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CHINA AND GLOBAL FOOD POLICY REPORT 2024

BUILDING A SUSTAINABLE AND DIVERSIFIED FOOD SUPPLY TO FOSTER AGRIFOOD SYSTEMS TRANSFORMATION

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2024 China and Global Food Policy Report

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BUILDING A SUSTAINABLE AND DIVERSIFIED FOOD SUPPLY TO FOSTER AGRIFOOD SYSTEMS TRANSFORMATION

Foreword I

Building a comprehensive socialist modernized country places the most daunting and arduous task on rural areas. Exploring the Chinese approach to agricultural and rural modernization is not just a mission of our time but also a critical responsibility of history. Food security, ecological conservation, and cultural heritage preservation constitute the unique tripartite functions of rural areas, ensuring these three securities are the fundamental line of thought for national security. The primary task of building an agricultural strong nation is to enhance the supply guarantee capability of staple grains and key agricultural products. In the journey toward constructing a comprehensive socialist modernized country, ensuring China's grain and food supply security has become a prominent issue that must be addressed to safeguard overall national security.

Despite continuous increases in grain production and self-sufficiency in staple grains, there are still gaps in the supply of important foods like feed,edible oils, sugars, meats, and dairy. Moreover, with a massive population and ongoing improvements in living standards, the demand for high-quality food continues to grow. Contradictions between supply and demand among agricultural products are becoming more pronounced regionally, and the variety structure of grain supply and demand remains imbalanced. China's food supply still faces challenges of inadequate overall quantity and highlighted structural contradictions. Overall, China's population and land relations determine that the supply and demand of grain will remain in a long-term state of tight balance. For a populous country like China, even achieving "absolute food security" does not guarantee complete peace of mind. There is a need to enhance awareness of potential risks, maintain a bottom-line mentality, and ensure national security.

General Secretary Xi Jinping pointed out: "People's food demands have become more diverse, which requires us to change our mindset, establish a concept of 'big agriculture' and 'big food,' and seek calories and proteins from arable land, grasslands, forests, oceans, plants, animals, and microorganisms through multiple avenues and approaches." The concept of "big food" is rooted in staple grains. While upholding grain security as a top priority, relations with other foods must be managed appropriately. The soft spot in China's food supply lies mainly in foods beyond staple grains. Efforts should be directed toward improving the supply of other foods while ensuring absolute grain security. It is necessary to look beyond arable land resources to the entire national land resources, adapting to local conditions to develop facility agriculture and construct a diversified food supply system. Simultaneously, it is crucial to make rational use of international agricultural resources and the international agricultural product market. However, it should be noted that there is growing uncertainty in the international food industry and supply chain.

Against this backdrop, the theme of the 2024 China and Global Food Policy Report, "Building a Sustainable and Diversified Food Supply to Foster Agrifood Systems Transformation," embodies a forward-looking and epochal perspective, showcasing the mindset of "big food" and "big agriculture." The report, based on data and models, focuses on optimizing various food sources, developing new alternative protein industries and "midstream" food and nutrient resources, and diversifying food imports. The report continues to reflect interdisciplinary, multisectoral, and international perspectives closely integrated with China's practices, offering important insights for decision-makers, researchers, industry personnel, and consumers. The report will further promote China's establishment and implementation of the concepts of "big food" and "big agriculture," driving China to construct a diversified food supply system, while also providing a Chinese solution for global food security.

Xiwen Chen
Member of the 13th National People's Congress Committee
Chairman of the Agriculture and Rural Affairs Committee

Foreword II

Since the reform and opening-up, China's food supply has grown significantly, nourishing nearly 20% of the global population with just 9% of the world's arable land. This remarkable achievement has shifted the historical narrative from "food scarcity" to "food security" for billions of people, earning global recognition for its success in eradicating hunger and ensuring food security. As economic development and incomes rise, residents are shifting from mere sustenance to seeking diverse and nutritious diets, leading to higher expectations for food quality and variety. However, China's current food supply systems face challenges, such as high concentration in grain production, an imbalanced diet structure, heavy reliance on arable land, supply–demand mismatches, structural deficiencies, and increasing international imports. These hurdles hinder meeting the growing demands for nutritious, sustainable, and diverse food. In a crucial rural directive, General Secretary Xi Jinping stressed adopting a vision of "big agriculture" and "big food," integrating agriculture, forestry, animal husbandry, and fisheries to build a diversified food supply system. Hence, establishing the concept of "big food" and optimizing food supply sources is essential to developing a sustainable and diverse food supply system.

Under the leadership of Chair Professor Shenggen Fan, the Academy of Global Food Economics and Policy of China Agricultural University, along with various domestic and international entities, has published the 2024 China and Global Food Policy Report. The report focuses on "Building a Sustainable and Diversified Food Supply to Foster Agrifood Systems Transformation." Drawing on practical cases, data, and comprehensive models, it addresses the healthy dietary needs of Chinese residents by exploring diverse food sources, "midstream" food and nutrient resource development, new alternative proteins, and diversified food imports. Its goal is to aid in constructing a sustainable diversified food supply system in China. This marks the fourth year of research and the flagship report on agrifood systems transformation released by the academy. This year's report is anticipated to attract global attention and spark discussions among policymakers and researchers worldwide, similar to past reports.

The 2024 report stresses the need for cross-sectoral coordination, enhancing support policies, systems, technology, and international cooperation based on citizens' healthy dietary needs. These efforts, spanning production, processing, distribution, and consumption, will drive the transformation of the agrifood systems supply chain, laying a strong foundation for a diverse food supply. This report not only guides China's progress in constructing a diversified food supply system but also provides a Chinese blueprint for global agrifood systems transformation. Going forward, the university will continue its mission as a national level agricultural institution, leverage interdisciplinary research strengths to pioneer frontier agricultural studies, boost new quality productivity, lead in agricultural development, and contribute effectively to national strategies like food security and rural revitalization.

Qixin Sun
Academician of the Chinese Academy of Engineering
President of China Agricultural University

Foreword III

In the current context of sluggish global economic growth and frequent regional conflicts, China's agricultural and food systems (agrifood systems) is confronting an increasingly complex and severe external environment. Amid such uncertainties, ensuring domestic food security and meeting citizens' nutritional and dietary needs have become critical goals. China, with only 9% of the world's arable land and 6% of freshwater resources, supports nearly one-fifth of the global population. It is a miracle, but also a challenge. Every day, China consumes approximately 700,000 tons of grain, 98,000 tons of edible oil, 1.92 million tons of vegetables, and 230,000 tons of meat. To address these immense consumption demands, China's agrifood systems would establish a sustainable and diversified food supply system. It is not only a requisite response to align with the transformation and upgrading of the food structure and address food security challenges, but also a vital strategy to meet the people's growing aspirations for an improved quality of life.

The 2024 Central No. 1 Document emphasizes, "Adopt the concept of 'Big Agriculture' and 'Big Food' and expand food sources through multiple channels." The concept of "Big Food" relates to the "vegetable baskets" and "grain sacks" of all Chinese households. In recent years, the concept of food has expanded from the narrow definition of grains to include all edible foods, emphasizing a balanced intake of dietary nutrients. Consumers' habits are also shifting toward eating well, eating nutritiously, and eating healthily. This shift has generated pressure for the food supply to adjust from a single production mode to a diversified supply. It has also expanded food sourcing methods from solely relying on arable land to include mountains, rivers, forests, arable land, lakes, grasslands, and deserts. Therefore, in the future, the transformation of the agrifood systems will need to further harness the potential of mountains and seas, optimize the utilization of forests and grasslands, enhance the production of fruits and vegetables, develop marine ranching, and expand green granaries. These efforts are essential to ensure the agrifood systems' sustainable and steady progress, maximize the utilization efficiency and production potential of various resources, and provide a clear direction for advancing agricultural strength and enhancing the resilience of food supply.

Therefore, the Academy of Global Food Economics and Policy, led by Chair Professor Fan Shenggen, in collaboration with multiple domestic and international research institutions, has published the 2024 China and Global Food Policy Report with the theme of "Building a Sustainable and Diversified Food Supply System to Promote Agrifood Systems Transformation." The report continues to focus on cutting-edge issues in agriculture and food systems. The report employs systematic analysis and interdisciplinary research methods to deeply explore feasible pathways for optimizing food sources, enhancing food production potential, and ensuring the nutritional quality and sustainable supply of food. The report highlights the potential of alternative proteins and their positive impacts on environmental protection and food safety, demonstrating that plant-based proteins, cultured meat, and other alternative products can not only reduce reliance on traditional agricultural resources but also effectively lower greenhouse gas emissions. These innovative future foods are expected to play an increasingly important role on Chinese dinning tables. Additionally, the report addresses the development and optimization of the midstream segments of the food supply chain, focusing on the potential market demand for nutritionally fortified foods and whole grains. These measures will directly impact the efficiency of the food supply chain and improve citizens' dietary structures, significantly enhancing public health. The publication of the 2024 report is expected to further drive the transformation of China's agrifood systems toward being nutritious, healthy, green, low-carbon, efficient, resilient, and inclusive. It aims to provide critical references for policymakers and researchers, thereby generating significant impact for the future.

Keming Qian
Chief Research Fellow at the Chinese Academy of Agricultural Sciences
Former Vice Minister of Commerce

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Executive Summary

The global food and nutrition security situation remains severe, with multiple crises exacerbating hunger and food insecurity. Climate change, regional conflicts, inflationary pressures, and slow economic recovery in many parts of the world have led to decreased incomes and purchasing power, worsening global hunger and malnutrition. The 2023 State of Food Security and Nutrition in the World indicates that between 691 million and 783 million people faced hunger in 2022, with a food insecurity prevalence of 29.6%, including approximately 900 million people experiencing severe food insecurity. Furthermore, over 3.1 billion people cannot afford a healthy diet due to diminished access to nutritious food.

Amid these compounded risks, climate change and natural resource challenges significantly hinder global progress against hunger and malnutrition. Rising temperatures, erratic rainfall, extreme weather, and natural disasters lead to land and water degradation, biodiversity loss, soil fertility decline, frequent pest outbreaks, and destabilized ecosystems. These issues severely affect agricultural production and food supply capabilities, posing risks to food and nutrition security. Climate change affects international and regional trade, disrupts food market stability, and causes prise spikes, threatening human nutrition and health. The impact is particularly pronounced in developing countries and vulnerable populations due to their resource constraints and limited climate adaptation capacities.

In response, the international community and many countries are actively promoting the transformation of agricultural food systems (agrifood systems) to ensure food and nutrition security and achieve sustainable development goals. The United Nations Food Systems Summit first held in 2021, emphasizes building sustainable, equitable, healthy, and resilient agrifood systems. The 2023 Rome summit assessed the current transformation progress. Additionally, the 2023 UN Climate Change Conference (COP28) emphasized food systems as a primary agenda and issued a declaration on building resilient agrifood systems to combat climate change. There is a consensus that agrifood systems must be transformed to be more resilient at global, regional, national, and community levels, with diverse food sources to meet the growing health and nutrition demands.

In China, the 20th Party Congress report demonstrated"establishing a comprehensive food outlook, developing facility agriculture, and creating a diversified food supply system." The Central Economic Work Conference and Rural Work Conference at the end of 2023 restated the need for a comprehensive approach to agriculture and food systems. The Food Security Law of the People's Republic of China, effective June 1, 2024, underscores the importance of a diversified food supply system to meet the diverse and healthy dietary needs of the population.

Over the past few decades, China has made remarkable progress in eliminating hunger, combating poverty, and ensuring food security, contributing significantly to global food security. However, China's current food supply system faces challenges such as reliance on extensive resource use, lack of nutritional focus, low supply efficiency, and mismatched supply–demand structure. First, the high-input, high-output agricultural model heavily relies on arable land, creating resource and environmental pressures. Second, the food supply system lacks nutritional orientation in the middle stream of the system or value chain (missing middle) , leading to inefficiencies and significant loss in food and nutrition. In addition, the weak linkage between food supply and demand increases reliance on imports of certain food categories like soybeans, meat, and corn, exacerbating trade deficits. The traditional focus on grain security emphasizes supply and quantity over nutritional health and balanced supply–demand structures, falling short of meeting the growing demand for sustainable, nutritious food. Therefore, it is urgent to transform China's agrifood systems and comprehensively reform the food supply system.

The proposal for a diversified food supply system is anchored in the overall development of China's national economy, aligns with current international development trends, and contributes to major national goals such as food security, nutritional health, green low-carbon development, and common prosperity. While constructing this system, it is crucial to address several key questions: How can China be guided by nutritional and health needs to explore future food supply potential and rationally develop and comprehensively utilize various food production resources? How can China improve efficiency, optimize the structure, coordinate domestic and international markets, and formulate corresponding agricultural food policies?

Jointly initiated and published by the Academy of Global Food Economy and Policy (AGFEP) of China Agricultural University, the China Academy for Rural Development (CARD) of Zhejiang University, the National Institute for Nutrition and Health (NINH) of the Chinese Center for Disease Control and Prevention (CCDC), the Institute of Food and Nutrition Development (IFND) of the Ministry of Agriculture and Rural Affairs, the International Food Policy Research Institute (IFPRI), the World Resources Institute (WRI), the Food and Land Use Coalition (FOLU), and the Environmental Defense Fund (EDF) Beijing Representative Office, the China and Global Food Policy Report (hereinafter referred to as the "report") has covered the years 2021–2023. It successively explored the direction of agrifood systems transformation for the past-covid era(2021), how to reform and optimize China's agricultural support policies(2022), and how to promote sustainable and healthy dietary patterns suitable for China(2023).

Based on the previous three years, this year's report focuses on the supply system, emphasizing "nutrition-oriented" and "system thinking" approach. It tries to thoroughly analyze how to develop China's diversified food supply system by examining resources, efficiency, structure, and trade. The goal is to meet consumers' increasingly diverse and nutritious food needs and promote agrifood systems' sustainable transformation. This report is grounded in multidisciplinary collaborative research, data analysis, and policy simulation, highlighting the integration of international perspectives with Chinese practices. It aims to provide systematic, and evidence based decision-making and research references for policymakers, researchers, and practitioners in the agrifood sector.

The first chapter of this report examines the current state and food security trends in China and in the world. It summarizes the main challenges facing food security today, explores the concept and characteristics of a diversified food supply system, and proposes policy pathways. The second chapter, guided by the demand for healthy diets, assesses the production potential of diverse food supply sources—including forests, grasslands, rivers and lakes, facility agriculture, and novel foods—and simulates the comprehensive impact of optimizing these food production sources. The third chapter focuses on the development and application prospects of alternative proteins in China, such as plant-based proteins, cultured meat, and insect proteins, evaluating their impact on food security, resource and environments through model simulations. The fourth chapter, through in-depth analyses of three specific cases—nutrition fortification, whole grains promotion, and food loss reduction—explores the important role of midstream segments of the food industry chain in ensuring food supply, improving nutritional contents, and enhancing resource efficiency. The fifth chapter, based on an analysis of China's food import characteristics and supply risks, investigates diversified imports' stability and cooperation potential to strengthen food import resilience.

The key findings of the report are as follows:

First, to better meet the people's demand for diverse, nutritious, and environmentally friendly food and to address the challenges of limited food supply resources and imbalanced supply-demand structure, China urgently needs to build a diversified, sustainable food supply system. As China's population stabilizes and disposable incomes continue to rise, the demand for grains and cereals has reached a plateau while the demand for diverse, nutritious, and environmentally friendly food is increasing. However, China's current agrifood supply system faces structural problems such as over-reliance on arable land, extensive and unsustainable production mode, and high import ratios for certain categories.

Second, embracing a healthy dietary approach and fully leveraging the potential and benefits of natural resources such as forests, grasslands, rivers, and lakes, can cater to residents' diverse nutritional needs and mitigate environmental impacts. In 2022, food sourced from arable land constituted 83.5% of China's total food energy, while forest and grassland products, aquatic harvests, and livestock accounted for only 4.8%, 0.4%, 1.5%, and

10%, respectively. Despite this, non-arable resources are pivotal in providing protein-rich, nutrient-dense foods. A comprehensive strategy to develop and utilize these varied production resources will boost the output of forest and grassland products, aquatic foods, and future food alternatives, fostering healthier and more varied diets for residents. This integrated approach could conserve 6.5 million hectares of arable land and cut carbon emissions by 180 million tons, marking a 19% reduction.

Third, advancing the alternative protein industry eases the strain on the livestock sector, preserves water and soil resources, curtails greenhouse gas emissions, and bolsters the resilience of agricultural food systems. By substituting plant-based meats for 10% of pork and beef, cultured meat for 1% of pork and beef, plant-based milk for 15% of dairy, and insect protein feed for 10% of soybean meal, we project a reduction of 8.2% and 16.6% in livestock and dairy production, respectively, by 2035. This shift would also lessen the demand for grains and soybean meal by 15.9 million tons and 9.23 million tons, correspondingly while conserving 1.2 million hectares of arable land and decreasing agricultural carbon emissions by 9%.

Fourth, optimizing the midstream stages of food supply through measures like food fortification, whole-grain provision, and food waste reduction can amplify the efficiency of food supply chain, enhance the utilization of limited arable land resources, and yield notable nutritional benefits. China currently loses over 170 million tons of food in post-harvest processing, storage, transportation, and marketing, resulting in a land footprint exceeding 10 million hectares, protein losses surpassing 7.5 million tons, and fat losses exceeding 5.2 million tons. Developing fortified and biofortified foods can effectively address micronutrient deficiencies for residents, particularly benefiting low-income groups. Increasing the provision of whole grains can reduce medical costs linked to associated ailments, increase usage efficiency of food, and diminish carbon emissions.

Fifth, China's food imports exhibit a significant concentration, necessitating enhancements in stability and dependability. The country's food trade reflects a trend where import growth outpaces exports, leading to a burgeoning trade deficit. The import structure is skewed, predominantly focusing on grains, oilseeds, and meat, constituting over 60% of total imports. Despite the ongoing import concentration, the source countries are undergoing a shift: reliance on the United States is diminishing while dependence on countries and regions such as Brazil, Russia, and ASEAN is increasing.

This report presents the following strategic recommendations based on the research findings outlined above:

1.Transformating Agrifood Systems. Leveraging technology development, policy reforms, business initiatives, and international collaboration, China can spearhead the development of a diversified food supply system under the "big food" concept. This strategic shift serves as an important case for global agricultural food systems transformation and strengthens food and nutrition security. It involves concerted efforts in production, processing, distribution, and consumption to achieve integrated and optimized supply chains. Technology policy, business, and international cooperation must continue to reform and optimise to support the construction of a diversified food supply system.

2.Constructing a Healthier and Sustainable Food Production System. It demands to set strategic goals based on the "big food" and "big resources" concepts. Detailed plans and pathways for optimizing food sources must be meticulously researched and refined. Encouraging the sustainable development of various food resources simultaneously achieves ecological resource protection and utilization. Government guidance is needed in fostering deep engagement from enterprises, scientists, and other stakeholders in developing various food resources. Optimizing policy support systems, increasing investment in key areas like forests, grasslands, water resources, facility agriculture, and future foods, and fostering research and development of new products and technologies will help to supply healthier, ecologically sustainable, and affordable foods.

3.Promoting Alternative Protein Industry Development. Simultaneous efforts in supply, demand, and policy are needed to drive the growth of the alternative protein industry. This entails increasing research and development investment, improving product quality, reducing production costs, and promoting interdisciplinary integration. On the consumption side, targeted promotional efforts, consumer guidance, and tailored marketing strategies are essential for more acceptance of alternative proteins. Accelerating the enhancement of standards, regulatory systems, and sustainable industry development is also needed for long-term success.

4.Enhancing Food Nutrition Utilization. Standardizing industry norms, reinforcing policy guidance, and leveraging technological advancements are key to optimizing food nutrition utilization. It calls for collaborative efforts among government departments, processing enterprises, and research institutions to establish a regulatory framework for food loss and waste assessment and enhance investment in research and development across various sectors.

5.Engaging in Global Governance. Deep engagement in global food supply system governance can enhance China's diversified food supply, promote global food security, and ensure stable food trade sources. Improving the business environment, encouraging participation in global food industry cooperation, enhancing global competitiveness, and actively contributing to global governance frameworks must be facilitated for sustainable development.

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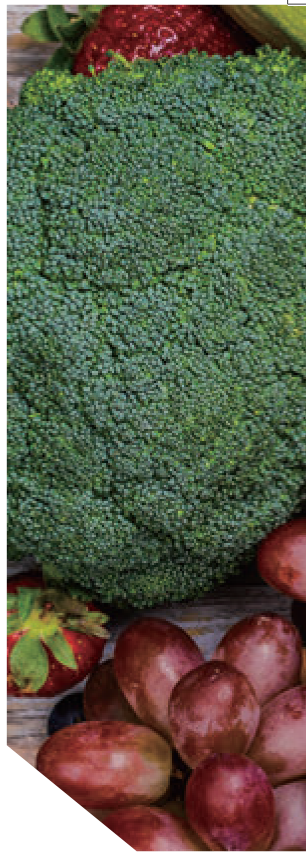
Chapter 1

Building a Diversified Food Supply System under the Big Food Concept



Ting Meng, Shenggen Fan, and Wenjin Long

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Key Findings

● Global food security now extends beyond addressing hunger to achieving balanced nutrition and healthy diets while minimizing resource and environmental impacts. It also aims to improve residents' livelihoods, promote social equity, and support welfare improvement. China's food security is too evolving toward "pursuing balanced and nutritious diets." However, the current food supply-demand system faces several challenges, including a high dependence on grain, imbalanced dietary structures, heavy reliance on arable land and extensive production methods, structural food shortages, and rising international imports.

● The trend of future food demand in China will become more diverse, with a greater emphasis on nutritional health and environmental sustainability. From the demographic perspective, an early arrival of population peak and an increasingly aging population are expected to decrease overall food and grain demand. From the economic perspective, residents' demand for diverse, more nutritious, and healthier foods will grow as per capita income rises. From the societal perspective, as environmental awareness deepens, the demand for environmentally friendly foods is anticipated to increase.

