, intelligent technologies provide tools for optimizing and controlling biological processes; on the other hand, bioengineering offers the process foundation for the application of intelligent equipment. Their deep integration is driving the food industry toward greener, more efficient, and more intelligent development.

### 4.3. Bioengineering-based substitution technologies in green food production

Green foods are defined as high-quality, safe, and nutritious products produced in accordance with sustainable development principles and certified production standards. In green food production, food bioengineering technology is primarily applied as a substitute for traditional chemical-based approaches.

Biopesticides as substitutes for chemical pesticides. The excessive use of chemical pesticides has led to residue problems, posing risks to food safety and the environment. Through genetic engineering, Bt protein genes can be introduced into crops; when pests ingest Bt proteins, their physiological processes are disrupted, inhibiting growth and achieving effective pest control. Studies have shown that the application of Bt protein in rice pest control can increase yields by approximately 11%. This technology significantly reduces the use of chemical pesticides and lowers the risk of residues.

Biopreservatives as substitutes for chemical preservatives. In traditional food processing, chemical preservatives are often used to extend shelf life, some of which may pose health risks. Bioengineering technologies enable the development of biopreservatives such as nisin and natamycin. These substances, derived from microbial metabolism, offer higher safety and effectively inhibit spoilage organisms and pathogenic bacteria.

Biofertilizers as substitutes for chemical fertilizers. By applying nitrogen fixation and conversion technologies, microbial fertilizers can be developed to reduce the use of chemical nitrogen fertilizers. The inoculation of functional microorganisms—such as nitrogen-fixing, phosphorus-solubilizing, and potassium-solubilizing bacteria—can enhance soil nutrient utilization efficiency and decrease fertilizer input, thereby ensuring the safety of agricultural products at the source.

The application of bioengineering-based substitution technologies constitutes a critical safeguard for green food production. As consumer awareness of food safety and environmental protection continues to grow, these technologies are expected to play an increasingly important role in advancing sustainable food systems.

## 5. Problems and challenges

Despite the significant progress achieved by food bioengineering technology within the context of the big health industry, a range of problems and challenges remain. These are mainly reflected in the following aspects:

### 5.1. Immaturity of core technologies

Food bioengineering is inherently interdisciplinary and technologically complex. At present, there remains a gap between China and leading international levels in fundamental research areas such as glyco-bioengineering, fermentation engineering, and enzyme engineering. For instance, technical approaches for glycan structure elucidation and functional analysis still require breakthroughs; the preparation technologies for highly active and stable engineered enzymes are not yet sufficiently mature; and efficient methods for the separation and purification of functional components remain underdeveloped.

These limitations in core technologies constrain the industrial application of food bioengineering. Many laboratory research outcomes are difficult to translate into commercially viable products, or the costs of transformation are too high and the efficiency too low to meet industrial requirements. Overcoming these technological bottlenecks and achieving a smooth transition from basic research to industrial application has become a critical issue.

### 5.2. Incomplete industry standards

Food bioengineering products involve multiple dimensions, including food safety, quality control, and functional evaluation, all of which require a well-established standardization system. However, the development of such a system in China remains relatively lagging, with several key issues. First, the coverage of standards is insufficient, as many emerging functional food ingredients and products lack unified standards. Second, standard indicators are incomplete, particularly in areas such as testing methods for functional components and evaluation methodologies for health functions. Third, the updating of standards is not timely enough to keep pace with rapid technological advancements.

The lack of a robust standard system creates challenges for both enterprises and regulators. On the one hand, companies lack consistent benchmarks for quality control, leading to uneven product quality. On the other hand, regulatory authorities lack effective criteria for supervision, making it difficult to ensure product safety and quality.

### 5.3. Weak integration of industry, academia, and research

The development of food bioengineering technology spans multiple stages, including basic research, applied research, and industrialization, requiring close collaboration among universities, research institutes, and enterprises. However, the integration among these sectors remains insufficient. Research conducted by universities and institutes often focuses on fundamental studies and may be disconnected from practical industrial needs; enterprises frequently lack strong in-house R&D capabilities and have limited capacity to absorb academic achievement; and collaboration mechanisms are underdeveloped, with a lack of long-term cooperative platforms and effective benefit-sharing arrangements.

This weak integration disrupts the innovation chain, resulting in a large number of research achievement remaining at the laboratory stage without successful commercialization. Establishing an effective collaborative innovation mechanism among industry, academia, and research institutions is therefore a key task for

advancing food bioengineering technology. Studies on the application of modern biotechnology in food engineering have emphasized that strengthening such collaboration is crucial for technological innovation [9].