● Clarifying the connotation of a diversified food supply system requires understanding of production resources, driving forces, and policy environment. Regarding production resources, the food supply system should fully utilize comprehensive and multi-pathway uses. Regarding driving forces, the increasing demand for nutritious, healthy, and sustainable food among residents drives the restructuring and optimization of the food supply system. Regarding environmental constraints, systematically consideration of the carrying capacity of resources, the environment, and the ecosystem can help to achieve harmonious development between the food supply system and the ecosystem. Building the policy environment calls for adopting multi-channel instruments to promote the transformation to sustainable healthy diets, including leveraging policies, education, and market interventions effectively.

Policy Recommendations

● Constructing a diversified food supply system under the big food concept provides a Chinese approach to promoting global agricultural and food system transformation and better ensuring food and nutritional security. Establishing a diversified food supply is also an important part of agrifood systems transformation. The following measures are recommended. First, fully utilize the potential and advantages of natural resources such as forests, grasslands, rivers, lakes, and seas while developing facility agriculture. Second, strengthen technological innovation and interdisciplinary cooperation and enhance policy and regulatory support for new alternative proteins. This includes promoting the research and application of plant-based proteins, cell-cultured meat, microbial proteins, and insect proteins. Third, explore food and nutritional resources in the mid-stream of food systems. Use technologies in breeding and processing to enhance food and nutritional resources, and reduce food loss and waste. Fourth, diversify the food trade. Promote the diversification of China's food trade by implementing flexible and well-defined trade policies, actively participating in the global food industry chain, and creating a healthy business environment for the food industry. These measures will help build a diversified food supply system, transform the agrifood systems, and enhance food and nutritional security.

● Innovations in technological, policy, and business models should be promoted to support a diversified food supply system. In terms of technology, it is recommended to promote the deployment and application of biotechnology, artificial intelligence, and information technology in the agriculture and food sectors, and facilitate the research and development of cutting-edge, disruptive technologies, scientifically utilizing soil, water, and natural resources to improve resource utilization efficiency and expand food source channels comprehensively. In terms of policy, it is suggested to increase support for nutritious and healthy foods, establish incentive mechanisms to encourage food supply chain entities to adopt green and low-carbon technologies, and strengthen the construction of high-standard farmland and agricultural product supply chain infrastructure. In terms of business, it is proposed to promote ecological and circular agriculture to use agricultural resources efficiently, strengthen the organic integration of the food industry with the leisure and tourism industries, innovate investment and financing models, and encourage enterprises and farmers to establish close cooperative and mutually beneficial mechanisms. These innovations will collectively support the development of a robust and diversified food supply system.

1.1 Global and China's Food Security Status and Trends

1.1.1 Global Food Security Faces Substantial Challenges

Since the 21st century, agriculture and food production have made significant progress, continuously improving global food security. However, since 2015, the global food security has faced numerous obstacles, with little progress in improving food insecurity and malnutrition. These challenges stem mainly from climate change, resource degradation, geopolitical conflicts, and the prolonged impact of global pandemics.

Climate Change: Climate change leads to frequent extreme weather events, which can cause secondary disasters, limit food supply capacity, reduce food availability, and compromise food quality, posing severe challenges to the function of the agrifood systems.

Resource Degradation: Human activities have led to increased land degradation, with about 40% of the global land currently degraded, affecting the production and living conditions of over half the world's population.

Geopolitical Conflicts: Conflicts, such as the Ukraine crisis, have created significant shocks to global energy, fertilizer, and food supply chains, exacerbating global food security instability.

Global Pandemics: The global economic slowdown and increased volatility in international markets post-pandemic have led to significant food price increases. Economic downturn has reduced disposable incomes, while the rising costs of healthy diets have further worsened food access for poor and vulnerable populations.

These factors collectively challenge the functions, and resilience of global food security, necessitating comprehensive strategies to address these multifaceted issues.

According to the 2023 Global Food Security and Nutrition Report, about 691–783 million people globally were affected by hunger in 2022. This represents a decrease of 3.8 million from 2021 but an increase of 122 million compared to pre-pandemic levels. Additionally, approximately 2.4 billion people globally lacked access to nutritious, safe, and sufficient food throughout the year.

Moreover, inflation resulting from the pandemic has evaluated overall price levels, reduced disposable incomes, and increased the costs of healthy diets. In 2022, the cost of a healthy diet increased by 4.3% compared to 2020 and 6.7% compared to pre-pandemic levels, making it increasingly difficult for billions to afford healthy diets.

Thus, despite some pause over the worsening hunger situation in the past two years, global food security remains grim. Countries must continue to work together to address hunger, food insecurity, and nutrition challenges, ensuring stable, nutritious, and sufficient food supplies for global citizens. The international community strives to transform the global agrifood system to address multiple challenges and risks more effectively, ensuring global food and nutrition security and promoting the achievement of the United Nations' Sustainable Development Goals (SDGs). This transformation process has received extensive attention and discussion at several major international conferences, such as the 2021 United Nations Food Systems Summit, the 15th Conference of the Parties to the Convention on Biological Diversity (COP15), and the 2023 United Nations Climate Change Conference (COP28). These events emphasize the critical role of food systems in addressing global challenges.

The Chinese government also highly values the importance of agrifood systems transformation. The report of the 20th National Congress of the Communist Party of China explicitly calls for establishing a big food concept and constructing a diversified food supply system to address the increasingly complex and volatile international environment and domestic demand. Furthermore, in December 2023, China passed the "Food Security Guarantee Law" to strengthen the agrifood system's risk prevention and resilience capabilities, ensuring an adequate food supply and national food security. These measures demonstrate China's strong commitment and proactive actions toward agrifood systems transformation, contributing significantly to the sustainable development of the agrifood systems. At this stage, food security has evolved beyond merely addressing hunger issues. The focus now includes achieving balanced nutrition and healthy diets while reducing resource and environmental burdens including mitigating changes, improving livelihoods, promoting social equity and welfare.

Nutrition: International organizations and numerous entities have incorporated nutrition security into the food security framework, aiming to enhance residents' access to nutritious and healthy foods.

Environment: Environmental sustainability is seen as the cornerstone of food security. The United Nations promotes climate-smart agriculture and production efficiency through multiple initiatives.

Equitable Livelihoods: Food security enhancement projects primarily focus on protecting the livelihoods and welfare of women, smallholder farmers, and low-income groups.

The international community continuously calls for countries to actively participate in international food security cooperation, enhancing the resilience of the global agrifood system through worldwide governance. This collective effort aims to accelerate the realization of sustainable global food security goals, thereby constructing a more efficient, healthier, sustainable, and inclusive food system.

1.1.2 China's Food Security Is Undergoing a Historic Transformation Toward Balanced and Nutritious Diets

Since the founding of the People's Republic of China, the country has successfully solved the problem of feeding over a billion people, achieving a historic transformation from "not having enough to eat" to "having enough to eat," and garnering global recognition for its significant achievements in food security. China is moving toward "eating well" and "eating nutritiously." The development of China's food security and the evolution of its food security concept can be roughly divided into the following stages (Fan and Meng, 2024):

First Stage (Founding of the PRC–Pre-Reform and Opening-Up): During this period, per capita grain availability was low and food supply levels were minimal, with the primary focus on increasing the "quantity" of staple food supply. In 1949, when the People's Republic of China was founded, the country faced numerous challenges, with grain production at only 113 million tons and per capita grain production at 208.9 kilograms. The central issue in food security was ensuring enough to eat. China implemented a planned economic system and experienced three years of difficulties, marked by severe material shortages and widespread famine, which resulted in low food supply levels. The traditional food security concept during this stage focused on basic grain self-sufficiency, primarily aiming to increase grain production.

Second Stage (Post-Reform and Opening-Up–2009): Grain supply levels steadily increased, with per capita grain availability surpassing the world safety line. Additionally, the demand for vegetables, fruits, meat, eggs, and dairy products gradually increased, necessitating a comprehensive increase in the "quantity" of major food categories. In 1996, the White Paper on China's Grain Issues explicitly proposed the basic policy of "relying on domestic resources to achieve basic grain self-sufficiency." As urbanization advanced and household incomes rose, the social development goal shifted from subsistence to moderate prosperity, and dietary habits evolved from "having enough to eat" to "eating a diverse diet." The demand and consumption of vegetables, fruits, meat, eggs, and dairy products continuously increased. After joining the WTO, China's food supply diversified, supported by a strategy of moderate imports. The reform and opening-up policies spurred rapid growth in grain production, surpassing 600 million tons in 2012. These developments ensured a stable and ample market grain supply, marking significant progress in China's food security.

Third Stage (2010–2020): During this stage, the supply of various foods was sufficient, and per capita food consumption significantly increased, prioritizing food supply security and quality improvement. Since 2013, China's grain production has maintained stable growth, consistently exceeding 600 million tons and surpassing 650 million tons since 2015. In 2013, the new food security strategy of "based on domestic supply, ensuring production capacity, moderate imports, and technological support" was established, shifting from emphasizing "grain self-sufficiency" to ensuring "food self-sufficiency capacity," and appropriately utilizing international markets to ensure domestic food security. While ensuring a stable food supply, the demand for food safety and quality improvement increased due to residents' growing concerns and the degradation of agricultural resources and the environment. In response, the "double reduction" policy for fertilizers and pesticides was introduced in 2015, increasing the supply of green and certified food. This period marked a significant emphasis on enhancing the quality and safety of the food supply alongside maintaining its sufficiency.

Fourth Stage (2020–Present): During this stage, residents' food demand has become more diversified, with food consumption moving toward balanced and nutritious diets. As a result, optimizing the food supply structure and improving quality have become primary tasks. The focus has moved from "eating a diverse diet" to "eating balanced and healthy diets," with nutrition and health becoming the primary concerns. Food security issues have shifted from quantity shortages to structural contradictions under resource constraints. The "No. 1 Central Document" of 2023 emphasized "establishing a big food concept and accelerating the construction of a diversified food supply system integrating grains, economic crops, and feed, integrating agriculture, forestry, animal husbandry, and fisheries, and integrating plants, animals, and microorganisms." The strategic requirements include understanding changes in residents' food structure, ensuring ample grain supply, and effectively supplying meat, vegetables, fruits, and aquatic products. This policy aims to meet residents' diverse dietary needs while ensuring food quality and safety through a diversified food supply system.

1.1.3 China's Food Supply and Demand System Faces Structural Imbalances

First, grain dominates the agrifood systems, leading to imbalanced diets and multiple forms of malnutrition. Grain occupies a significant proportion of the agrifood systems, with rice, wheat, and corn production at 208.495 million tons, 137.723 million tons, and 277.203 million tons, respectively, accounting for 30.37%, 20.06% in 2022. This dominance of grain consumes a disproportionate amount of arable land and water resources compared to other crops. In 2022, the sown area for grain crops was 118.33 million hectares, constituting 69.7% of the total sown area for crops. Agricultural water use, primarily for grain production and processing, exceeds 60% of China's water consumption.

However, the high proportion of grain supply does not match residents' dietary nutrition needs. China's dietary structure requires revision, as it currently exhibits excessive consumption of red meat and refined grains, with insufficient intake of fruits, vegetables, beans, dairy, and fish (Chinese Nutrition Society 2021). The Report on the Nutrition and Chronic Disease Status of Chinese Residents (2020) indicates that over half of adult residents are overweight or obese. Moreover, the rates of overweight and obesity among children and adolescents aged 6–17 and under 6 years old are 19% and 10.4%, respectively. Additionally, nearly 300 million people suffer from hidden hunger due to insufficient micronutrient intake (Liu et al., 2023).

Second, agricultural production in China heavily relies on arable land resources and employs extensive prodution methods. Accelerated industrialization and urbanization have led to persistent shortages and degradation of water and soil resources, with medium- and low-yield land accounting for about two-thirds of the total arable land area. The effective utilization coefficient of agricultural irrigation water is only 53%, and nearly 20% of arable land is affected by soil pollution (Hu et al., 2023).

Climate change has increased the frequency of extreme weather and natural disasters, posing significant threats to agricultural production. For example, the widespread summer–autumn drought in the Yangtze River Basin in 2022 severely impacted local agriculture. Moreover, due to further urbanization and the extensive agricultural production methods involving excessive use of fertilizers and pesticides, China's arable land area continues to decrease, and land quality has degraded.

The average multiple cropping index of arable land has risen from 1.14 in 2001 to 1.30 in 2018, with some areas reaching over 3.00, indicating an over-reliance on arable land resources. The high-load utilization of arable land persists, contributing to food loss and waste throughout the entire industry chain. China's food loss and waste rate is 22.7%, equivalent to 312 trillion kilocalories, which could meet the annual nutritional needs of 380 million people (Chen et al., 2023). This situation exacerbates food security pressures and burdens resources and the environment.

Third, structural food shortages persist alongside continuous increases in international imports. According to data from the General Administration of Customs, China imported 161.96 million tons of grain in 2023, an increase of 11.7% year-on-year. The optimization and quality improvement of residents' dietary structure, coupled with rising demand for high-quality staple food and animal protein, has elevated China's reliance on international markets for premium food items, such as high-quality wheat and feed grains like soybeans.

Since 2004, China has transitioned from a net exporter to a net importer of agricultural products, with net imports of critical agricultural products such as grain increasing annually. The soybean import ratio has consistently exceeded 70% since 2010, with soybean imports amounting to 91.08 million tons (import ratio of 81.5%) in 2022. Additionally, to meet residents' diverse consumption needs, China imports substantial quantities of meat, dairy, and aquatic products, with beef imports accounting for 28.20% in 2022.

1.1.4 China's Future Food Demand Will Be More diverse, Emphasizing Nutrition and Environmental Friendliness

Given the domestic and international food security challenges, the new trends in China's food demand structure needs to be understand in depth. It helps identify multiple pathways to develop food resources from the demand side, meeting the population's increasingly diversified food consumption needs. It also aids in designing a top-down approach to sustainable development that prioritizes ecology, environmental friendliness, and resource conservation. This approach is instrumental in building a food system that balances food productivity and resource-carrying capacity. As the economy gradually recovers from the three-year impact of COVID-19, there is a noticeable increase in residents' demand for safe, nutritious, and healthy food. This surge in demand is leading profound changes in China's food demand structure, highlighting the importance of adapting to evolving consumer preferences and ensuring sustainable food production practices. First, population peak and aging will likely reduce the demand for grain and cereal consumption. According to the World Population Prospects 2022, China's population peaked in 2022 and is projected to decline gradually, with a notable increase in the aging population. According to the National Bureau of Statistics, China's population at the end of 2022 was 1.4 billion, showing a decrease of 850,000 compared to 2021. The proportions of the population aged 0–14 and 15–64 decreased slightly by 0.5% and 0.1%, respectively, while the proportion of those aged 65 and above increased by 0.7%. As the population ages, the demand for grains and tubers among the elderly decreases relative to the population's age. Since staple grains like rice and wheat are the primary sources of energy and carbohydrates in the daily diet of the Chinese population, their consumption is expected to decrease slightly as the population declines and the aging deepens.

Second, residents' demand for more diverse, nutritionally healthy foods will persistently increase as per capita income rises. In recent years, both urban and rural residents have experienced steady income growth. In 2022, urban and rural residents' per capita disposable income reached 49,283 yuan and 20,133 yuan, respectively, an increase of 104.3% and 140.0% over the past decade. As income levels rise, there is a noticeable shift in people's food consumption structure, primarily manifested in a significant decrease in grain and a substantial increase in high-protein food. This shift has transformed food consumption patterns from primarily plant-based to a more diverse mix of plant- and animal-based foods. Consequently, there has been an acceleration in the structural transformation in grain demand toward a significant increase in feed grain. Statistics show that China consumes about 250 million tons of grain annually for food, 270 million tons for feed, and 160 million tons for industrial purposes.

Third, as environmental awareness deepens across society, the demand for environmentally friendly food is increasing, and related environmental regulations and policies are becoming stricter. With growing concerns about food safety issues related to environmental pollution, residents' environmental expectations for food production, packaging, transportation, and other aspects are also rising. Since 2015, China has implemented a series of policies such as the "Double Reduction" policy for fertilizers and pesticides, initiatives for the resource utilization of livestock and poultry manure, and actions to improve arable land productivity. These measures comprise a new stage of green and sustainable agricultural development.

At the same time, various sectors of society, including environmental protection organizations, social groups, and international institutions, are increasingly focusing on environmental protection and the restoration of ecological resources and actively engaging in actions that require the food production sector to accelerate the reduction and efficient use of chemical inputs. This shift encourages agricultural and food enterprises to adopt more environmentally friendly production equipment, processes, and packaging materials. Additionally, optimizing the production and processing processes throughout the food supply chain to reduce energy consumption and waste generation is demanded for mitigating the resource and environmental burden. These measures collectively contribute to the sustainable development of the entire food industry chain, achieving a win-win situation for environmental protection and food safety.

1.2 The Connotation and Characteristics of a Diversified Food Supply System

1.2.1 The Connotation of a Diversified Food Supply System

Clarifying the connotation of a diversified food supply system requires understanding it from four aspects: production resources, driving forces, environmental constraints, and policy environment.

Production Resources: Food production resources of the supply system should be comprehensive and multi-pathway. This means leveraging a variety of local resource endowments to develop food resources beyond the limitations of arable land. The principle is to grow grain where suitable, develop economic crops where suitable, raise livestock where suitable, fish where suitable, and plant forests where suitable. This approach aims to form a modern agricultural production structure and regional layout that matches market demand and resource and environmental carrying capacity. The goal is to achieve balanced supply and demand for various foods. At the same time, food supply methods should be diversified, encompassing different industries such as planting, breeding, and food processing. This involves multiple entities such as agricultural enterprises, farmers, and new types of business entities and covers various traditional and new business forms such as wholesale, retail, and direct sales, forming a network system that collectively constitutes a diversified food supply approaches.

Driving Forces: The increasing demand for nutritionally healthy and sustainable food among residents drives the restructuring and optimization of the food supply system. Building a diversified food supply system should be based on consumers' nutritional needs, focusing on the healthy requirement of residents' dietary nutritional structure. This involves systematically considering the supply and regional layout of different agricultural products. Therefore, the core idea of a diversified food supply system is "production based on demand." This means determining the scale and variety of production based on market demand to meet consumer needs while improving the efficiency and effectiveness of agricultural food supply. The implementation of this model relies heavily on technology, such as data analysis and intelligent agriculture. The future development of agricultural food products will shift from "ensuring enough food" to "eating well and healthily," transitioning from "food security" to "nutrition security." Therefore, a diversified food supply system must emphasize both the quantity and quality of food and establish a nutrition-oriented agricultural production system. This requires examining population size and structure, dietary structure changes, and eating habits, as well as conducting food consumption forecasts based on residents' consumption and nutritional needs.

Environmental Constraints: Seek harmony between food supply and the ecosystem by considering resource, environmental, and ecological carrying capacity constraints. Food supply and agricultural production depend highly on water, soil resources, and ecosystems. Inputs, supply methods, food circulation, and food waste can all significantly burden the ecological environment. Agrifood systems account for about one-third of total greenhouse gas emissions, significantly impacting global climate change. A diversified food supply system should minimize or avoid adverse impacts on resources, the environment, ecology, and climate by transforming food supply methods. It calls to emphasize circular and regenerative agriculture, reduce food loss and waste, and promote the harmonious development of the food supply system and the ecosystem. This approach includes avoiding resource waste and environmental pollution, improving resource utilization efficiency, reducing greenhouse gas emissions, and focusing on ecological diversity restoration and enhancing ecosystem stability.

Policy Environment: Promote the transformation to sustainable healthy diets through multiple channels, fully utilizing policy, education, and market intervention tools. Residents' food demand and consumption should prioritize nutrition and health, emphasizing food variety and balanced dietary structure. Encouraging the adoption of low-carbon, environmentally friendly dietary models will help to reduce the food supply's environmental impact and alleviate the burden on water, soil, and ecological resources. To facilitate this transformation, must be leveraged a range of tools and strategies. These include dietary guidelines and policies, nutritional and sustainable dietary model promotion, and food labeling. In addition, implementing sugar taxes, carbon taxes, and other market intervention tools can effectively guide and influence residents' food demand concepts and consumption behaviors. These measures aim to foster sustainable development and healthy lifestyles by promoting awareness and adoption of sustainable, nutritious, and environmentally friendly dietary practices.

1.2.2 Linking the Big Food Concept and Agrifood Systems Transformation to a Diversified Food Supply System

The big food concept provides theoretical support for a diversified supply system. This system can help to fulfill the goals outlined by the big food concept, which aims to meet people's needs for a better life by comprehensively developing food resources through multiple pathways. The concept emphasizes obtaining calories and protein not only from farmland but also from grasslands, forests, oceans, and various plants, animals, and microorganisms.

Understanding the trends in residents' food structure changes is key to implementing the big food concept effectively. This involves ensuring the effective supply of grains and other essential foods such as meat, vegetables, fruits, and aquatic products. The big food concept expands the scope of the food supply system to include a variety of foods beyond grains, emphasizing meeting people's dietary needs and pursuing a better quality of life.

The big food concept advocates for obtaining necessary nutrients from diverse resources and not completely relying on arable land as the sole food source. It proposes comprehensive development of food resources through multiple pathways, obtaining calories and protein from farmland, grasslands, forests, oceans, and various plants, animals, and microorganisms. Conversely, the diversified food supply system is key for practicing the big food concept. It clarifies the importance of a diversified food system's production resources, supply channels, circulation chains, and other aspects. Only through systematically building a diversified supply system can the developmental goals of the big food concept be achieved, meeting the people's diverse dietary needs and aspirations for a better life.

Constructing a diversified food supply system is one critical element in transforming agrifood systems, but it is not the only aspect. Besides focusing on the supply system, the transformation of agrifood systems includes technological innovations, transforming dietary demand, optimizing policy systems, and reshaping market structures.

On the one hand, constructing a diversified food supply system promotes the development of agrifood systems toward nutritional health, green and low-carbon practices, efficiency, resilience, and inclusiveness. This approach helps China achieve multiple development goals, such as food security, nutritional health, carbon neutrality, and shared prosperity.

On the other hand, transforming agrifood systems is a complex systemic project that requires promoting transformation across various dimensions, including research, market, demand, policy, and other aspects besides supply. Although constructing a diversified food supply system is closely related to technological innovations, dietary demand, supporting policies, and market organization, it primarily focuses on supply-side changes and innovations.

Achieving comprehensive transformation of the agrifood systems requires systematic optimization and coordination among various links and stakeholders. This includes integrating technological advancements, understanding and influencing dietary trends, formulating and implementing effective policies, and creating robust market structures supporting a holistic transformation toward a more sustainable and resilient agrifood system.

1.2.3 Characteristics of a Diversified Food Supply System

A diversified food supply system expands upon traditional food supply systems by broadening the range of supply sources, enhancing resource utilization, diversifying production processes, and strengthening support systems. First, supply objects beyond traditional grain boundaries should be expanded to include various foods. While a diversified food supply system is based on grain supply, it progressively broadens its scope to encompass not only traditional grains and staple foods but also a wide range of essential agricultural products, including crops, edible oils, meat, eggs, dairy, vegetables, fruits, tea, and other essential agricultural products and their by-products. In nature, food is "holistic," with grains being just a "partial" element and staple grains even more so as "partial of the partial." By expanding the supply scope from "partial" grains to "holistic" food, a diversified food supply system enriches people's dietary structure and improves their nutritional levels and overall health.

Second, expanding resource utilization should reflect comprehensive development and full utilization of national land resources. Given the increasing scarcity of arable land, addressing food security issues cannot rely solely on limited arable land. China has 426.2 million acres of forestland, 396.8 million acres of grassland, 35.2 million acres of wetlands, and 54.4 million acres of water bodies, offering immense potential for a diversified food supply system. By fully utilizing these diverse resources, food supply diversification can be achieved, enhancing food supply stability and sustainability while promoting ecological conservation and restoration. Leveraging biological resources from forestland, grassland, wetlands, and water bodies can enhance food production efficiency and quality. This approach supports shifting toward a more technological and intelligent food industry, meeting the growing demand for healthy, diverse foods. Such comprehensive resource utilization promotes the upgrading and transformation of the food supply system, aligning with ecological conservation and ensuring long-term food security.

Third, expanding production links involves integrating and optimizing production processes to ensure a coordinated and efficient full-chain supply. A diversified food supply system encompasses a complete industrial chain: "research–input–production–circulation–consumption." This includes extending to microbial resources, plant and animal germplasm research and development, input factors, food circulation, and processes like storage, transportation, sales, branding, consumer experience, consumption, and services. It involves all participants and interconnected value-added activities and environments, fostering synergy. Establishing integrating industrial chains with green, and high-efficiency processes, such as grain security industrial belts and agricultural product industrial belts, which serve as a model, will drive the improvement of the entire food supply system. This approach helps improve the spatial matching of food supply and demand, reduce long-distance and large-scale transportation, lower losses, and achieve a more sustainable food supply. It ensures food security and quality, promotes the efficient use of agricultural products, and supports sustainable resource utilization, guiding the entire food supply system toward a more environmentally friendly, efficient, and sustainable direction.

Fourth, expanding support systems is needed for breaking down departmental barriers and upgrading the supply system through dual circulation. In the context of economic globalization, the global food system faces significant risks and uncertainties due to overlapping changes and conflicts. China's food security and supply-demand balance are under pressure from internal and external market risks. A diversified food supply system leverages domestic and international markets and resources, relying on institutional, industrial, and organizational management systems for external openness. This transition moves beyond single-product international trade to comprehensive international resource allocation. By fully utilizing international resources and trade, the system promotes dual circulation between international and domestic markets, ensuring a safer and more stable food supply chain. Establishing a diversified food supply system addresses global challenges and risks by optimizing resource allocation and diversifying the food supply chain, thereby enhancing stability and security. It also fosters the development of domestic markets and strengthens food security, increasing China's influence and discourse power in the global food system.

1.3 Pathways to Construct a Diversified Food Supply System

1.3.1 Promoting Agrifood Systems Transformation and Expanding Production Resources of the Food Supply System

Constructing a diversified food supply system under the big food concept requires adopting a systemic agrifood systems perspective (Fan, 2022). This approach provides a Chinese perspective on promoting global agrifood system transformation and better ensures food and nutrition security. It is a crucial pathway for establishing a diversified food supply system, integrating various elements of production, distribution, and consumption to create a more resilient and sustainable food ecosystem.

First, leveraging various resources for food supply capacity is of utmost importance. China's heavy reliance on arable land for food sources has led to a relatively monotonous food consumption structure, with rice and wheat alone accounting for half the energy sources in food consumption. This single planting structure necessitates further optimization to meet residents' growing and diverse dietary needs. Without expanding and optimizing the current food production source structure beyond arable land resources, satisfying the demand for fruits, nuts, aquatic products, and dairy products will be fundamentally challenging. A health-oriented dietary approach should optimize food production sources based on the big food concept to address food demand challenges. This means fully leveraging natural resources such as forests, grasslands, rivers, lakes, and seas, utilizing the potential and advantages of facility agriculture and future food technologies. These measures can provide more nutritionally rich and diverse foods, reduce dependence on food imports, alleviate pressure on arable land resources, and minimize negative environmental impacts. Such optimization measures will help establish a more sustainable and healthy food supply system, ensuring a balanced and varied diet for the population while preserving environmental integrity.

Second, the potential of alternative proteins should be fully explored. As global population growth and economic development continue, the rapid increase in meat consumption poses significant challenges to protein supply, health environmental pressures, and resource constraints. The alternative protein industry potentially offers an effective solution to reduce the environmental impact of food production and reliance on limited resources. Promoting plant-based meat, plant-based milk, cell-cultured meat, and insects as feed can help replace livestock products, reducing the pressure on traditional livestock and dairy farming while decreasing reliance on soybean meal and other feeds. Estimates suggest that increasing the production of plant-based meat, plant-based milk, and cell-cultured meat by 7.68 million tons, 10.53 million tons, and 550,000 tons, respectively, can significantly replace traditional livestock products, reducing pork and beef consumption by 6.46 million tons and 900,000 tons, respectively, and milk by 7.02 million tons. Driving this transformation need to enhance technological innovations and interdisciplinary cooperation, supported by policies and regulations that foster the development of the future food industry, such as alternative proteins. Increasing consumer acceptance and promoting the discovery and utilization of plant-based proteins, cell-cultured meat, microbial, and insect proteins will be key.

Third, it calls for expending midstream food and nutritional resources. The midstream stages of the food supply chain, particularly processing, often involve over-processing (including high salt, high sugar, high oil, and food additives), contributing to micronutrient deficiencies and issues like overweight and obesity. By utilizing advanced biology, breeding, and processing technologies, such as promoting nutrition fortification and whole-grain production,food production efficiency and the supply of nutritious foods can be enhanced effectively achieving "open source" for nutritious food. Food loss and waste are prevalent at every stage of the food supply chain, from production to consumption, causing significant loss of nutrients. Addressing this issue is essential for the food system's sustainable transformation and achieving sustainable development goals. Efforts should focus on reducing food loss and waste throughout the supply chain to minimize nutritional losses, achieving "flow saving" of food resources. By implementing measures to reduce food loss and waste and enhance the nutritional quality of processed foods, the country can increase the availability of nutritious food sources, decrease environmental burdens, and reduce resource waste. This comprehensive approach improves public health and supports a more sustainable and resilient food system.

Fourth, the layout and structure of the international food trade should be optimized. China is at the forefront of global agricultural openness, with international grain markets and overseas agricultural resources playing a vital role in supplementing domestic production gaps. However, China's food import structure remains imbalanced, with essential agricultural products such as grains, oilseeds, and meat accounting for over 60% of total imports. Additionally, the concentration of food import sources presents challenges. While dependence on the United States is decreasing, reliance on Brazil, Russia, and ASEAN is increasing, raising concerns about import stability and reliability. To address these challenges, it demands to diversify China's food trade layout and implement flexible, refined trade policies. Active participation in global food industry chain cooperation and creating a healthy business environment for the food industry are important steps. China should engage in deep trade and investment cooperation with South–South cooperation countries, reducing market risks associated with traditional food import channels and promoting diversified food types and sources. These measures can effectively improve the stability and reliability of China's food imports, reduce dependence on specific countries, and optimize the food import structure. By doing so, China can ensure the safety and stability of its food supply and play a more active role in global food trade. This approach will also contribute to developing and improving the global food trade system, promoting a more resilient and diversified international food market.

1.3.2 Integrating the Entire Food Industry Chain to Enhance the Resilience and Efficiency of the Food Supply System

Constructing a diversified food supply system requires comprehensive reforms throughout the supply chain. This involves focusing on production, processing, circulation, and consumption, achieving integrated and optimized full-chain coordination.

First, the production stage should be strengthened as a stabilizing force in the food supply system. Production is the foundation of food supply and requires comprehensive coordination of production resources. Adjusting the production layout based on regional resource endowments and environmental carrying capacity is demanded for maintaining ecological balance while meeting market demand and regional advantages. Following the principles of growing grains where suitable, developing economic crops where suitable, raising livestock where suitable, fishing where suitable, and planting forests where suitable, crop planting and livestock breeding structures should be reasonably arranged. Promoting scientific and technological applications will optimize production systems, leading to more efficient, environmentally friendly, and sustainable production methods. This ensures an ample and balanced supply of various foods such as grains, meat, eggs, dairy, vegetables, and fruits. Integrating local resource advantages and market demand, driving technological innovations, and improving agricultural production efficiency and quality. Emphasis should also be placed on ecological conservation, avoidance of overdevelopment, and prevention of environmental pollution. By reasonably arranging crop planting and livestock breeding structures and promoting modern agricultural technologies and management models, diversified and balanced food production can be achieved. This approach provides people with a more prosperous, safer, and healthier food selection while contributing to ecological conservation and sustainable resource utilization, achieving sustainable agricultural development.

Second, the processing stage should be carefully managed to optimize efficiency and quality. This involves scientifically planning the location and procedures of processing enterprises, extending the processing chain appropriately, and guiding processing levels to ensure a balance between initial and deep processing of agricultural food products. This approach enhances the technical capability and innovation potential of processing enterprises, increases the added value of agricultural by-products by developing specialty products, extends the industrial chain, and elevates the value chain, thus creating space and advantages for agricultural development. Diversity and differentiation in food processing should avoid overprocessing, which can lead to nutrient loss and resource waste. By carefully managing the extent of processing, the added value of agricultural products can be gained, promoting the upgrading of the agricultural industry and enhancing their market competitiveness. Extending the industrial chain and improving the value chain will further boost agricultural development. Scientific planning and management of processing enterprises and procedures can effectively prevent the adverse effects of over-processing on food's nutritional value and environmental resources. It contributes positively to the sustainable development of agricultural production and the food supply system, ensuring a balance between enhancing product value and preserving nutritional integrity.

Third, key points in the circulation stage should be strategically managed. This involves promoting informatization logistics within a national strategic framework for food supply. Improving information-sharing coverage and efficiency through regional cooperation and exchange can facilitate resource-sharing, complementary advantages, industrial cooperation, and regional balance. Such a comprehensive strategy can effectively optimize the national food supply structure, improve resource utilization efficiency, reduce transportation costs, and ensure food quality and safety. Promoting informatization logistics enables real-time information sharing and transmission, improving the efficiency and accuracy of supply-demand matching. Strengthening regional cooperation and exchange allows for effective integration and optimization of resources, promoting balanced regional development. Additionally, it calls to reduce food loss and resource waste throughout the transportation and storage chain. To achieve this, grain-saving and loss-reduction initiatives should be promoted, including innovations in storage and transportation technologies,and the development of cold chain logistics. Scientific methods should be used to ensure food quality and safety, thereby increasing the edible utilization rate of nutritious and healthy foods. Improving the transportation and storage chain can effectively reduce food loss. Developing cold chain logistics and innovating transportation technologies can enhance food freshness and quality assurance. Using scientific management methods and technologies can increase the edible utilization rate of nutritious and healthy foods, meeting people's demand for high-quality food.

Fourth, the consumption stage should be activated as a driving force. The final stage of the food supply chain relies on guiding consumers to develop healthy and balanced dietary habits. Enhancing consumer education on food knowledge and improving awareness of nutrition and safety can guide informed choices when purchasing and consuming food. Strengthening education and deepening awareness of food nutrition and safety are needed to encouraging the selection of diverse food types and building reasonable dietary structures. Additionally, advocating for thrift, opposing waste, and encouraging consumers to cherish food and consume reasonably can help consumers use food sparingly and reasonably, avoiding unnecessary waste. Furthermore, advocating for green consumption and lifestyles encourages consumers to choose environmentally friendly and sustainable foods and products, reducing negative environmental impacts. By educating consumers about nutrition, safety, and the importance of reducing food waste, they can make more informed and conscientious choices. Promoting green consumption practices further ensures that consumers contribute to environmental sustainability, ultimately driving the food supply system toward sustainable development. This healthy, balanced, frugal, and environmentally friendly consumption model and lifestyle benefits individual health and promotes the food supply system toward more sustainable and stable development.

1.3.3 Supporting a Diversified Food Supply System through Technology, Policy, Business, and International Cooperation

First, expanding food source channels and strengthening technological research and development should be implemented to accelerate the construction of a diversified food supply system. They rely on technological research and innovation to break through resource limitations and expand food channels based on resource endowments, ecological conditions, and industrial foundations. Scientific development planning should incorporate technologies like the internet, big data, and cloud platforms to develop production resources and innovate management models. Under ecological conservation, technology should support vigorously developing non-arable resources such as saline-alkali land, rivers, lakes, seas, forests, and grasslands, expanding food supply from arable land to the entire national land resources. Improving resource utilization and enhancing food supply quality should be achieved through applying biological, artificial intelligence, and information technologies in the agriculture and food sectors. Moreover, catalyzing frontier disruptive technology research and development to scientifically utilize water, soil, and natural resources; enhancing resource utilization efficiency; and producing more nutritious, healthy, safe, delicious, and sustainable "future foods" are key instruments.

Second, agricultural and food policies need to be innovated under the big food concept. Residents' future dietary structure will shift from "eating enough" to "eating well, eating healthily, and eating diversely."The big food approach to coordinate grain production and the production of essential agricultural products should be established. Policies should fully support the construction of a diversified food supply system. Expanding the scope of food support policies; increasing production support for vegetables, fruits, poultry, meat, and aquatic products; and developing policies to support the production of forest food and forage food are key strategies. Optimizing the structure and direction of agricultural policy support involves increasing production subsidies for nutritious and healthy foods, establishing incentive mechanisms to encourage food supply chain entities to adopt green and low-carbon technologies, and strengthening the construction of high-standard farmland and agricultural product supply chains. policy tools is must be actively expended. Developing more targeted financial service products and providing medium and long-term credit to new food development enterprises will meet the funding needs of the big food concept. Emphasizing dietary diversification to guide production diversification, conducting essential work on collecting and predicting residents' food consumption data, scientifically planning food supply, and guiding residents to adopt balanced healthy dietary models suitable for different regions and populations through dietary education, demonstration guidance, subsidies, and tax incentives should also be implemented. These measures will promote the realization of multiple win-win goals, including a stable food supply, improved residents' nutritional health, and enhanced environmental sustainability.

Third, agricultural food industry development should be accelerated to cultivate new formats and models. With residents' food consumption structure continuing to evolve, new formats such as circular agriculture, subscription agriculture, community-supported agriculture, and e-commerce direct sales are emerging to meet consumers' demand for green, nutritious, and healthy agricultural food products. Promoting the development of circular agriculture involves creating circular models such as livestock and poultry manure utilization, integrated planting and breeding, ecological orchards, aquaculture, and multi-layer management. These models achieve efficient utilization of agricultural resources while promoting ecological conservation. Building a broad food nutrition balance, incorporating health concepts, integrating the food industry with leisure tourism, and catalyzing elderly care and health industries are important steps. Additionally, carbon-labeled foods to support green and low-carbon agricultural development should be actively promoted. Innovating agricultural business models and improving agricultural information services are also critical steps. Strengthening rural logistics systems, supporting enterprises in exploring and unlocking new models, and establishing close cooperation and mutually beneficial mechanisms between enterprises and farmers are also needed. Developing public–private partnership models and tailoring investment and financing models to local conditions will further enhance the agricultural food industry's growth and sustainability. By embracing these new formats and models, the agricultural food industry can better meet consumer demands and contribute to a more sustainable, efficient, and resilient food supply system.

Fourth, the agricultural food sector requires coordinating domestic and international markets and strengthening international cooperation . China should promote high-level openness in agriculture and food, embracing the concept of openness and sharing. This involves coordinating the utilization of domestic and international markets and resources and enhancing the security, stability, and sustainability of international food supply chains.Stable and diversified international food supply chains should be This include broadening new channels for agricultural food product imports, implementing a diversified source country strategy for imports, and promoting diversification and seasonal diversification of imported varieties. Optimizing trade methods and layouts for agricultural food products and increasing medium- and long-term trade in agricultural food products will also be important. China's transnational agricultural food enterprises and should be nurtured and expended value chain cooperation with production areas should be further strengthen. By utilizing global agricultural trade rules to build a community of shared interests and stable, mutually beneficial trade relationships. Strengthening international investment and global cooperation will further support these efforts. Pathways include actively participating in global food security governance and enhancing global and regional cooperation in disaster prevention, mitigation, and response to emergencies in the food system. Jointly addressing global challenges such as climate change and extreme disasters will enhance China's international influence in the agricultural food sector. By promoting these strategies, China can contribute significantly to global food and nutrition security, ensuring a stable and sustainable food supply for domestic and international markets.

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Chapter 2

Simulation Analysis of Food Sources Diversification

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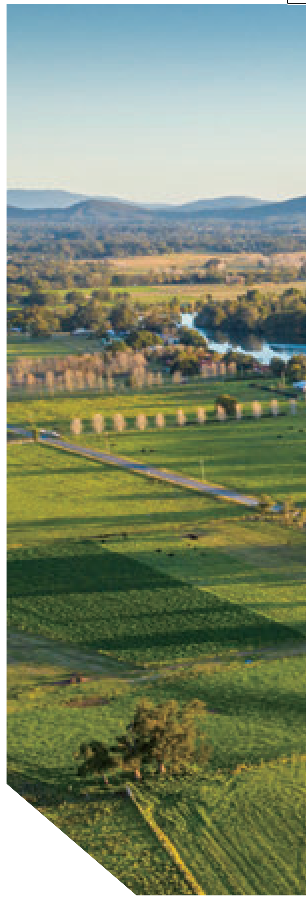


Key Findings

● Currently, China's food production is highly dependent on cultivated land. In 2022, food produced from cultivated land provided 83.5% of the total food energy. Livestock products from farming areas, forest foods, aquatic products, and livestock products from grasslands accounted for only 9.8%, 4.8%, 1.5%, and 0.4% of the total food energy, respectively. Food produced from cultivated land contributed 72.8% of the protein and 46.0% of the fat. Meanwhile, livestock products from farming areas, aquatic products, forest foods, and grasslands accounted for 17.6%, 6.4%, 2.2%, and 1% of the protein supply and 44%, 2.2%, 6.6%, and 1.2% of the fat, respectively.

● China's food self-sufficiency rate has significantly declined, with some products highly dependent on the international market. In 2021, China's food energy self-sufficiency rate dropped to 82.6%, down 15.8 percentage points from 2000. The self-sufficiency rates for protein and fat decreased even more significantly, falling to 71.0% and 75.7% in 2021, down 26 and 20 percentage points from 2000, respectively.

● Exploring the potential of forests, grasslands, rivers, lakes, ocean, facility agriculture, and new alternative proteins can increase food supply and improve food consumption structure while significantly alleviating pressure on cultivated land and the environment. A comprehensive scenarios, simulated by the Agrifood System Model developed by China Agricultural University (CAU AFS model). The results of combined scenario show that the proportion of food energy produced from cultivated land will decrease from 83.1% in 2022 to 79.5% in 2035. Similarly, the proportion of protein and fat from cultivated land will decrease from 72.2% to 67.7% and from 46.1% to 41.7%, respectively. Concurrently, the shares of food energy, protein, and fat from forests, grasslands, aquatic products, and other food sources will increase to 21.5%, 32.3%, and 59.2%, respectively. This transformation includes a significant increase in the production of under-consumed foods such as fruits, nuts, dairy products, and aquatic products. Additionally, this scenario could save 6.5 million hectares of cultivated land and reduce agricultural carbon emissions by 180 million tons of CO_2 equivalent, representing a 19% reduction.

Policy Recommendations

● Building on the concept of the big food and the concept of broad resources, cross-departmental cooperation mechanisms should be established to formulate strategies and develop plans to create a healthier, more sustainable, and diversified food production system. This involves two key approaches. One approach is to expand food sources. Enhance food production capacity by diversifying sources from forests, grasslands, rivers, lakes, oceans, facility agriculture, and new alternative proteins. The other approach is to promote technological innovations of green, efficient, and low-carbon food production.

● Strike a balance between protection and development to avoid excessive conservation, achieve harmonious development. Within the carrying capacity of resources, fully utilize forest, grassland, and marine resources to provide more high-quality ecological food and healthy.

● Reposition and optimize agricultural and technological support policies by increasing investment and support for forest, grassland, water resources, facility agriculture, and new alternative proteins. Redirect investment and subsidies from traditional staple crops to diversified food production by developing new products and technologies, enhancing food production capacity, improving production methods, and reducing food production costs to ensure healthy, ecological, and sustainable food more affordable for everyone.

2.1 Introduction

Since the reform and opening-up, China's food production capacity has significantly increased, meeting the food consumption and nutritional health needs of its residents. However, the current food production system faces major challenges of land scarcity and unsustainability: arable land resources are overloaded and severely degraded, ecosystems are fragile, and the diversity of food production structures is insufficient.

The 2023 Central Rural Work Conference emphasized the strategic need to "establish big food concept and the broad resource perspective, integrate agriculture, forestry, animal husbandry, and fishery, and build a diversified food supply system," aiming to meet the growing demand for nutritious and healthy food sustainably. While these concepts provide new concepts, more in-depth research is needed to fully tap into various resources, enhance diversified food supply capacity, and ensure consumption demands for a diverse and healthy diet.