#### 5.4. Consumer awareness and acceptance

The application of food bioengineering technology—particularly genetic engineering in the food sector—raises issues related to consumer perception and acceptance. Some consumers remain skeptical about bioengineered foods, especially with regard to their safety, and such cognitive biases can hinder market adoption.

Addressing this challenge requires strengthening public science communication to improve consumer understanding of food bioengineering technologies. At the same time, developers should enhance product transparency and traceability to build consumer trust and facilitate broader acceptance of bioengineered food products.

## 6. Countermeasures and recommendations

In response to the above problems and challenges, the following countermeasures and recommendations are proposed:

### 6.1. Strengthening fundamental research to break through core technological bottlenecks

Greater investment should be directed toward fundamental research in food bioengineering, with particular support for frontier fields such as glyco-bioengineering, synthetic biology, and enzyme engineering. Priority should be given to achieving breakthroughs in key technologies, including glycan structure elucidation and functional analysis, the development of highly efficient enzyme preparations, advanced separation and purification techniques for functional components, and the design of novel bioreactors. Advancements in these foundational areas will provide essential technological support for industrial development.

At the same time, efforts should be made to strengthen the construction of shared technology platforms, such as food bioengineering research and development centers and pilot-scale testing facilities. These platforms can lower the barriers to technological innovation for small and medium-sized enterprises and promote the transformation and application of research achievement.

### 6.2. Improving the standardization system to regulate industrial development

The establishment of a comprehensive standard system for food bioengineering products should be accelerated, covering the entire industrial chain from raw materials to production processes and final products. Key tasks include developing quality standards for emerging functional food ingredients, improving testing methods for functional components, establishing technical specifications for the evaluation of functional foods, and formulating labeling standards for bioengineered products.

Standard development should align with international practices by drawing on advanced global experience, thereby enhancing the international influence of domestic standards. At the same time, standards must reflect practical industry conditions, balancing safety, scientific rigor, and operational feasibility.

### 6.3. Promoting industry–academia–research collaboration to accelerate technology transfer

An effective collaborative innovation mechanism integrating industry, academia, and research institutions should be established to foster deeper cooperation. First, collaborative platforms—such as technology development consortia and industrial innovation alliances—should be created to facilitate the aggregation and

sharing of innovation resources. Second, cooperation models should be diversified by encouraging enterprises to participate in university education and research activities, including the establishment of joint laboratories and co-developed research centers. Third, incentive mechanisms should be improved by implementing intellectual property sharing and benefit distribution systems to stimulate the active participation of all stakeholders.

#### 6.4. Strengthening science communication to enhance public awareness

Efforts should be intensified to improve public understanding of food bioengineering technologies. This includes disseminating basic knowledge through media platforms, clarifying misconceptions, and establishing authoritative information channels to respond promptly to public concerns. Researchers should be encouraged to engage in science communication activities to enhance the professionalism and credibility of outreach efforts. In addition, strengthening product labeling and management systems will help safeguard consumers' right to information and increase product transparency, thereby fostering greater public trust.

#### 6.5. Enhancing talent development to support sustainable industrial growth

The innovative development of food bioengineering technology depends fundamentally on human capital. There is a need to cultivate interdisciplinary professionals who possess expertise in bioengineering as well as knowledge of food science, nutrition, and information technology. Universities should optimize curricula and strengthen interdisciplinary training, while enterprises should enhance in-service training programs to improve technological development and application capabilities. Furthermore, talent recruitment and incentive mechanisms should be improved to attract high-level overseas professionals and support their contribution to domestic development [4].

## 7. Conclusion

The rapid expansion of the health and wellness industry has created broad application prospects and significant development opportunities for food bioengineering technologies. Key technologies—including glyco-bioengineering, fermentation engineering, genetic engineering, and enzyme engineering—are being increasingly applied in functional food development, green food production, and food safety assurance. These advancements are profoundly reshaping the food industry and driving its transformation toward enhanced nutrition, functionality, and sustainability.

At present, China has made notable progress in the development of food bioengineering technologies. However, several challenges remain, including the immaturity of core technologies, an incomplete standard system, and insufficient integration among industry, academia, and research institutions. Looking ahead, efforts should focus on strengthening fundamental research to overcome technological bottlenecks; improving the standardization system to regulate industrial development; promoting collaborative innovation among industry, academia, and research sectors to accelerate the commercialization of research achievement; enhancing science communication to improve public awareness; and reinforcing talent cultivation to support sustainable industrial growth.

With the continued implementation of the "Healthy China" strategy and the ongoing upgrading of food consumption demand, food bioengineering technologies are expected to play an increasingly vital role in the health and wellness industry, contributing significantly to the improvement of public health and the high-quality development of the food sector.

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