This chapter aims to comprehensively analyze the current status and challenges of the food production system; explore the development of various resources such as grasslands, forests, and water bodies; assess the potential of facility agriculture and new alternative proteins; and optimize food sources to meet growing food consumption demands sustainably while alleviating the environmental pressure on arable land resources.

2.2 Current Status and Challenges of Food Sources in China

2.2.1 Diverse and Abundant Natural Resources

China boasts a complex and diverse range of land resources, including vast expanses of arable land, forests, grasslands, deserts, and tidal flats. According to the "2022 China Natural Resources Statistical Bulletin," the country's land resources in 2022 included 127.6 million hectares of arable land, 20.13 million hectares of fruits, vegetable and tea land, 283.53 million hectares of forest land, and 23.57 million hectares of wetlands nationwide. Additionally, China's grassland areas reached 264.27 million hectares, comprising 213.3 million hectares of natural grassland, 590,000 hectares of artificial grassland, and 50.4 million hectares of other grasslands.

Furthermore, China is blessed with abundant water resources, featuring 45,203 rivers with a drainage area of 50 square kilometers or more, along with 2,865 lakes with a perennial water surface area of 1 square kilometer or more. The country's ocean area spans about 3 million square kilometers, with a coastline length of 32,000 kilometers, including over 18,000 kilometers of mainland coastline and more than 14,000 kilometers of island coastline.

2.2.2 Food Production Sources are Becoming More Diversified, but Cultivated Land Remains Dominant

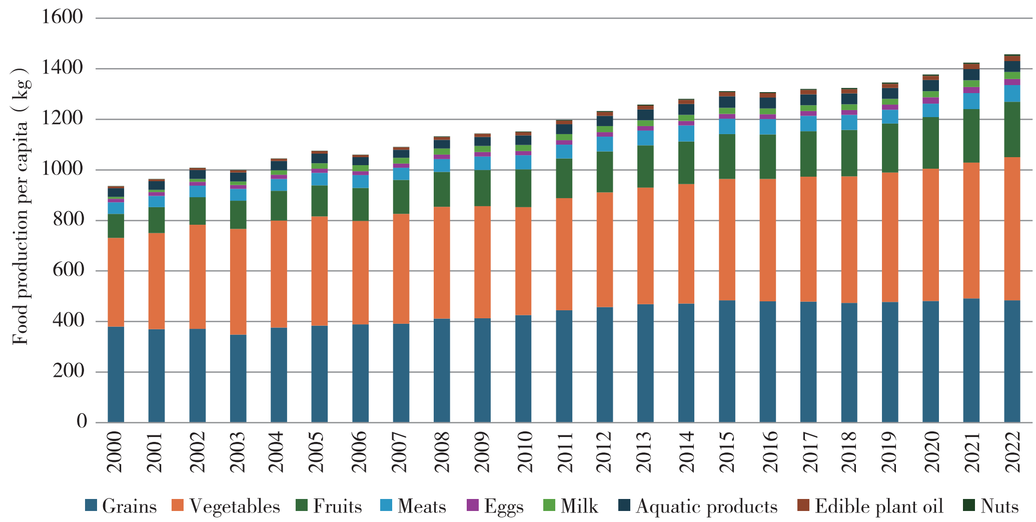
To conduct a comprehensive analysis of the current food production system and the composition of food sources, this section relies on publicly available statistical data to examines in detail the food and nutritional composition derived from cultivated land, forests, grasslands, rivers, lakes, oceans, and livestock and poultry farming in agricultural areas. It is important to note that due to the limitations of statistical data, only major foods with available statistics are included. This excludes unrecorded foods such as livestock and poultry products raised under forests. Although there may be some estimation biases, these data generally reflect the sources of food.

First, over the past two decades, China's food production capacity has significantly improved, leading to a substantial increase in per capita food production. In 2023, the national grain output totaled 695.41 million tons, with oilseed and sugar production at 8.7 million tons and 115.04 million tons, respectively. These figures represent increases of 50%, 31%, and 51% compared to 2000. Additionally, vegetable and fruit production reached nearly 800 million tons and 312.96 million tons, respectively, marking increases of 80% and 120% compared to 2000. Meat, egg, and dairy production reached 96.41 million tons, 35.63 million tons, and 41.97 million tons, respectively, while aquatic product output stood at 71 million tons. These outputs reflect increases of 60%, 63%, 400%, and 92%, respectively, compared to 2000.

The level of per capita food security has also significantly improved. In 2023, per capita grain output was 493 kilograms, an increase of 30% since 2000. In 2022, per capita fruit and vegetable production were

222 kilograms and 566 kilograms, representing increases of 62% and 130%, respectively, since 2000. Per capita production of livestock and poultry meat and eggs was 68 kilograms and 25 kilograms, respectively, reflecting increases of 52% and 70% since 2000. Additionally, per capita dairy and aquatic product production reached 30 kilograms and 50 kilograms, marking increases of 300% and 44%, respectively, compared to the year of 2000.

Figure 2-1 Food production per capita in China, 2000–2022 (kg/year)

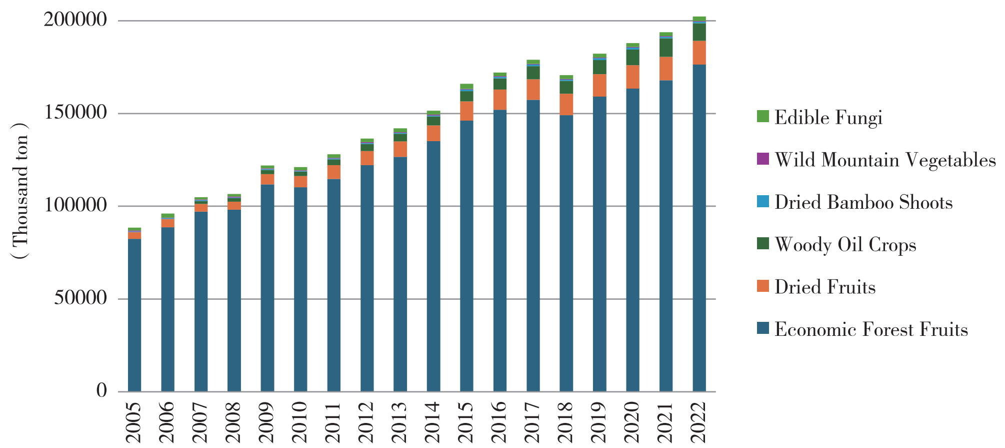


Source: National Bureau of Statistics of China.

Second, in terms of food sources, cultivated land produces the majority of the food, including grains, oilseeds, sugar crops, vegetables, and melons. Forests, grasslands, rivers, lakes, and seas also contribute significantly to the food supply. In addition to livestock grazing on grasslands in pastoral and semi-pastoral areas, livestock and poultry farming in agricultural areas are crucial sources of animal-based food. This section specifically analyzes the contribution of these diverse food sources.

(1) Forest foods are diverse and growing rapidly. Forest foods mainly include fruits, nuts, woody oils, bamboo shoots, and edible mushrooms. According to the National Forestry and Grassland Administration, in 2022, the output of economic forest fruits reached 176 million tons, an increase of 110% compared to 2005, with an average annual growth rate of 4.6%. Nut production increased from 3.5 million tons in 2005 to 12.81 million tons in 2022, an increase of 270%. Woody oilseeds, primarily camellia oilseeds, walnuts, olives, and

Figure 2-2 China's forest food production, 2005–2022

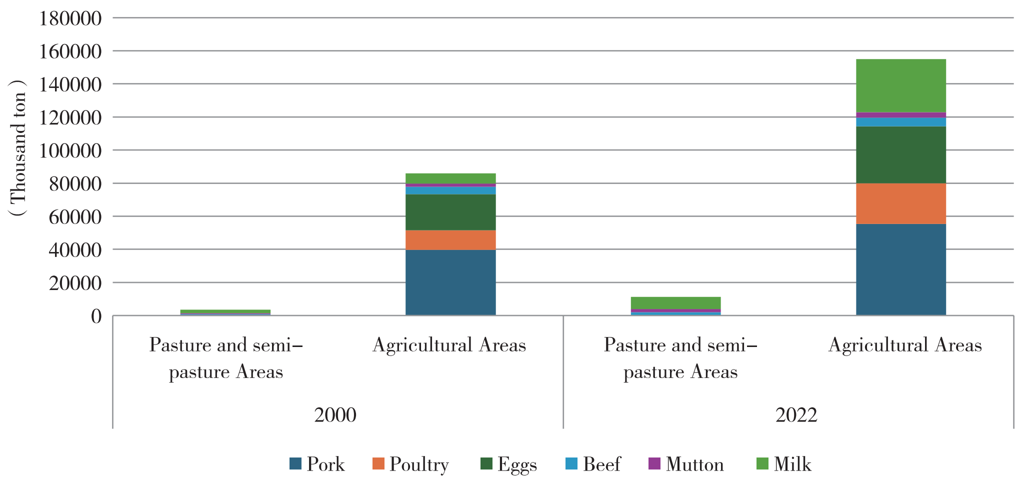


Source: National Bureau of Statistics of China.

oil peony seeds, saw a production of 9.34 million tons in 2022, an increase of 490% since 2007, with an average annual growth rate of 12.5%. In 2022, other forest foods produced amounted to 8.01 million tons, with bamboo shoots, edible mushrooms, and wild vegetables accounting for 4.73 million tons, 2.31 million tons, and 0.4 million tons, respectively. Additionally, the planting area of edible and medicinal flowers in 2022 was 315,000 hectares, yielding 495,000 tons and generating an output value of 17.67 billion yuan.

(2) The output of animal products in pastoral and semi-pastoral areas is continuously increasing, though it still accounts for a relatively low proportion of the total animal product output. According to the "China Animal Husbandry Yearbook," the production of beef, mutton, and dairy products in pastoral and semi-pastoral areas increased from 0.75 million tons, 0.65 million tons, and 2.19 million tons in 2000 to 2.01 million tons, 1.87 million tons, and 7.33 million tons in 2021, respectively. The share of national beef and mutton production from these areas rose from 14% and 24% in 2000 to 28.8% and 36.4% in 2022. However, the share of dairy production decreased from 28% in 2000 to 19.4% in 2022.

Figure 2-3 China's livestock production and composition, 2000– 2022



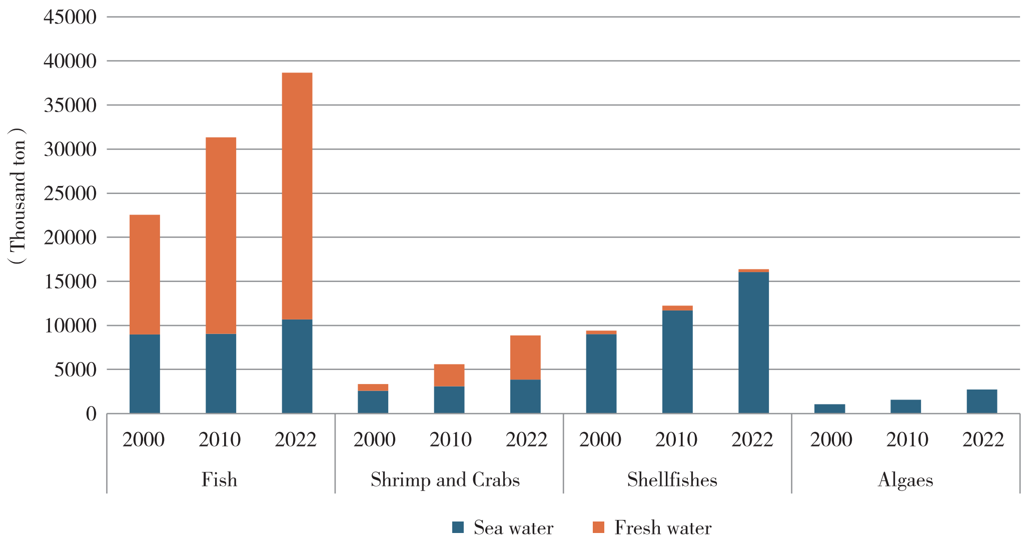
Source: National Bureau of Statistics of China.

(3) The production of aquatic products from rivers, lakes, and seas has grown rapidly, significantly contributing to the food supply. In 2022, the total national aquatic product output reached 68.66 million tons. Fish production was 38.68 million tons, an increase of 10.51 million tons since 2000. Freshwater fish production rose from 17.94 million tons in 2000 to 28 million tons in 2022, with its share of total fish production rising from 63.5% to 72.4%. Between 2000 and 2022, shrimp and crab production grew from 4.36 million tons to 8.66 million tons. Freshwater shrimp and crab production increased from 1.39 million tons to 2.48 million tons, with their share climbing from 32% to 57%. Marine shrimp and crab production also saw an increase, from 2.97 million tons to 3.94 million tons. Shellfish and algae products, primarily produced through marine aquaculture, increased from 9.96 million tons and 1.2 million tons in 2000 to 16.38 million tons and 2.73 million tons in 2022, respectively, as shown in Figure 2-4.

Aquaculture remains a major source of aquatic products. In 2022, marine aquaculture production was 22.76 million tons, and freshwater aquaculture production was 32.9 million tons, accounting for 41% and 59% of total aquaculture production, respectively, and 81% of total aquatic product output. By water area, freshwater pond aquaculture accounted for the largest share, over 40% of total production; marine and tidal flat aquaculture followed, accounting for over 20% and 10% of total production, respectively.

However, it is noteworthy that the yield and area of rice field aquaculture have increased rapidly, with the fastest growth rate in production from 2010 to 2022, tripling during this period and reaching 7% of total production in 2022. In contrast, lake aquaculture areas have significantly

Figure 2-4 China's aquatic product production and its source composition, 2000–2022



Source: National Bureau of Statistics of China.

decreased, and production has sharply declined, showing a 46.1% drop in 2022 compared to 2010.

The growth in aquaculture production is attributed to the development of facility fisheries. In 2021, facility fisheries accounted for 52% of total aquaculture production. Among marine products, raft aquaculture and bottom sowing were the most significant, contributing 30.0% and 24.7% of total marine aquaculture production in 2022, respectively. Freshwater aquaculture methods underwent significant changes between 2015 and 2022. Production from pen and cage farming dropped considerably, while factory farming production increased. This shift is mainly due to adjustments in the areas allocated to different farming methods. By 2022, the areas for pen and cage farming had reduced to just one-thirtieth and one-tenth of their 2015 levels, respectively, while the area for factory farming expanded by 81.4% compared to 2015.

Finally, the nutritional content of food produced from different resources was analyzed. The analysis examined food production for energy, protein, fat, carbohydrates, and nutrients like vitamins A, C, and E, calcium, and iron by resource type (see Figures 2-5 and 2-6). The results show a decrease in the share of food energy from cultivated land from 86.3% in 2000 to 83.5% in 2022. Similarly, the protein share decreased from 74.8% to 72.8%, while the fat share remained stable at around 45%. Cultivated land remains the most important source of carbohydrates, although its share decreased from 96.7% in 2000 to 93.9% in 2022.

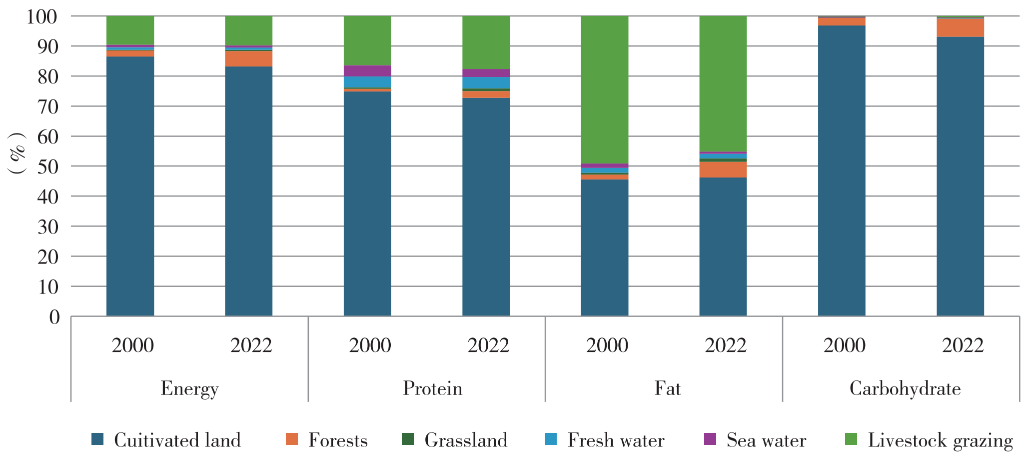
The share of nutrients provided by food from forests and grasslands increased, though their overall proportions remain low. The share of food energy from forests increased from 2.3% to 4.8%, protein from 1% to 2.2%, fat from 2.8% to 6.6%, and carbohydrates from 2.7% to 5.2%. Grasslands saw an increase in their share of food energy from 0.2% to 0.4%, with protein and fat shares rising from 0.5% and 0.7% to 1.0% and 1.2%, respectively.

Aquatic products provide a small proportion of energy and fat, both less than 2%, but they account for a significant 6%–8% of protein. Livestock and poultry farming in agricultural areas are important sources of nutrients, contributing 44% of fat, 17.6% of protein, and approximately 10% of energy in 2022.

Cultivated land remains the most important source of vitamins and minerals. In 2022, food from cultivated land accounted for 87% of vitamin B1, 72% of vitamin B2, and 76% of vitamin B5. It provided 75% of vitamin C and 83% of vitamin E, but only 49% of vitamin A. Additionally, it accounted for 74% of calcium and 76% of iron. Forest foods made significant contributions to vitamin C, increasing their share from 12% in 2000 to 23% in 2022. Grasslands and water areas had relatively higher shares of calcium, contributing 1.7% and 8.2% in 2022, respectively.

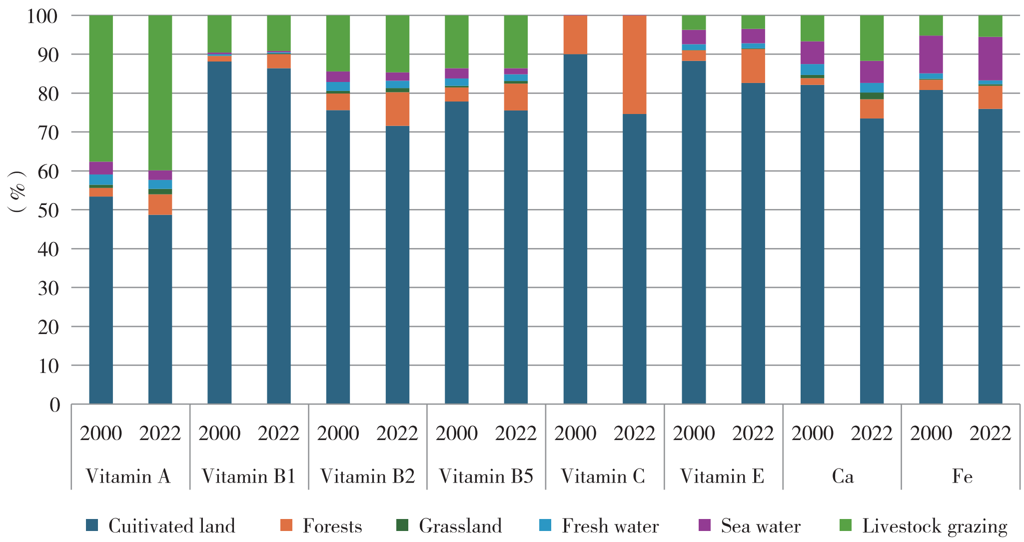
Livestock farming in agricultural areas also provided a considerable portion of vitamins A, B, and

Figure 2-5 Share of macronutrients in foods produced by source in China



Source: Authors' calculation.

Figure 2-6 Share of vitamins and micronutrients in foods produced by source in China



Source: Authors' calculation.

trace elements. In 2022, agricultural livestock farming contributed nearly 40% of total vitamin A, 9% of vitamin B1, 15% of vitamin B2, and 14% of vitamin B5. It also provided 12% of calcium and 6% of iron.

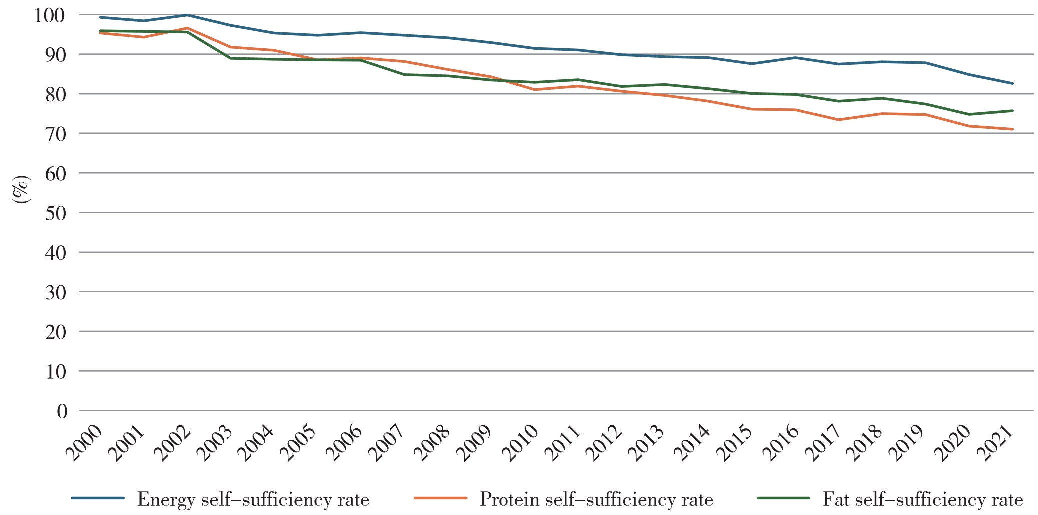
2.2.3 Challenges of Food Production in China

Despite significant improvements in China's food production capacity, food security continues to face challenges such as declining self-sufficiency rates, and insufficient diversification in the food production structure. Furthermore, the development of various food resources is hindered by numerous challenges.

First, the food self-sufficiency rate has significantly declined, with certain products heavily reliant on the international market. Despite the rapid growth in food production over the past decades, meeting the growing food consumption demands of residents remains challenging. From 2000 to 2021, China's food energy self-sufficiency rate dropped from 98.4% to 82.6%, while protein and fat self-sufficiency rates fell from both 95.9% to 71.0% and 75.7%, respectively (see Figure 2-7). This decline is primarily due to the substantial increase in imports of products such as soybeans, dairy products, and livestock meat.

Second, there is a scarcity of arable land, and the diversity of food crops is inadequate. As of the end of 2022, the total arable land in China was 1.914 billion

Figure 2-7 Self-sufficiency rate of nutrients in food in China, 2000–2021



Source: Authors' calculation.

mu (127.6 million hectares), representing only 9% of the global total. The per capita arable land resource is just 1.36 mu, which is 40% below the world average. Additionally, the quality of arable land is generally low. Grain crops dominate the cultivated land area, accounting for 70%, with maize, rice, and wheat collectively making up 57%. In contrast, soybeans constitute 7%, potatoes 4%, and other miscellaneous grains and beans collectively only about 3%. Third, grassland production faces significant challenges in achieving coordinated ecological development. There is a critical shortage of fodder, particularly high-quality fodder. Most grasslands are situated in ecologically fragile areas with arid and semi-arid climates, where intense utilization and low investment hinder grassland recuperation. Approximately 90% of grasslands have experienced varying degrees of degradation, resulting in a continuous decline in productivity. Since the early 1960s, the average grass yield nationwide has decreased by one-third to two-thirds. The productivity of grasslands is notably low, with the per unit area livestock product yield being only one-tenth of Australia's, one-twentieth of the United States', and one-eightieth of New Zealand's (Zhang et al., 2022).

The degradation of grasslands has resulted in reduced soil seed stocks, decreased microbial diversity, nutrient loss, and poorer forage quality. The current natural grassland production is insufficient to meet the high-quality development needs of grassland animal husbandry. To address the forage gap, the main strategies include natural grazing, feeding straw and other agricultural by-products, increasing the proportion of grain feed, and importing forage. According to customs statistics, China imported 1.94 million tons of hay in 2022, with an import value of 991 million US dollars.

Fourth, forest food production faces challenges, including long production cycles, extensive management, and low levels of intensive operations, leading to low and fluctuating yields. The breeding cycle for quality forest food is lengthy, with high research and development costs and significant externalities, resulting in a low return on investment. Additionally, the low level of mechanization in forest food production results in high labor costs and inadequate control, leading to low efficiency and unstable yields.

Also, forest food processing and sales face issues such as inadequate technological support, incomplete industry chains, low added value of products, and low market prices. Currently, there is insufficient effective connection between forest food raw material processing bases and forest product processing enterprises. Storage facilities need improvement, deep processing of products is minimal, and mature business models and stable sales channels are lacking. Domestic consumers often lack awareness of ecological purity, lack of pollution, and healthy nutrition benefits of forest foods. Consequently, market prices do not fully reflect the true value of these products.

Fifth, restrictions such as fishing bans and environmental pollution hinder the sustainable development of the aquaculture industry. Unreasonable intensive farming methods negatively impact the environment. Issues like aging ponds and traditional net cages are widespread in aquaculture facilities, and low rates of water treatments lead to significant nutrient enrichment in water bodies. Over-capacity fisheries aquaculture also has irreversible effects on large aquatic ecosystems. Furthermore, numerous regulations have been implemented to protect the ecological environment, such as catch limits and bans in rivers, lakes, and oceans. While these measures are crucial for environmental protection, they also restrict the development of aquaculture to some extent.

Last, the development of modern-facility agriculture remains insufficient in both quantity and quality. Despite having a certain scale, small- and medium-sized greenhouses and plastic greenhouses occupy more than 70% of the area. Facility agriculture faces high equipment and maintenance costs, along with challenges in technical development and upgrading. In addition, facility agriculture impacts the environment through high energy consumption and increased greenhouse gas emissions. Other issues include the cultivation of single crop varieties, significant obstacles to crop rotation, and the excessive use of fertilizers and pesticides.

2.3 The Potential Analysis of Diverse Food Resources Development

Due to the limitations of arable land resources and the increasing difficulty of improving land productivity, food production methods highly reliant on arable land resources are unsustainable and inadequate for meeting the diverse nutritional needs of a healthy diet. Consequently, it is important to further explore the potential of alternative food production resources. This chapter analyzes the potential of developing forest, grassland, river, lake, sea, facility agriculture, and alternative protein resources for sustainable food production.

2.3.1 Potential Development of Forest Foods

Currently, there is significant potential for expanding the area, improving yields, and exploring new markets for forest foods. According to the data from the third national land survey, China has 119.4 million hectares of arable land with slopes of 15–25 degrees or more that can be converted to forest for producing forest foods. The issue of low and fluctuating yields can be addressed by adopting improved varieties and techniques, cultivating superior species suited to the environment, improving cultivation methods, and implementing precision farming.

For instance, the average yield of camellia oil per hectare is currently 150 kg, with even lower yields of less than 75 kg per hectare for low-yield camellia forests. However, the application of improved varieties and management techniques in high-yield camellia forests can increase yields to over 900 kg per hectare. The "Development Plan for the Forestry and Grassland Industry (2021–2025)" by the National Forestry and Grassland Administration aims to increase the national output of camellia oil to 2 million tons by 2025, accounting for about 12% of the domestic vegetable oil production. This increase would save approximately 10 million mu (0.67 million hectares) of arable land annually, which would otherwise be used for cultivating herbaceous oilseed plants.

Additionally, forest-based economies have tremendous potential in terms of food supply. By developing forest undergrowth such as medicinal herbs, fungi, flowers, vegetables, fruits, tea, and grass, as well as forest-based animal husbandry including birds, livestock, fish, frogs, and bees, the forest undergrowth sector can make a significant contribution. In 2022, the value of forest undergrowth economies reached 736 billion yuan. By 2025, the total area managed and utilized for forest undergrowth economies is expected to reach 650 million hectares, with the total output exceeding 1 trillion yuan and the number of national demonstration bases for forest undergrowth economies reaching 800.

2.3.2 Potential Development of Foods from Grassland

In 2022, the Ministry of Agriculture and Rural Affairs issued the "14th Five-Year Plan for National Forage Industry Development," aiming to maintain the self-sufficiency rates of beef, mutton, and milk at around 85% and 70%, respectively. The total demand for high-quality forage is expected to exceed 120 million tons, leaving a current gap of nearly 50 million tons. Therefore, improving natural grasslands and constructing artificial pastures are critical measures to ensure the safe supply of high-quality forage.

Based on recommendations and estimates from the National Agricultural Science and Technology Strategy Research Institute of China Agricultural University, several strategies can be implemented. These include accelerating the improvement and utilization of degraded natural grasslands, promoting the rational use of severely desertified and salinized grasslands, and enhancing the development and utilization of grasslands and slopes in southern China. Specific actions involve initiating large-scale reseeding and improvement projects in degraded grassland areas, constructing high-standard improved pastures, and establishing high-standard forage fields in sand and saline-alkali grasslands. Additionally, providing policy support for the development and construction of grasslands and slopes in southern China can significantly boost grassland productivity and quality.

Comprehensive calculations show that through these in-depth developments of grassland resources, an additional supply of 37.45 million tons of forage can be generated. This would meet the forage needs of 48.89 million sheep units and 1.5 million dairy cows, increasing meat production by 1.47 million tons and dairy production by 12 million tons (Zhang et al., 2022).

2.3.3 Potential Development of Foods from River, Lake, and Sea Resources

China's aquatic resources still have significant potential for development and utilization. As living standards rise, the demand for aquatic products among residents continues to grow. The future increases in aquatic product production will primarily depend on the expansion of aquaculture, particularly industrialized and paddy field aquaculture. One notable ecological circular agriculture model is integrated rice-fish farming. From 2015 to 2020, its production doubled, with an increase of 71% in area and 22% in yield.

Moreover, improvements in nearshore aquaculture environment are underway, while deep-sea aquaculture space is expanding, indicating vast potential for facility-based aquaculture. Notably, facility-based aquaculture yields are 70% higher than traditional methods, making it an efficient approach that will play a crucial role in bolstering future aquatic product production.

2.3.4 Potential Food Development by Facility Agriculture

The "National Facility Agriculture Construction Plan (2023–2030)" outlines ambitious goals for expanding facility agriculture using non-arable land and enhancing the production capacity of key facility agricultural products, such as vegetables, meat, eggs, and milk. By 2030, facility-grown vegetables will account for 40% of the total vegetable production, livestock and poultry farming will reach 83%, and facility aquaculture products will comprise 60% of the total aquaculture production.

Furthermore, the plan also emphasizes promoting green development in facility agriculture. This includes improving the efficiency of pesticide and fertilizer use, widely adopting water-saving irrigation technology, and significantly increasing the application rate of integrated water and fertilizer use. Large-scale livestock and poultry farms will achieve a 100% matching rate for waste treatment facilities. New green circular development models, such as integrated farming and circular agriculture, will be further promoted. Efforts in agricultural energy conservation and emission reduction will be significant, with an accelerated application of new energy in facility agriculture.

2.3.5 Potential Development of Novel Alternative Proteins

With the increase in consumption and production of animal-based foods, serious health and environmental issues have emerged. In response, various scientific technologies are being applied to produce healthier and more sustainable novel alternative proteins. These technologies include genome editing, cultured meat, and microbial fermentation, which help minimize dependence on the environment, climate, and natural resources.

Currently, novel alternative proteins include plant-based meats, plant-based milk, cultured meats, microbial proteins, and insects. Developing these novel alternative proteins is seen as a new opportunity with enormous development potential. As of 2021, the global retail market for plant-based milks reached $17.8 billion, and the retail market for plant-based meats grew to $5.6

billion (The Good Food Institute, 2022). In the United States, plant-based milk is already a mature product, accounting for over 15% of retail milk sales, with plant-based meats representing $1.4 billion in sales, or 1.4% of total meat retail sales (The Good Food Institute, 2021).

China has a long history of producing soy products and has a considerable vegetarian population, providing huge market potential for plant-based meats and plant-based milk. In 2020, Singapore became the first country to approve the sale of lab-grown meat, allowing the American startup Eat Just to sell lab-grown chicken meat. In recent years, many governments have increased their support for these emerging foods, aiming to achieve price parity with traditional counterparts and improving consumer accessibility (Climate Works Foundation and Foreign et al., 2021).

2.4 Analyzing the Impact of Optimizing Diversified Food Sources on Food Consumption and the Environment

2.4.1 Methodology and Data

This study applied the interdisciplinary model system—the Agrifood System Model developed by China Agricultural University (CAU-AFS model)—to simulate and optimize diversified food production and its comprehensive impacts. The CAU-AFS model integrates agricultural partial equilibrium models and computable general equilibrium models as its core components. It flexibly combines models related to agricultural production, nutrition and health, natural resources, and the environment, establishing linkages between different models to leverage their respective advantages. The model aims to support research on major interdisciplinary issues in the agrifood systems transformation and provide timely and effective decision-making references for government policies.

The agricultural partial equilibrium model of agricultural products was developed by the Academy of Global Food Economics and Policy (AGFEP) of China Agricultural University. Based on the concepts of "big food" and "big resources," the national agricultural partial equilibrium model covering 85 agricultural products, processed products, and by-products better reflects the food production and variations across different resources. The data foundation of this model includes supply–demand balance sheets for various agricultural products, encompassing production, area, yield, and five consumption types: food, feed, industrial use, seed waste and losses. It covers not only food produced from arable land but also various forest products, grassland products, and aquatic products, enabling analysis of the relationships between different food sources. In addition, the model incorporates nutrition and environmental modules to analyze the impact of agricultural production on nutrition, health, and the environment. The nutrition module calculates the supply and demand of macro-nutrients such as energy, carbohydrates, proteins, and fats based on food nutritional components. The environmental module analyzes the impact of food production on carbon emissions. Therefore, the model can conduct comprehensive evaluations of policy effects from multiple dimensions.

This study first used the model to project future food demand, and then apply it to simulate and analyze the important food production sources diversification. The baseline year of the model is 2021, and it operates using recursive dynamic methods until 2035.

2.4.2 Scenario Design

The CAU-AFS model is applied to simulate the changes in food sources and their impact on food consumption, trade, nutrition, and the environment. The programs include the baseline and simulations. The baseline (BASE) refers to simulating future changes in food supply and demand based on historical trends, serving as a reference scenario. On the other hand, the scenarios focus on evaluating the comprehensive impact of optimizing changes in food production sources.

The Baseline focuses on future trends in population, economic development, and technology. Under this scenario, we project changes in food production, consumption, and trade trends over the next decade. China's population development will be characterized by a total decrease, accelerated urbanization, and more prominent aging issues. According to data from the National Bureau of Statistics, China's population peaked in 2021 and slightly declined to 1.412 billion in 2022. The latest population outlook from the United Nations Population Division in 2022 projects that China's population will decrease to 1.39 billion by 2035, with an urbanization rate reaching 71% and an aging rate of 28.7%.

Additionally, China's economic growth rate is expected to slow down. In 2023, China's GDP exceeded 126 trillion yuan, with a per capita GDP of 80,976 yuan (equivalent to 12,551 US dollars), positioning China as an upper-middle-income country. According to the World Bank's projection in January 2024, China's GDP growth rates for 2024 and 2025 are expected to be 4.6% and 4.1%, respectively. Therefore, this study sets the average GDP growth rate from 2023 to 2035 at around 4%.

The scenarios focus on exploring food production sources to a more diverse and resilient food supply. Six scenarios are designed, including the forest scenario, grassland scenario, water resource scenario, facility agriculture and low-carbon production secnario, new alternative protein substitution scenario, and combined scenario. Each scenario is simulated up to the year 2035. Details of the six specific scenarios are listed in Table 2-1.

First, the forest scenario involves the scientific

Table 2-1 Scenario Design of multiple food resources development

Scenario name	Scenario description	Reference
Baseline scenario (BASE)	Business as usual	Future population and structure, GDP changes, and historical trends in food supply and demand.
Forest scenario (CFOR)	Promote the development of forest food by 2035, the production of forest fruits increase by 50%, nuts, camellia oil, and dried bamboo shoots and fungi increase by 100% compared to the Baseline.	Based on the historical growth trends and future growth potential of various forest products from 2011 to 2022.
Grassland scenario (CGRS)	Improve grassland resources, increase the forage supply and carrying capacity, increase mutton and beef production in pastoral and semi-pastoral areas by 50%, and increase milk production by 1.5 times.	The literature shows that the potential for mutton and beef and milk production in pastoral and semi-pastoral areas can increase by 1.47 million and 12 million tons, respectively (Zhang et al., 2022).
Water scenario (CWAT)	Increase investment in aquaculture, develop facility farming and ecological farming models such as rice-fish farming, and increase aquaculture production, assuming the farming production of fish and shrimp and crab increase by 30% compared to the Baseline.	Based on the historical growth trends and changes in farming methods of various aquatic products from 2011 to 2021.
Facility agriculture and low-carbon scenario (CTEC)	On the one hand, develop facility vegetables and replace open-field vegetable planting area, assuming the proportion of facility vegetables in total vegetable production increases from 30% to 50%, with a 30% higher yield than open-field vegetables. On the other hand, use low-carbon production methods and green technologies. eg.,fertilizer use decreases by 20% for various crops, feed conversion rate decreases by 20%, and carbon emission intensity decrease by 20%	According to materials such as the "National Agricultural Product Cost and Benefit Survey Data,", the yield of facility vegetables is 30% higher than that of open-field vegetables. Based on reference literature, the potential for feed conversion rate and carbon emission reduction is assumed to increase by 20%.
New alternative protein substitution scenario (CFUT)	It is assumed that 10% of pork and beef production is substituted by plan based meat, 15% of dairy product production is substituted by plant-based milk, 1% of pork and beef production is substituted by cultured meat, and 10% of soybean meal feed demand is substituted by insect protein.	See the details of scenario design of alternative proteins in Chapter 3
Combined scenario (CCMB)	Combined the above five scenarios.	Combine above five scenarios.

Source: Author's compilation.

development and utilization of forest food resources, focusing on the breeding and improvement of forest food varieties; promoting green production, large scale production; and promote the development of forest economy according to local conditions. Simultaneously, it means enhancing the storage and processing methods for forest foods, diversifying food categories, and increasing the overall food supply to cater to diverse nutritional and healthy dietary needs. This involves increasing investment in forest resources and significantly boosting the production of forest fruits, nuts, camellia oil, and other forest foods. Notably, from 2010 to 2022, there was substantial growth in the production of fruits, nuts, and woody oil crops, increasing by 60%, 115%, and 290%, respectively.

The production of dried bamboo shoots, edible fungi, and wild vegetables, alongside other forest foods, saw significant increases of 89%, 46%, and 21%, respectively. There is a planned increase in investment in forest resources to boost fruit production by 50% and to double the production of nuts, woody oils, and other forest foods by 2035. By implementing these strategies, the forest scenario aims to increase the total food supply, meeting diverse nutritional and healthy food consumption needs. This approach will help ensure a more sustainable and resilient food system through enhanced forest food production. Second, the grassland scenario is the improvement of natural grassland ecological restoration and the construction of artificial grassland to enhance the development of grassland animal husbandry. This includes initiatives such as enhancing the research and extension of high-quality forage grass varieties, investing in natural grassland ecological restoration, establishing special financial subsidy support, improving grassland reseeding, constructing the irrigation facilities, and encouraging production entities to actively participate in forage planting to enhance the production capacity of high-quality forage. According to calculations by researchers from College of Grassland Science and Technology at China Agricultural University, the measures such as improving grass species resources, increasing investment in high-standard grassland infrastructure, and developing Southern Mountain grassland can increase meat production by 1.47 million tons and dairy production by 12 million tons.

Third, the water scenario encompasses the period from 2010 to 2022, during which aquatic product output increased by 28%. Fish and shrimp/crab production saw rises of 24% and 59%, respectively, while seaweed production increased by 60%. To further enhance aquaculture, there will be increased investment to accelerate biological breeding, improve the quality and effective supply level of fish seedlings, and promote the research and development of key mechanical and modern fishery equipment in the industry. Technologies such as paddy field fish farming, industrialized aquaculture, deep-sea cage culture, and raft culture will be developed to enhance the efficiency and supply capacity of aquatic products. The scenario assumes a 30% increase in aquatic product output by 2035 compared to the BASE scenario.

Fourth, in the facility agriculture and low-carbon production scenario, the focus is on improving food production per unit area through technological innovations and transforming production methods to produce more nutritious food in a greener, low-carbon manner. This involves enhancing production efficiency, particularly in facility vegetables. The goal is to increase the proportion of facility vegetables in total vegetable production from the current 30% to 50% and achieve a 50% higher yield for facility vegetables compared to open-field vegetables. Modern scientific technologies will be utilized to transform existing agricultural production methods, improving the efficiency of fertilizer use, increasing feed conversion rates, and reducing carbon emission intensity. Based on relevant literature, the scenario assumes a 20% increase in fertilizer use efficiency by 2035. Future technological developments are expected to further increase feed conversion rates and carbon emission intensity by 20%.

Fifth, in the new alternative protein substitution scenario, the focus is on replacing some animal meat and dairy products with new alternative protein. Given the high consumer acceptance and rapid growth of plant-based meat and plant-based milk in the market, the scenario assumes that these alternative proteins will replace 10% of animal meat and 15% of milk, respectively. Cell-based meat research has also shown significant progress and rapid development. The scenario assumes that by 2035, cell-based meat could replace 1% of animal meat production. In addition, insect protein is considered a promising protein feed source, with studies suggesting significant potential for replacing 20% of protein feeds. The scenario assumes that insect protein feeds will replace 10% of soybean meal feeds.

Last, the combined scenario involves running all five scenarios simultaneously—forest, grassland, water area, facility agriculture, and new alternative protein substitution—to comprehensively simulate the impact of diversified food production on food production, consumption, trade, and the environment. This scenario aims to understand the synergies and trade-offs of implementing multiple strategies together, providing a more comprehensive outlook on the potential transformations in the agrifood systems.

2.4.3 Simulation Results

Here, we comprehensively analyze the integrated impact of diversified food resource development on food production, consumption, trade, nutrition, and environmental effects, focusing on the results for 2035, which are presented in Figures 2-8 and 2-9 for detailed insights. First, the BASE scenario shows that the structure of future food consumption demand among residents will undergo significant changes, influenced by factors such as economic development, rising incomes, and increased aging.

Simulation results indicate that per capita cereal consumption will continue to decrease from 192 kg/year in 2021 to 169 kg/year in 2035, a 14% decline. Conversely, per capita consumption of vegetables and fruits will continue to rise, increasing from 124 kg/year and 92 kg/year in 2021 to 133 kg/year and 108 kg/year in 2035, reflecting growth rates of 6.7% and 17.2%, respectively.

Additionally, per capita consumption of animal and aquatic products shows an increasing trend. Per capita consumption of poultry and livestock meat will increase from 54 kg/year in 2021 to 67 kg/year in 2035, a rise of about 20%. Similarly, per capita dairy consumption will increase from 37 kg/year in 2021 to 51 kg/year in 2035, a 38% increase. Per capita consumption of aquatic products will increase from 22 kg/year in 2021 to 26 kg/year in 2035, a 30% increase.

Moreover, consumption of other forest foods besides fruits (such as dried bamboo shoots, wild vegetables, and honey) will increase from 12 kg/year to 15 kg/year. Due to a relatively small change in total population, the growth trends in total food consumption and per capita food consumption are similar. Production of new alternative proteins will maintain a steady growth, although the growth rate will slow down.

By 2035, cereal production will remain stable, while legume production will experience significant growth. Vegetable and fruit production will see modest increases, and meat production growth will slow down. In contrast, legumes, milk, and aquatic products will show larger growth rates. Imports of dairy products, aquatic products, and fruits will continue to grow moderately, whereas imports of soybeans and similar products will grow at a slower rate. Second, under the forest scenario, by 2035, forest fruit will increase by 50%, and nut production will double. The production of fruits, dried fruits, and other forest foods increased by 75.77 million tons, 14.63 million tons, and 14.40 million tons, respectively. Consequently, the nutritional value provided by forest foods will also increase significantly. By 2035, the proportions of energy, protein, and fat from forest foods will rise from 4.8%, 2.1%, and 7.1% to 7.2%, 3.6%, and 12.3%, respectively, representing increases of 2.6%, 1.5%, and 5.2%, respectively.

The increase in forest food production will enrich the variety of residents' food consumption, decline food prices, and optimize food consumption structure. Per capita fruit consumption will significantly rise to 143 kg/year, an increase of 35 kg/year compared to the Baseline. Consumption of other forest products such as honey, mushrooms, and dried bamboo shoots will double, reaching 25 kg/year, an increase of 10 kg/year compared to the Baseline. The addition of 1 million tons of camellia oil will replace some soybean oil, optimizing edible oil consumption structure and improving oil quality.

Due to the decrease in forest food prices and increase in consumption, other food items will become more expensive relatively, leading to a decrease in other food consumption. For example, per capita cereal consumption will decrease by 5 kg/year by 2035 compared to the Baseline, per capita vegetable consumption will decrease by 5.2 kg/year, and per capita poultry and livestock meat consumption will decrease by 0.5 kg/year. As a result of these changes in consumption patterns, the agricultural production structure will also adjust. Grain and legume production will decrease, saving 1.24 million hectares of cultivated land. Forest food has lower carbon emissions and minimal environmental impact, keeping carbon emissions essentially unchanged. In the grassland scenario, meat and dairy production in pastoral and semi-pastoral areas increased by 2 million tons and 12 million tons, respectively. The proportion of food energy provided by grasslands increased from 0.4% to 0.8%, protein from 1.0% to 1.8%, and fat from 1.2% to 2.4% compared with the Baseline. The increase in grassland meat and dairy products led to lower prices for these products, boosting their consumption. By 2035, per capita dairy consumption increased by 7.7 kg/year, a 15% increase compared to the Baseline. However, the increase in grassland meat production results in a slight decrease in meat production and per capita meat consumption, with only a 0.3 kg/year increase in per capita consumption.

Due to the lower prices and higher consumption of dairy and meat products, consumption of other foods decreases by around 1%. This shift leads to a reduction in crop planting area, saving 790,000 hectares of land. However, the increased production of meat and dairy also results in a rise in carbon emissions, adding 66.12 million tons of CO_2 equivalent, which account for about 7% of agricultural carbon emissions. In the aquatic resource scenario, aquatic product production increases by 30% compared to the Baseline, with fish and crustacean production increasing by 12.7 million tons and 3.42 million tons, respectively. Nutritionally, the proportions of protein and fat provided by aquatic products increase from 7.2% and 2.4% to 9.4% and 3.1%, respectively, while the proportion of energy rises from 1.7% to 2.2%.

The increase in aquatic product production leads to lower prices and increases consumption. Per capita consumption of fish and crustaceans increases from 14 kg/year and 7 kg/year in the Baseline to 20 kg/year and 9 kg/year, respectively. The price reduction and higher consumption demand would optimize residents' dietary structure. For example, per capita consumption of poultry and livestock meat decreases by 0.6 kg/year, and meat production decreases by 12.61 million tons.

As a result of the adjustment in food consumption, the planting structure also adjusts accordingly, saving a total of 270,000 hectares of cultivated land. Since aquatic products have lower carbon emissions intensity, increasing their production and replacing some meat production contributed to a reduction in carbon emissions. The water scenario shows a slight decrease in agricultural carbon emissions compared to the BASE, with a reduction of 4.03 million tons of CO_2 equivalent.

In the fifth scenario, focusing on facility agriculture and green low-carbon production technologies, the development of facility vegetables significantly increases vegetable production. Additionally, adopting greener and low-carbon production methods reduces fertilizer usage, increases feed conversion rates, and reduces carbon emissions through various green technologies. By 2035, facility vegetable production will increase by 89.41 million tons, an 11% growth compared to the Baseline. With a 20% increase in feed conversion rates, grain feed demand will decrease by 40.26 million tons, and soybean meal feed demand will decrease by 3 million tons, saving 2.97 million hectares of arable land. The improved feed conversion rate lowers feed grain demand and prices, reducing production costs for animal products and thereby promoting livestock production. Meat, egg, and milk production will increase by 3.4%, 4%, and 4.5%, respectively.

The increase in animal food production will lead to the increase in demand for feed grains, partially offsetting the decrease in feed consumption due to improved feed conversion rates. The decrease in grain demand will lead to adjustments in planting structure, increasing vegetable planting area and production by 11%. Additionally, reduced soybean meal demand will lower soybean prices, encouraging changes in direct soybean consumption.

These changes in agricultural production will significantly impact residents' food consumption. Specifically, per capita grain consumption will decrease by 3%, while per capita consumption of beans and vegetables will increase by 13% and 12%, respectively. Consumption of meat, eggs, and milk will increase by 2.9%, 2.4%, and 5.2%, respectively. Overall, arable land will decrease by 3.11 million hectares, and carbon emissions will decrease by 150 million tons of CO_2 equivalent, accounting for about 16% of agricultural carbon emissions.

In the sixth scenario, the new alternative protein substitution scenario, the traditional meat and dairy are replaced with plant-based and cell-cultured alternatives, alongside using insect protein as feed. By 2035, plant-based meat will replace 10% of pork and beef, plant-based milk will replace 15% of milk, cell-cultured meat will replace 1% of pork and beef, and insect protein will replace 10% of soybean meal feed demand.

Compared to the Baseline, by 2035, meat

and poultry production will decrease by 6.5%, beef production will decrease by 11%, and milk production will decrease by 15%. This decrease in livestock product output will lower the demand for feed grains. Additionally, the direct replacement of soybean meal with insect protein as feed will also can significantly reduce the demand for feed grains.

As a result, grain feed demand will decrease by 15.28 million tons, and soybean meal feed demand will decrease by 9.23 million tons. Consequently, grain and soybean production and planting area can be reduced by 1.27 million hectares. Furthermore, agricultural carbon emissions will decrease by 83.74 million tons of CO_2 equivalent, accounting for 9% of total agricultural carbon emissions.

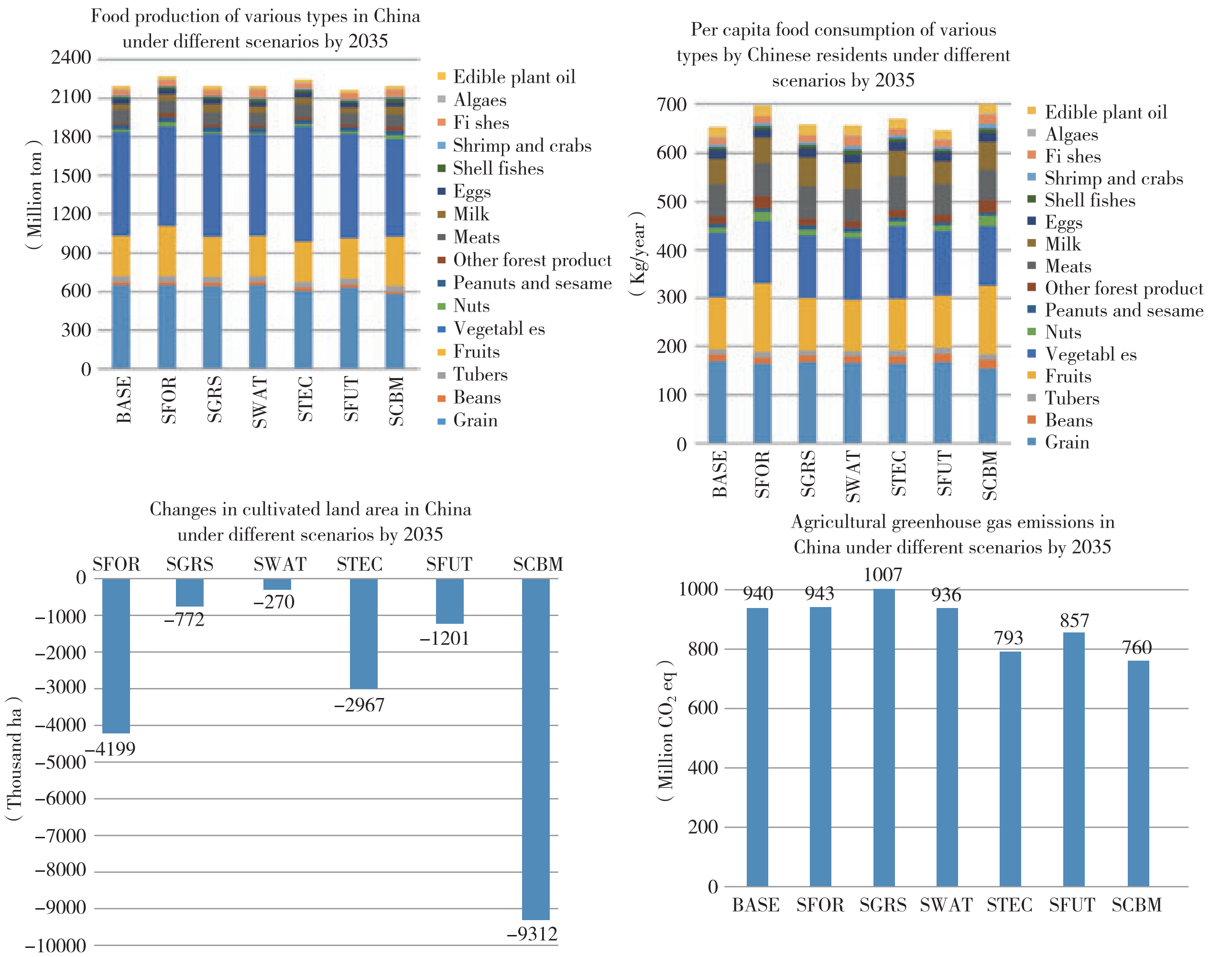
In the combined scenario, the increase of diversity of food sources, further alleviating the pressure on food production from cultivated land and imports. By 2035, the proportion of food energy from cultivated land production will decrease from 83.1% to 79.5%, the proportion of protein will decrease from 72.2% to 67.7%, and the proportion of fat will decrease from 46.0% to 41.7%.

The proportion of food energy provided by forests will increase from 4.8% to 7.8%, and the proportion of grassland livestock products in total protein and fat will increase from 1.0% and 1.2% to 1.9% and 2.5%, respectively. Additionally, the proportion of protein from aquatic products will increase from 7.2% to 10%.

The structure of residents' food consumption demand will significantly improve, with notable increases in consumption of fruits, nuts, dairy products, and aquatic products, increasing by 33 kg/year, 10.6 kg/year, 6.5 kg/year, and 12.5 kg/year, respectively. Conversely, the consumption of poultry and meat will decrease by 4 kg/year.

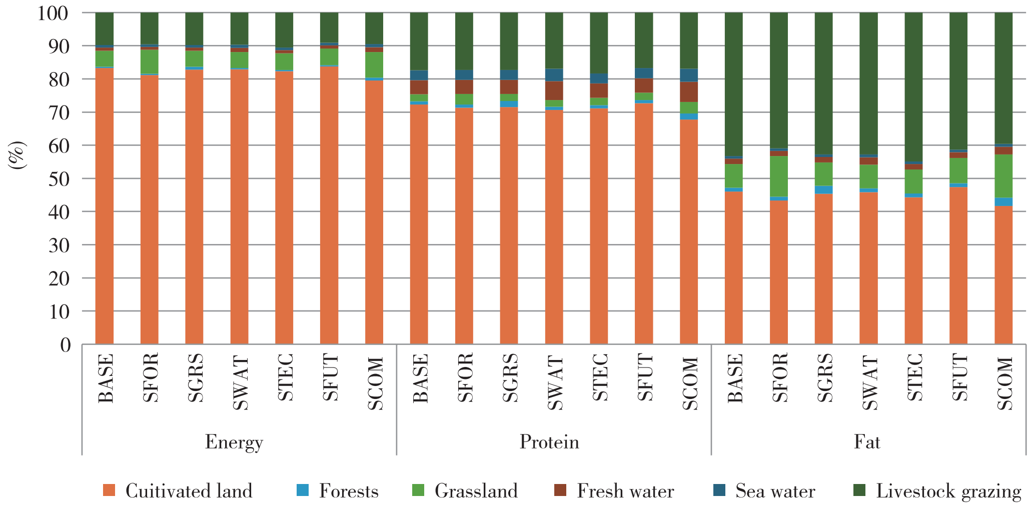
Due to the adjustment in production structure, the planting area of cultivated land will decrease by 6.5 million hectares. Food production methods will become

Figure 2-8 Simulation results of agricultural production, consumption, and resource-environment under different scenarios



Source: Simulation results of CAU-AFS model.

Figure 2-9 Nutritional composition of food produced from various resources in China under different scenarios by 2035



Source: Simulation results of CAU-AFS model.

more environmentally friendly and low carbon, resulting in a decrease of 1.8 billion tons of CO_2 equivalent in carbon emissions, representing a 19% reduction.

2.5 Policy Recommendations for Building a Diversified, Healthy, and Sustainable Food Production System

This chapter applies the CAU-AFS model to simulate various scenarios, including diversified cultivation on arable land; expanding food source from forests, grasslands, rivers, lakes, and oceans; facility agriculture, and new alternative protein. Optimizing these food sources has enormous potential. It not only increases food and nutrition supply but also alleviates the pressure on arable land resources and reduces the need for food imports while reducing carbon emissions. But, this requires support from institutions, policies, technology, and market development.

First, establish a cross-departmental coordination mechanism to set unified strategic goals for building a sustainable and diversified food supply system. Define specific plans and pathways for optimizing food sources. Constructing this diversified system involves multiple departments, such as the Ministry of Agriculture and Rural Affairs, the National Forestry and Grassland Administration, and the Ministry of Ecology and Environment. Each of these departments oversees different foods and domains, potentially leading to conflicts or contradictions in decision-making. Therefore, strengthening communication and coordination between departments is critical to finding cooperative, win-win solutions.

Second, establish a comprehensive food monitoring and statistics system. Currently, the National Bureau of Statistics mainly monitors the production and consumption of major agricultural products, while information on food supply from resources such as forests, grasslands, rivers, lakes, and oceans are scattered. Additionally, there is limited data on the utilization and development potential of these various resources, which requires an improved statistical monitoring system based on the big food concept. This system should include statistics on the quantity, quality, nutrition, and cost of food produced from forests, grasslands, rivers, lakes, and oceans, as well as information on resource quantity, quality, and carrying capacity. The monitoring and statistics are complex and require cross-departmental cooperation.

Third, optimize agricultural support policies and technology policies to promote the development of diversified food resources, producing more nutritious and healthy food sustainably. Historically, policy goals have primarily focused on food security, with agricultural support and technology policies concentrated on staple grains. However, as residents' demand for diversified food consumption increases, policies need timely adjustments.

On the one hand, policy support and technological investment should be increased for forests, grasslands, water resources, and facility agriculture. This includes the development of various food sources, such as new protein alternatives; overcoming technological bottlenecks; improving food quality and production capacity; and reducing production costs to ensure the supply of diversified and nutritious food.

On the other hand, arable land remains the most important food source. Optimizing crop planting structures, such as relaxing restrictions on the use of high-standard farmland, can support the production of grains as well as other diversified foods. This balanced approach will help meet the growing demand for a varied and nutritious diet. Fourth, promote the moderate and rational development of various food resources, ensuring a balance between ecological protection and resource utilization. Forests, grasslands, and aquatic farming resources hold significant potential for food production.It's important to aviod either excessive development or overly restrictive protection that could hinder resource use.

Within the carrying capacity of resources, forests, grasslands, and marine resources should be fully utilized to provide more high-quality, ecologically sustainable, and healthy food. Adopting a science based approach to harmonize protection and utilization is needed. Excessive environmental protection measures, such as strict prohibitions on logging, grazing, hunting, and fishing, can adversely affect the development of various food resources.

The cooperation between the Ministry of Ecology and Environment and the Ministry of Agriculture and Rural Affairs should be strengthened to ensure environmental protection while maintaining a steady food supply. This approach not only safeguards the ecological environment but also fosters the sustainable development of food production.

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Chapter 3

Novel Alternative Proteins: Exploring the Potential for Future Healthy and Sustainable Food

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Key Findings

● Compared to traditional animal proteins, novel alternative proteins offer advantages of higher production efficiency, lower resource consumption, reduced environmental impact, and no seasonal constraints, paving new ways for a more sustainable food supply. In recent years, plant-based alternative proteins have gained widespread consumer acceptance and secured a stable market share. Cultured meat is currently in the research and promotion phase, with the potential for large-scale production and cost reduction. Insects, known for their high conversion efficiency of feed and protein content, can be consumed directly or used as feed. Insect-based feed, in particular, holds significant potential as a substitute for traditional protein feed.

● Simulation results show that by 2035, replacing 10% of pork and beef with plant-based meat, 15% of dairy with plant-based milk, 1% of pork and beef with cultured meat, and 10% of soybean meal with insect protein feed would save 15.9 million tons of grains and 9.23 million tons of soybean meal, reduce arable land usage by 1.2 million hectares, and lower agricultural carbon emissions by 9%.

● As a new protein sources, the development of novel alternative proteins still faces challenges. These include technical bottlenecks, high production costs, complex safety assessments and market regulations for new products, and low consumer acceptance. To overcome these obstacles, technological innovation and policy support are urgently needed to facilitate development of novel alternative proteins and integration into the mainstream food supply.

Policy Recommendations

● The government should seize the opportunity presented by the novel alternative protein industry as an important measure to alleviate arable land resource and environmental pressures. It should incorporate the industry into the diversified food supply system framework, formulate long-term development strategies and plans for novel alternative proteins, and increase policy support to encourage technological innovation in this area. Additionally, the government should promote the establishment of comprehensive food safety standards and regulatory systems for novel alternative proteins, safeguarding the industry's sustainable development and enhancing China's global leadership in this sector.

● The private sector should be encouraged to actively participate in the development of the novel alternative protein industry, vigorously promoting research, development, and production, and enriching the variety of novel alternative products. The private sector should leverage novel protein resources from traditional food cultures, incorporating modern concepts and production methods to reduce costs and diversify products. At the same time, improving product quality to enhance price competitiveness will increase consumer accessibility and expand market share.

● Intensify communication and education efforts on the nutritional value, safety, and environmental benefits of novel alternative protein foods, guiding consumers to increase their acceptance and recognition of these products.

3.1 Introduction

Since 2000, livestock production and consumption has grown rapidly in China and globally. In 2022, global meat production reached 360 million tons, a nearly 30% increase compared to 2000. According to OECD-FAO projections, global meat production will continue to grow at an annual rate of 2% over the next decade (OECD and FAO, 2023). The livestock industry is a significant source of greenhouse gas emissions, accounting for an estimated 80% of the increase in agricultural emissions over the next 10 years. Meat production and consumption in China have also grown rapidly, with total meat production reaching 96.41 million tons in 2023, a 60% increase compared to 2000. To meet growing domestic demand, imports increased to 9 million tons. China consumes 450 million tons of feed grains annually, including 80 million tons of soybean meal as the primary protein feed source. This has led to a significant increase in soybean imports, highlighting concerns over feed grain security. Livestock production has also contributed to greenhouse gas emissions, with emissions from the livestock reaching 370 million tons in 2018, accounting for 46% of emissions from agriculture in China.

Additionally, the rising meat consumption also led to an increase in obesity and chronic diseases. In 2019, the rate of overweight and obesity among urban and rural adults exceeded 50%, the rate of overweight and obesity among children and adolescents aged 6–17 reached 19%[1] The production and consumption of animal-based foods have also contributed to issues such as zoonotic diseases, antibiotic resistance, foodborne illnesses, and chronic diseases, posing significant threats to human health (van Boeckel et al., 2019).

To address the challenges posed by livestock production, such as resource and environmental pressures, health concerns, and food security issues, it is crucial to explore new sources of protein and uncover the potential for future healthy and sustainable foods. Novel alternative proteins such as plant-based meat products, cultured meat, and insect proteins are considered to significantly reduce greenhouse gas emissions, land, and water resource utilization compared to traditional meat production. Smetana et al. (2015) compared the greenhouse gas emissions of plant-based meat products, cultured meat, and traditional beef, finding that plant-based meat products and cultured meat have carbon footprints of only 29% and 17% of traditional beef, respectively. Mattick et al. (2015) estimated that if renewable energy is used as the power source, the carbon emissions of cultured meat could be reduced to 4%–23% of traditional beef.

Internationally, research on novel alternative proteins is already underway. Existing studies, such as Kozicka et al. (2023), used the Global Biosphere Model (GLOBIOM model) to evaluate the potential impacts of plant-based alternative proteins. They found that replacing 50% of meat with these alternatives could significantly reduce environmental impacts, including freeing up 25% of global cropland area, reducing global nitrogen fertilizer input by 30%, and reducing greenhouse gas emissions from agricultural land use by 40%.

China has a long-standing dietary culture with diverse food sources, and plant proteins and insects have been incorporated into the dietary habits of some residents. Embracing the concept of a "grand food perspective," the potential of the novel alternative protein industry for diversified food supply and its environmental impact should be explored. Currently, research on the development of the alternative protein industry in China is primarily focused on technological development, leaving economic and policy discussions relatively unexplored. This chapter aims to delve into major alternative protein products, such as plant-based foods, cultured meat, and insect proteins, analyzing their development status and prospects in China. It will use interdisciplinary models to simulate and evaluate the impact of these novel alternative proteins on food consumption, arable land resource utilization, and the environment, and provide recommendations for promoting the sustainable development of China's novel alternative protein industry.

3.2 Development Status and Future Prospects of Major Novel Alternative Proteins

Currently, various alternative protein products are

[1]The data come from the Report on Nutrition and Chronic Disease Status of Chinese Residents (2020): https://www.gov.cn/xinwen/2020-12/24/content_5572983.htm

available in the domestic market. This section mainly introduces the development status of plant-based meat products, plant-based milk, cultured meat products, and insect protein feed. It covers key aspects such as nutritional composition, production processes and costs, existing market size, and consumer acceptance.

3.2.1 Development Status and Future Prospects of Plant-Based Foods

China's plant-based food culture has a long historical and cultural heritage. Traditional soy products such as tofu, soy milk, and soy pudding can be traced back thousands of years, and vegetarian dishes have long been popular. Although contemporary emerging plant-based meat products differ in flavor from traditional soy products, they are both derived from plant proteins such as soybeans, laying a solid foundation for the development of plant-based proteins in the Chinese market. These plant-based meat products are crafted to mimic the characteristics of meat and are often given names with meat connotations, such as “vegetarian chicken” or “vegetarian duck,” to satisfy consumers’ craving for a meat-like sensory experience.

Plant-based proteins include plant-based meat products, plant-based milk, and plant-based eggs, which can be made into products such as nuggets, burgers, meatballs, patties, sausages, and hot dogs. The main ingredients are plant-based foods such as soybeans, peas, and sweet potatoes, processed through techniques such as extrusion and reshaping. Soy protein isolates and other plant proteins typically account for around 15% of these products (Deng, 2017; Jin, 2021; Li et al., 2021; Ma et al., 2020).

In terms of nutritional value, plant-based meat products have protein content comparable to traditional meat, with approximately 13–19 grams of protein per 100 grams of product, similar to the protein content of around 15 grams per 100 grams of pork and 20 grams per 100 grams of beef (Yang, 2020). Plant proteins also have high digestibility, with soy protein having a digestibility rate close to that of animal-based proteins, and they contain rich and balanced essential amino acids. Additionally, plant-based alternative proteins also offer advantages over traditional animal-based products, such as being rich in vitamins and minerals, low in fat, cholesterol-free, and easily digestible and absorbable. They also have lower carbon emissions during production, making them an environmentally friendly option.

To support the development of the plant-based food industry, the government has introduced some policy measures. In 2021, the Chinese Institute of Food Science and Technology issued voluntary industry standards such as “Plant-Based Meat Products” and “General Rules for Plant-Based Foods.” These standards provide guidance and support for the standardized development of the industry, ensuring quality and safety while promoting innovation and growth in the plant-based food sector.

Leveraging the various advantages of plant-based foods, their market development has maintained a positive trajectory, with plant-based alternative proteins receiving widespread attention and acceptance globally and in China. In recent years, the plant-based food market has exhibited exponential growth. In 2022, the global plant-based meat product market was worth $4.4 billion, accounting for 0.5% of total meat sales, and is projected to continue growing at a compound annual growth rate of 24.9% from 2023 to 2030.[2] According to Bloomberg Intelligence’s latest forecast in 2022, the global plant-based alternative market could grow to $166 billion over the next decade.[3] Statistics show that in 2021, retail sales of plant-based meat products in the United States increased to $1.4 billion, a 74% increase over three years (Dueñas-Ocampo et al., 2023). From 2020 to 2022, the market share of plant-based milk in the United States remained stable at 15% of the milk product market and 1.4% of total meat volume (Kozicka et al., 2023).[4]

Chinese consumers have a relatively high acceptance of plant-based protein foods. In 2020, China’s plant-based meat market was worth $116 million, accounting for more than 70% of the Asia-Pacific region (Euler Information Consulting, 2021).[5] This indicates a strong potential for growth and expansion in the Chinese market as consumer awareness and demand for sustainable and healthy food options continue to rise.

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[2] https://www.grandviewresearch.com/industry-analysis/plant-based-meat-market

[3] https://foodinstitute.com/focus/bloomberg-boosts-10-year-plant-based-market-forecast-to-166-billion

[4] https://gfi.org/marketresearch

[5] https://gfi-apac.org/new-report-pathways-to-plant-based-market-success-in-china

Despite being the most promising alternative to animal-based proteins and having a broad market prospect in China, plant-based foods still face technical and cultural challenges. Currently, the production cost of plant-based foods is relatively high, and there is still a noticeable gap in texture compared to traditional meat, requiring further efforts in process improvement and product optimization. Consumer preferences are also an important factor influencing the development of plant-based foods.

China has a deeply ingrained meat-eating culture, where meat is viewed as nutritious and an essential part of the diet, closely associated with social activities such as festivals and family gatherings. This cultural context means some consumers are hesitant to completely abandon meat consumption, which poses a significant challenge for the widespread adoption and promotion of plant-based foods.

3.2.2 Development Status and Future Prospects of Cultured Meat

Although cultured meat is currently in the preliminary research and development stage, it is considered a technology with tremendous potential for alternative proteins. Cultured meat typically uses animal muscle cells as the raw material, promoting cell growth and division in a nutrient-rich culture medium with growth factors to produce food products with a texture closely resembling real meat (Zhang et al., 2022). This process offers several advantages, including reduced emissions and environmental impact, as it does not heavily rely on traditional agricultural and livestock production methods.

The protein content of cultured meat is approximately 19 grams per 100 grams,[6] comparable to traditional meat. Many institutions globally have predicted that in the future, cultured meat will occupy an increasing market share in the meat market. McKinsey forecasts that cultured meat could account for as much as 0.5% of the world's meat supply by 2030, with an estimated market size of $25 billion.[7] Kearney Consulting goes further, predicting that by 2040, cultured meat could meet 35% of meat demand, reaching a market value of $630 billion. [8] However, achieving this immense potential market share depends on prerequisites such as cost reduction, scalability in production, and market regulation.

Despite its promising prospects, cultured meat still faces numerous challenges to achieving large-scale commercialization. The primary challenge is the high production cost, which, although gradually declining, remains far above the cost level of traditional meat. Early examples, such as the world's first lab-grown beef burger in 2013, cost as much as $320,000, mainly due to expensive inputs such as culture medium, growth factors, and scaffold materials (Vergeer et al., 2021). To continuously reduce the production cost of cultured meat, future efforts should focus on optimizing culture medium formulations, finding low-cost growth factor alternatives, developing edible scaffold materials, and exploring other cost-saving approaches (Levi et al., 2022; Specht and Scientist, 2020; Su et al., 2023).

Another hurdle is the need to enhance production capacity and address safety concerns. The main food safety considerations for cultured meat lie in cell collection, the cultivation process, and scalability. The cultivation process involves culture medium components, micronutrients, and scaffold technology; scaling up involves the application of bioreactors, endogenous growth factors, and the extraction of parent cells. Moreover, the lack of regulatory systems and standards also presents challenges. Different countries vary in their formulation of relevant laws and regulatory measures, the developed countries such as the United States and Singapore have established regulatory frameworks, while the European Union and Japan are still working on them. China's cultured meat research developed rapidly, but it lacks comprehensive regulation, clear legal definitions, and standards, hindering its full-scale development.

In China, cultured meat companies have begun to emerge, and the industry is transitioning from the initial stage of technological research and development to a new phase of commercialization and industrialization. As the world's largest meat consumer, China presents a significant market opportunity for cultured meat. Experts believe that if cultured meat can replace or supplement 1%–10% of China's meat market, its output value is

[6] The data are from the appendix of Mazac et al. (2022).

[7] Cultivated meat: Out of the lab, into the frying pan | McKinsey [EB/0L,. [2022-06-21]: https://www.mckinsey.com/indus-tries/agriculture/our-insights/cultivated-meat-out-of-the-lab-into-the-frying-pan"

[8] https://www.foodtalks.cn/news/46876.

expected to reach 30–300 billion yuan (Zhou et al., 2020). It is anticipated that after breakthroughs in core technologies, cultured meat may be launched in China between 2025 and 2030, positioning cultured meat as a vital player in the alternative protein field (Sustainable Future Center and Research Institute of Food and Nutrition Development, Ministry of Agriculture and Rural Affairs, 2023).

3.2.3 Development Status and Future Prospects of Insect Protein

As a new source of protein, insects offer multiple advantages such as high nutritional value and environmental benefits. Nutritionally, insects are rich in protein, omega-3 fatty acids, omega-6 fatty acids, and trace elements. They also have special effects such as anticoagulation, thrombolysis, and microcirculation improvement, providing a high-quality source of protein and energy. Environmentally, insect farming requires significantly less land, water, and feed compared to traditional livestock farming, and it produces considerably lower greenhouse gas emissions. Currently, insects are widely used in food and feed production, highlighting their potential as a sustainable protein source.

In China, southern regions have a relatively traditional habit of consuming insects, while this is less common in the north. In southern regions such as Guangxi, Guangdong, and Yunnan provinces, people often eat locusts, grasshoppers, and silkworm pupae, which are considered delicacies by locals. In contrast, insect consumption is less common in northern China, where cultural practices do not typically include insects in the diet.

However, overall, the acceptance of directly consuming insects is relatively low among Chinese consumers. Despite this, the number of patent applications for edible insect products in China has recently increased rapidly, mainly focusing on products processed from raw insect forms, while related derivatives are still in the early stages of research, development, and testing, with a relatively small market scale (Feng et al., 2020).

As people's awareness of the nutritional value of insects continues to increase, the culture of insect consumption may gradually become more widespread nationwide. Many companies in Western countries have begun producing and selling insect meat products, such as insect burgers and insect protein powder, mainly targeting young fitness-conscious consumers. Although the commercialization of global edible insect production is still in its infancy, the market value has gradually become apparent. In 2023, the global edible insect market was valued at $1.18 billion,[9] with the Asia-Pacific region accounting for $480 million, ranking first among all regions.[10]

Direct consumption of insects still faces certain challenges in consumer acceptance and the marketization process. Among various alternative protein foods, the acceptance of legumes and plant-based alternative proteins is the highest, followed by high-tech alternative proteins such as cultured meat and biofermentation, while the acceptance of insect meat is the lowest (Hartmann et al., 2015).

The acceptance of different types of alternative proteins varies significantly among different population groups. For example, younger people are generally more open to trying alternative protein products compared to older people. Within younger demographics, males are more willing to accept insect meat than females, while young females show a greater preference for plant-based meat products. This variation is partly because young males have a lower level of food neophobia, making them more receptive to insects as a meat alternative (Verbeke et al., 2010).

In general, consumers tend to prefer products that are similar to or surpass traditional meat in appearance, nutrition, convenience, and dietary solutions (Kyriakopoulou et al., 2021). Acceptance of insect protein increases significantly when it is presented in less visible forms, such as flour or powder, which can be incorporated into various food products without being immediately recognizable as insect-based (Verbeke et al., 2010). This approach helps mitigate the psychological barrier many consumers face regarding direct insect consumption.

Compared to direct consumption, using insects as a feed protein alternative has significant potential. Insects

[9] https://www.statista.com/statistics/882321/edible-insects-market-size-global.

[10] https://www.statista.com/statistics/882360/edible-insects-market-size-globa-l by-region.

such as crickets, mealworms, and black soldier flies can be efficiently reared using food waste, livestock manure, and other waste materials. Due to their short growth cycle, low metabolic rate, and ease of management, insects have high resource utilization efficiency and low environmental impact. Research shows that China's insect production in 2019 was approximately 100,000 tons and is expected to exceed 2 million tons by 2025 (Bai et al., 2023).

Although the current cost of alternative insect protein is higher than that of soybeans, it will continue to decline with technological advancements. In the long run, fully utilizing China's abundant food and agricultural waste for insect rearing could yield substantial benefits. Literature indicates that China has the potential to produce 21–31 million tons of insect protein, of which 17–24 million tons are suitable for animal feed, which could replace 20% of the current feed demand. This could reduce soybean imports by 27 million tons, increasing soybean self-sufficiency by 11% and reducing carbon dioxide emissions by approximately 2.3 billion tons (Bai et al., 2023). Therefore, whether as a direct food source for humans or as an animal feed alternative, insect protein has a broad development prospect and emission reduction potential.

3.3 Impact of China's Alternative Protein Industry Development on Food Security and the Environment: An Analysis Based on Model Simulation

3.3.1 Simulation Methods and Scenario Design

This study uses the CAU-AFS model to quantitatively simulate and analyze the impact of novel alternative proteins (including plant-based meat products and plant-based milk), cultured meat, and insect proteins as alternatives to traditional livestock products and soybean meal on food security and the environment. These alternative proteins are considered substitutes for traditional livestock products and soybean meal. The model incorporates data on the nutritional composition and greenhouse gas emissions of various novel proteins. Nutritional composition data and greenhouse gas emission coefficients are sourced from existing literature, which are shown in Tables 3-1 and 3-2. The carbon emission data is based on the life- cycle assessment method.

Table 3-1 Nutritional composition comparison of traditional protein sources and various alternative proteins (per 100 g product)

Product	Energy/kJ	Protein/g	Fat/g	Carbohy-rate/g	Sodium/mg	Calcium	Source
Pork	1,370	15.1	30.1	0	56.8	6	Yang, 2020
Beef	669	20	8.7	0.5	64.1	5	
Lamb	581	18.5	6.5	1.6	89.9	16	
Chicken	608	20.3	6.7	0.9	62.8	13	
Cow's milk	271	3.3	3.6	4.9	63.7	107	
Plant-based beef average	396.8	18.8	11.3	7.8	430.7	21	Liu Haodong et al., 2023; Tang Weiting et al., 2022
Plant-based pork average	466.8	13.4	6	3.8	350.3	54	
Plant-based milk average	265.5	1.4	2.5	5.4		80.5	Zhou Sumei et al., 2023
Cultured meat average	76	19			56	6	European Sust-Food database
Insect powder average	441.2	55	17.6	15.7	284	139	

Data source: Compiled by the authors.

Table 3-2 Carbon emission coefficient comparison of traditional protein sources and alternative proteins (unit: kg CO_2 eq/kg product)

Category	Life-cycle carbon emissions	Life-cycle carbon emission range	Raw material acquisition process carbon emissions	Processing stage carbon emissions	Source
Pork	2.92	(2.8–7.5)	–	–	(Cai et al., 2022; FAOSTAT, 2023)
Beef	31.26	–	–	–	
Lamb	23.68	–	–	–	
Poultry	1.68	(1.6–5.9)	–	–	
Cow's milk	1.26	(0.9–1.7)	–	–	
Plant-based meat products	0.70	(0.7–3.4)	0.63	0.07	(Heller et al., 2018; Mazac et al., 2022)
Plant-based milk	0.42	–	0.38	0.04	(Mazac et al., 2022)
Cultured meat	3.13	(1.9–25.19)	–	–	(Mattick et al., 2015; Parodi et al., 2018; Sinke et al., 2023; Smetana et al., 2015; Tuomisto et al., 2022, 2011; UNEP 2023)
Insects	0.30	(0.11–17.2)	0.30	–	(Bai et al., 2023; Oonincx et al., 2012; Parodi et al., 2018, 2018; Smetana et al., 2016)

Data source: Compiled by the authors.

Note: The coefficients for cultured meat vary greatly, with an important reason being whether clean energy is used.

1. The BASE scenario. The BASE scenario assumes that future food production, consumption, and trade volumes will follow current trends in population growth, economic development, and technological progress trends. Serving as the reference scenario, the BASE scenario aligns with the projections detailed in Chapter 2 and extends these projections to the year 2035.

2. The alternative protein scenarios. This chapter designs five scenarios to analyze the impact of substituting traditional proteins with novel alternative proteins, including plant-based meat products, plant-based milk, cultured meat, and insect protein feed. The substitution ratios are based on the principle of equivalent protein substitution, with necessary food raw materials for the production of plant-based meat and milk. The specifics of scenario design are shown in Table 3-4.

Scenario 1: Plant-based meat product substitution (PMEAT). It simulates replacing 10% of the baseline pork and beef production with plant-based meat products, reducing pork and beef production by 5.69 million tons and 760,000 tons, respectively. According to the principle of equivalent protein substitution, 1 kg of traditional pork is equivalent to 1.16 kg of plant-based pork, and 1 kg of beef is equivalent to 1.05 kg of plant-based beef. This increase in plant-based meat production requires an additional 3.84 million tons of soybeans.

Scenario 2: Plant-based milk substitution (PMILK). In the BASE scenario, by 2035, dairy production is projected to be 48.7 million tons. In the simulation, plant-based milk gradually replaces 15% of dairy production by 2035, reducing dairy production by 7.64 million tons. Plant-based milk, primarily derived from soy milk, requires about 0.1 kg of soybeans per kg of plant-based milk. Since the protein content of plant-based milk is usually lower than that of cow's milk, 1.5 kg of plant-based milk is needed to replace 1 kg of cow's milk. This requires an additional 1.21 million tons of soybeans to produce 10.53 million tons of plant-based milk.

Scenario 3: Cultured meat substitution (CMEAT). Cultured meat replaces 1% of pork and beef production. With 19 grams of protein per 100 grams, cultured meat requires 0.79 kg to replace 1 kg of traditional pork and 1.05 kg to replace 1 kg of beef. This scenario assumes an increase in cultured meat production by 550,000 tons, reducing pork production by 590,000 tons and beef production by 80,000 tons.

Scenario 4: Insect protein substitution for soybean meal feed (INSECT). It assumes that insect protein will replace 10% of soybean meal feed consumption by 2035. Insect protein can be produced using vegetable and fruit waste and livestock waste as raw materials, without relying on agricultural products. Replacing 1 kg of soybean meal requires approximately 3.94 kg of insects (equivalent to dry matter). In the BASE scenario, by 2035, the consumption demand for soybean meal feed is projected to be 74.49 million tons, with 6.05 million tons of insect protein replacing 7.5 million tons of soybean meal.

Scenario 5: Comprehensive substitution (COMB). Scenario 5 simulates the overall effects of the above four scenarios. It assesses the overall impact of substituting traditional meat and dairy products with plant-based meat, plant-based milk, cultured meat, and insect protein. The parameter settings are derived from the first four scenarios.

By analyzing these scenarios, the study aims to evaluate the potential benefits and challenges of integrating novel alternative proteins into China's food system.

Table 3-3 Scenario design for alternative proteins

Scenario name	Scenario content	Setting basis
Plant-based meat product substitution scenario (PMEAT)	By 2035, plant-based meat products replace 10% of pork and beef production, i.e., pork and beef production decrease by 5.69 million tons and 760,000 tons, respectively. To produce plant-based products, soybean demand increases by 3.84 million tons.	In 2022, plant-based meat products accounted for 1.3% of actual meat sales in Europe and the United States (The Good Food Institute, 2021). According to Kearney Consulting, by 2040, plant-based meat products will account for 25% of the meat market, and the Boston Consulting Group predicts that protein alternatives will account for 11%–22% of the meat market (Witte et al., 2021).
Plant-based milk substitution scenario (PMILK)	By 2035, plant-based milk replaces 15% of the dairy production in the BASE scenario for the same period, i.e., dairy production decreases by 7.64 million tons, and soybean consumption increases by 1.21 million tons.	Referencing the situation in the United States, from 2021 to 2022, plant-based milk accounted for 15% of the actual sales in the U.S. dairy product market (The Good Food Institute, 2021).
Cultured meat substitution scenario (CMEAT)	By 2035, cultured meat replaces 1% of the pork and beef production in the BASE scenario for the same period, reducing pork by 590,000 tons and beef by 80,000 tons.	According to McKinsey & Company's forecast, by 2030, global cultured meat sales will reach 531,000 tons, accounting for 1% of the global meat market sales (Brennan et al., 2021).
Insect substitution scenario (INSECT)	By 2035, insect protein feed replaces 10% of the soybean meal in the BASE scenario for the same period, i.e., 840 million tons of insect protein replace 750 million tons of soybean meal.	It is estimated that China's poultry and livestock solid manure production is 1.661 billion tons/year, with a maximum potential to produce 17–24 million tons of insect protein, which can replace up to 20% of protein feed (Bai et al., 2023).
Comprehensive scenario (COMB)	Simultaneously simulates the overall effect of the first four scenarios.	

Data source: Compiled by the authors.

3.3.2 Simulation Results

This study aims to analyze the impact of replacing traditional foods with novel alternative proteins from multiple perspectives, including agricultural production, arable land area, feed grain consumption demand, and carbon emissions.

Scenario 1: Plant-based meat product substitution (PMEAT). By 2035, it is projected that plant-based meat products could replace 10% of pork and beef production, reducing pork and beef output by approximately 10% compared to the BASE scenario. This would result in a decrease of 5.94 million tons of pork and 760,000 tons of beef. However, the production of plant-based meat products will require processing soybeans into isolated protein. For each kilogram of plant-based meat, about 0.5 kg of soybeans are needed. Consequently, soybean demand will increase by an additional 3.84 million tons.

The results indicate that the reduction in pork and beef production will lead to a decrease in feed grain consumption. Compared to the BASE scenario in 2035, grain feed consumption will decrease by 12.87 million tons (a 5% reduction), and soybean meal feed consumption will decrease by 2.25 million tons (a 3.1% reduction). This decrease in feed consumption will also result in a 2.2% reduction in grain production and a 1.02-million-hectare reduction in grain planting area. Despite the reduced feed demand for livestock products, the demand for soybeans will increase due to the production of plant-based meat, leading to an increase in soybean production by 520,000 tons and an expansion of soybean planting area by 190,000 hectares.

Changes in livestock and soybean production will also impact the production of other agricultural products. The model results show that the area of agricultural crops will decrease by 660,000 hectares. These shifts in livestock and crop production will have significant environmental impacts. Under Scenario 1, emissions from the breeding industry are expected to decrease from 625 million tons to 587 million tons, a reduction of 37.53 million tons, or about 6%. Carbon emissions from the crops will also decrease by 2.03 million tons. As a result, total agricultural emissions will drop from 940 million tons to 900 million tons, a reduction of approximately 40 million tons, or about 4%.

Scenario 2: Plant-based milk substitution (PMILK). It is assumed that by 2035, dairy production will decrease by 15% compared to the BASE scenario, resulting in a reduction of 7.41 million tons. However, there will be an additional demand for soybeans, amounting to 1.21 million tons for the production of plant-based milk. This shift will lead to a decrease in feed consumption of grains and soybean meal by 890,000 tons and 570,000 tons, respectively.

The decrease in dairy production will also cause a decline in feed consumption prices, leading to a slight increase in consumption for food and other purposes. Overall, this scenario will have a relatively limited impact on grain and soybean production, with grain production decreasing by 750,000 tons and soybean production increasing by 240,000 tons.

Due to the reduction in dairy production, carbon emissions from the livestock are expected to decrease by 12.06 million tons. However, carbon emissions from the crops are likely to remain unchanged. Consequently, total agricultural emissions are projected to decrease by 12.21 million tons, equivalent to a 1.3% reduction.

Scenario 3: Cultured meat substitution (CMEAT). It is anticipated that by 2035, cultured meat will replace 1% of pork and beef, leading to a reduction of 590,000 tons and 80,000 tons in pork and beef production, respectively. Similarly, feed consumption will also decrease, with grain feed consumption decreasing by 1.47 million tons and soybean meal feed demand decreasing by 250,000 tons.

This reduction in livestock products and feed consumption will have a positive impact on emissions. Emissions from the livestock are expected to decrease by 3.38 million tons, while emissions from the crops will decrease by 240,000 tons. Overall, total agricultural emissions are projected to decrease by 3.61 million tons.

Scenario 4: Insect protein substitution for soybean meal feed (INSECT). In Scenario 4, it is assumed that insect protein replaces 10% of soybean meal by 2035. This substitution will lead to a decrease in soybean meal feed consumption by 7.35 million tons compared to the BASE scenario. Assuming imports and exports remain unchanged, soybean production will decrease due to reduced soybean meal demand. However, the significant decrease in demand for soybeans will likely cause a substantial decline in soybean prices. Meanwhile, direct food consumption demand for soybeans will increase by

6.19 million tons, offsetting some of the reduction in total soybean demand.

Consequently, soybean production decreases by only 3.93 million tons, resulting in a reduction of planting area by 920,000 hectares. At the same time, the production of insect protein will also require energy for drying and sterilization before it can be used for feed consumption, contributing to a certain amount of carbon emissions. Therefore, the overall change in agricultural carbon emissions is minimal, with a slight increase of 750,000 tons.

Scenario 5: Comprehensive substitution (COMB). In Scenario 5, it is assumed that imports and exports will remain unchanged by 2035 and envisions plant-based meat products replacing 10% of pork and beef, plant-based milk replacing 15% of dairy, cultured meat replacing 1% of pork and beef, and insect protein replacing 10% of soybean meal.

Compared to the BASE scenario for the same period, this comprehensive substitution will lead to an 8% decrease in overall livestock and poultry meat production, with beef production declining by 12% and dairy production by 16%. Similarly, due to the decrease in livestock production and soybean meal feed, feed grain demand will drop by 15.9 million tons, and soybean meal

Figure 3-1 Changes in agricultural product production under different alternative protein scenarios (2035 compared to the BASE scenario)

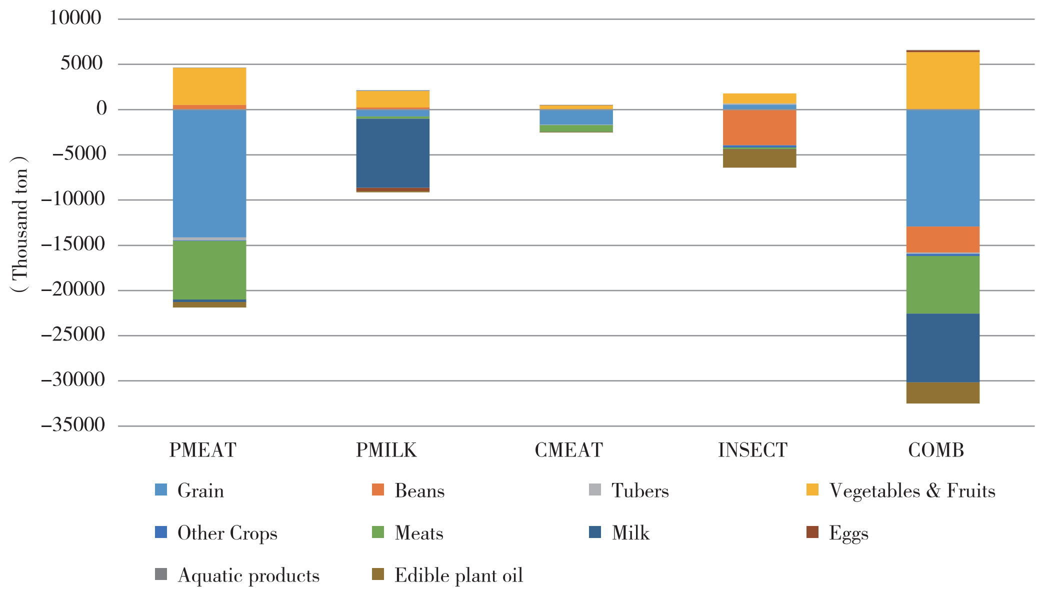


Figure 3-2 Changes in cultivated area under different alternative protein scenarios (2035 compared to the BASE scenario)

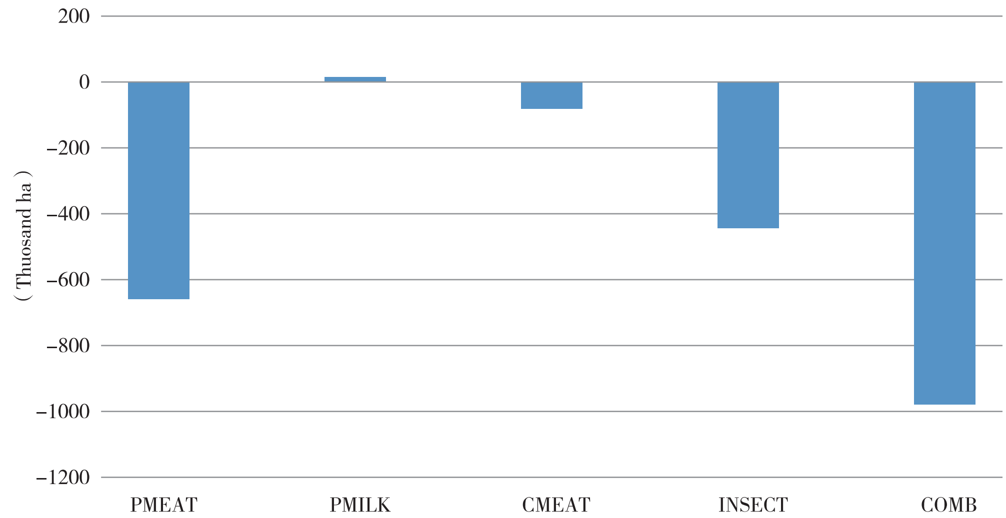
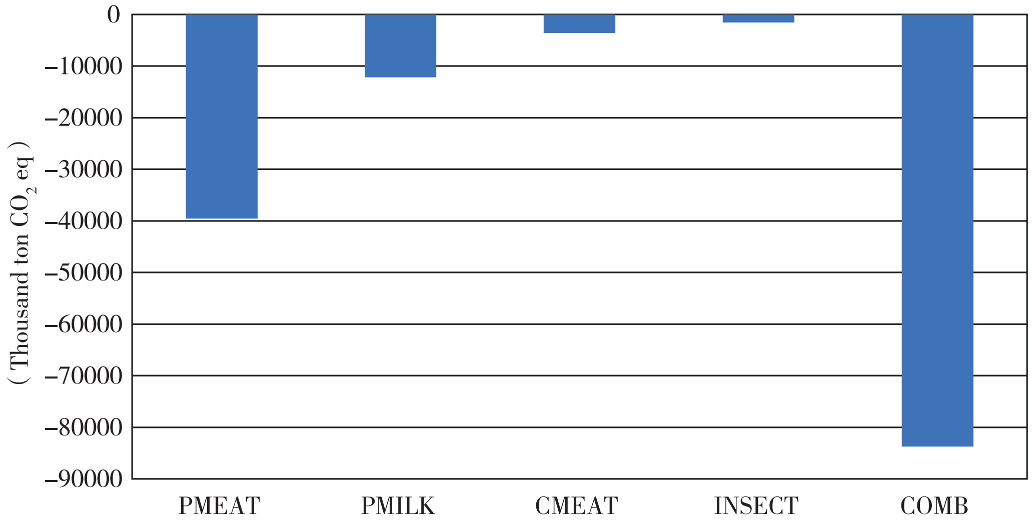


Figure 3-3 **Changes in agricultural greenhouse gas emissions under different alternative protein scenarios (2035 compared to the BASE scenario).**



Data source: Simulation results of the CAU-AFS model.

Note: PMEAT = alternative plant-based meat products; PMILK = plant milk alternatives; CMEAT = cell culture meat alternatives; INSECT = alternative insect protein solutions; COMB = comprehensive plan.

feed consumption will decrease by 9.23 million tons.

The decrease in feed grain consumption will also indirectly affect production and planting area, with arable land area decreasing by 1.2 million hectares. Agricultural carbon emissions will decrease by 83.7 million tons, accounting for 9% of total agricultural carbon emissions.

3.4 Policy Recommendations for the Development of the Novel Alternative Protein Industry

The novel alternative protein industry can potentially play an important role in diversifying the food supply. It offers benefits that extend beyond just replacing edible protein to also substituting feed protein. This industry has the potential to save land resources, reduce carbon emissions, and improve feed grain self-sufficiency. These benefits open new pathways to meet China's demand for high-quality protein and alleviate current resource and environmental pressures, while also offering significant health and environmental benefits.

However, the novel alternative protein industry faces numerous challenges in production, consumption, and policy. To promote its sustainable development, targeted measures are required. These measures should address technical and economic barriers, enhance consumer acceptance, and establish supportive regulatory frameworks.

First, increasing public investment and policy support for the novel alternative protein industry will further enhance the development of the industury. Currently, the development of the novel alternative protein industry faces various challenges in technology, cost and market, constraining its further growth. To address these challenges, the government should incorporate the novel alternative protein industry into the long-term development strategy and make a plan for building a diversified food supply system and increase public investment. This includes strengthening basic research, promoting technological innovation, improving product quality, and reducing production costs. By implementing these measures, the government can foster a more sustainable and resilient food system.

Second, diversification of plant-based protein products should be faciliated. The traditional techniques for vegetarian meat and soy products should be improved, and integrate plant protein products with meat products to achieve partial substitution. While maintaining the original taste, the protein nutritional value should be improved, and the calorie and fat content should be reduced. Plant protein resources in traditional food cultures should be fully explored with modern concepts and production methods.

Third, as an emerging food category, novel alternative proteins require robust government regulation to ensure food safety. To achieve this, the government should: (1) Establish comprehensive food safety standards and a regulatory system tailored to novel foods. (2) Enhance communication among various stakeholders, including industry representatives, researchers, and consumers. (3) Improve relevant food standards to address the unique characteristics of alternative proteins. (4) Strengthen the construction of the regulatory system specific to this new industry. (5) Further support government regulatory measures, including safety assessments, production standards, and product approvals. This will create a favorable policy environment for the healthy development of the alternative protein industry and actively address the potential negative impacts that may arise.

Fourth, it is important to encourage private sector to invest and actively participate in the development of the novel alternative protein industry. This will promote product marketization and position China as a leader in the global alternative protein market. Many alternative protein companies have emerged in China, and more large-scale food enterprises should be encouraged to invest in alternative protein-related fields and become leaders in the novel alternative protein industry, promoting its sustainable development. By fostering enterprise involvement and investment, China can drive the sustainable development of the alternative protein industry and secure a leading position in the international market.

Finally, intensify publicity efforts to educate consumers about the nutritional value, safety, and environmental benefits of alternative protein foods. This will help guide consumers toward a deeper understanding and greater acceptance of novel alternative protein foods, for example, displaying food characteristics on product packaging to enhance consumer acceptance of alternative proteins; deconstructing the traditional concept of meat, presenting protein foods in advertising as simpler biological structures to reduce consumers' associations of alternative proteins with artificial life, promoting a positive consumer attitude; adopting comparative strategies, and analogizing the production process of alternative proteins with the natural growth process of animals and plants to reduce consumers' perception of violating natural laws. By adopting these strategies, consumer attitudes toward alternative proteins can be positively influenced, fostering a more informed and receptive market.

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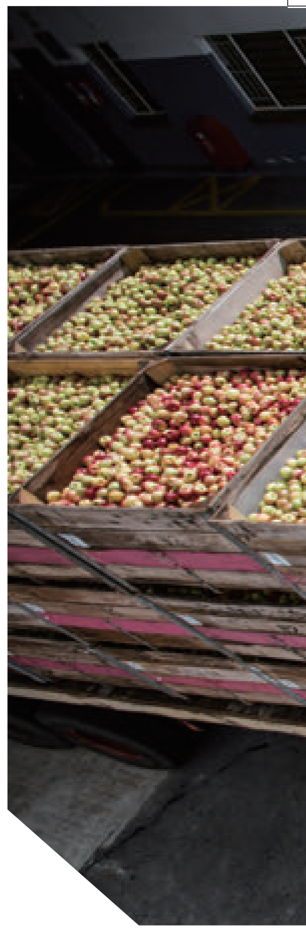

Chapter 4

Exploring Food and Nutritional Resources: The Role of the "Mid-Stream"

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Key Findings

● The "midstream sector" of the food supply chain, connecting producers and consumers, play a significant role in information flow, product circulation, and the delivery of healthy and diverse food options. Despite their significance, the role of the middle sector in addressing food and nutritional security, as well as public health concerns, has largely been overlooked. In light of ongoing efforts to build a diversified food supply system, it is crucial to address the challenges faced by the "missing middle" through targeted actions and approaches.

● Implementing changes within the midstream sector, such as food fortification, whole-grain provisioning, and food waste reduction, holds significant potential to enhance food supply chain efficiency. These approaches optimize the utilization of limited arable land resources while delivering substantial nutritional benefits. Consequently, they contribute to tackling challenges related to nutrition, health, and sustainability.

● However, the midstream sector of the food industry currently faces challenges in insufficient technology, inadequate standards, and limited incentives. To meet the growing demand for diverse and healthy food products, urgent innovation and policy interventions are needed. Technological breakthroughs, particularly in nutritional fortification, whole-grain processing, and cold chains should be supported to address these challenges. Furthermore, a robust standard system for fortified foods, coupled with stricter regulations, can foster the development of the nutritional food industry. Finally, the implementation of diversified incentive mechanisms will stimulate innovation and growth within the midstream sectors.

Policy Recommendations

● Standardization and Regulations: Standardization efforts should encompass not only food safety and quality but also nutritional content and environmental impact. A robust regulatory framework will ensure that businesses adhere to established standards, minimize compliance issues, and prevent unfair competition.

● Policy Guidance and Institutional Incentives: Comprehensive legal frameworks, increased financial support, and tax incentives should be implemented to encourage midstream enterprises to prioritize the development and utilization of diversified food and nutrition resources. Clearly defined roles and responsibilities, effective policy guidance, and long-term policy stability and transparency can provide a solid foundation for businesses to make long-term planning and investment decisions.

● Strengthening Technological Support and Collaborative Innovation: Increased investment in fundamental and applied research, through dedicated research funds, R&D support, and incentive mechanisms, will help to stimulate innovation and drive technological breakthroughs. Close collaboration among agricultural research institutions, enterprises, universities, and the government can effectively overcome technological bottlenecks and enhance the ability to adapt to market changes.

4.1 Introduction

The ever-growing complexity of the food security challenges and the diverse dietary preferences underscore the importance of adopting the "big food" concept and establishing a diversified food supply system. These measures are crucial for safeguarding China's food security and fulfilling the people's aspirations for a better quality of life. The "midstream sectors"[1] of the food supply chain significantly impact the food environment, accessibility, and prices (Veldhuizen et al., 2020). In recent years, there has been significant enhancement in the "midstream sectors," including storage, transportation, processing, wholesale, and retail of agricultural products. This improvement has been pivotal in ensuring a steady food supply. The annual business revenue of China's agricultural product processing industry exceeded 9 trillion RMB in 2023, an 11% increase from the pre-pandemic year of 2019, accounting for more than 6.7% of the total business revenue of industrial enterprises (National Bureau of Statistics 2024).

However, China's agricultural sector currently faces a notable mismatch between the increasingly diverse consumer demands for food and the relatively singular structure of the supply side. While "midstream" sectors of the supply chain are essential in bridging this gap, their full potential remains underutilized. As living standards improve, Chinese consumer seek not only nutritious, safe, and convenient but also diversified food options. Yet, the supply has not fully adapted to satisfy these changing demands. Some food processing industries rely heavily on additives and over-processing, compromising nutritional quality and raising health concerns. The emergence of ready-to-cook and ultra-processed foods further exacerbates these issues. The triple burdens of malnutrition pose a significant challenge: ensuring a nutritious and healthy food supply while fostering the sustainable growth of the food processing industry. Furthermore, significant food loss and waste (FLW) throughout the food system, including in the midstream, contributes to resource depletion and environmental damage. Consequently, focusing on the role of the "midstream" sectors in managing food and nutritional resources is important to address these issues effectively.

Ensuring an effective supply of nutritious and healthy food requires a multidimensional approach that emphasizes both quantity and quality, specifically the nutrient contents of the food. This presents new requirements and development opportunities for the "midstream" sectors. These sectors can enhance overall resource utilization by efficiently leveraging existing nutritional resources, such as developing by-products and minimizing waste. Additionally, they can expand nutritional sources by developing novel foods to meet personalized demands, enhancing nutrient fortification to increase the nutritional value of food, and exploring traditional food resources to diversify food varieties.

However, current policies and incentives predominantly focus on the production and consumption sides of the supply chain, neglecting the potential of the midstream sectors. This lack of attention has resulted in inadequate industry standards, relevant regulations, and incentives, which in turn reduce the motivation for processing and distribution enterprises to transform and upgrade. Consequently, the supply of green and healthy foods remains underdeveloped.

This chapter examines the pivotal role of the "missing middle" through three case studies on fortified foods, whole-grain products, and food loss reduction. By evaluating their potential to enhance food and nutritional resources, we identify strategies for optimizing these midstream sectors and provide policy recommendations for promoting a sustainable and nutritious food supply in China.

4.2 The Potential of Food and Nutrition Resources in Midstream Sectors

Over the past few decades, the agricultural supply chain has expanded vertically, while international trade in agricultural products has grown rapidly. This expansion has led to a greater separation between agricultural production decisions and consumer food choices, elevating the significance of the midstream agrifood

[1]The "midstream sectors" in this chapter refer to all stages between food handling from post-harvest (production) and pre-purchase (consumption). Specifically, this includes storage, transport, processing, wholesale? and retailing. Midstream decision-makers are closely linked with producers and retailers, and their actions significantly affect supply chain sustainability (Grabs et al., 2024).

sectors. Participants in these midstream sectors play a crucial role in connecting producers and consumers, facilitating the flow of information and products. Their actions and decisions influence the sustainability and efficiency of the entire food supply chain (Grabs et al., 2024; Reardon, 2015). Despite the extensive policies and regulations in agricultural production, the midstream sectors face challenges such as inadequate policies, insufficient investment, and lack of incentives, which hinder progress toward sustainable development goals. Particularly in processing, logistics, and distribution, the midstream sectors suffer from significant investment shortfalls in technology and infrastructure (Reardon, 2015). Midstream participants play a key role in ensuring food supply diversity and managing supply-demand imbalances, yet their importance is often underestimated (Grabs et al., 2024).

This section will focus on the midstream sectors of the food supply chain, exploring their potential to address nutritional health and sustainability challenges through several case studies.

4.2.1 Increasing Sources of Food and Nutritional Resources

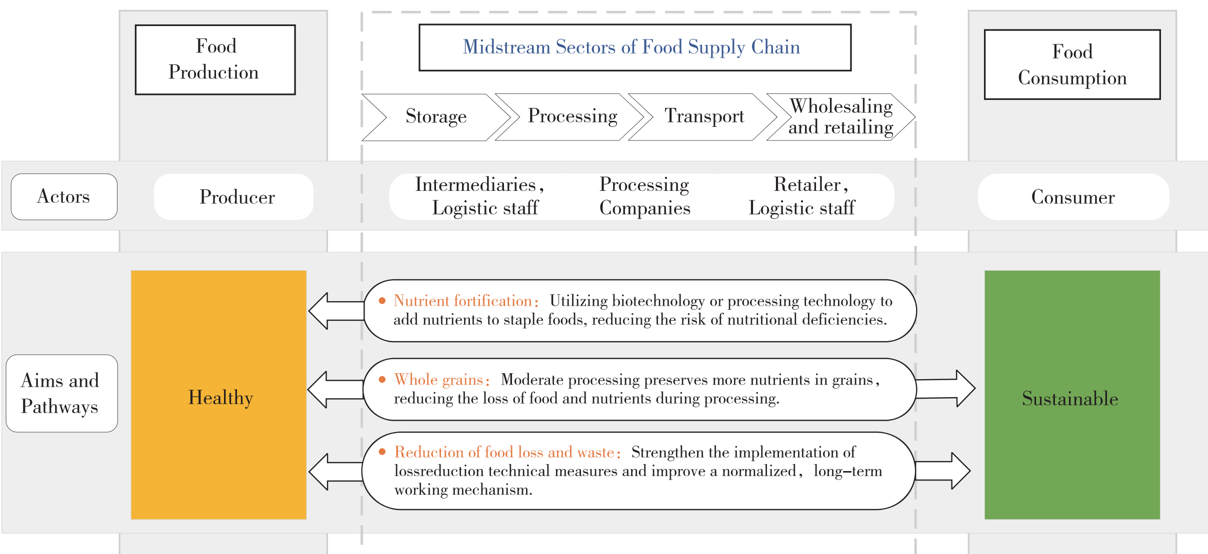
Currently, undernutrition still exists in China, particularly in remote rural areas. Deficiencies in essential micronutrients such as calcium, iron, vitamin A, and vitamin D remain a significant problem, affecting nearly 300 million people with hidden hunger (Liu et al., 2023). This issue is related not only to dietary imbalances but also to the unique dietary cultures of certain demographics and regions. Moreover, there are nutritional risks associated with dietary shifts toward less meat consumption or predominantly plant-based diets.

Midstream participants can utilize nutrition-oriented technologies to enhance the availability of nutritious foods and optimize limited resources for broader nutritional benefits (Figure 4-1). Specifically, key players in the midstream sectors, such as processing companies, can implement various strategies to combat malnutrition and facilitate the "increase-sourcing" of nutritious foods.

On the one hand, the nutritional quality of traditional foods can be improved by developing healthy and sustainable alternatives of whole-grain products, legumes, and fungi. On the other hand, the introduction of a variety of new food options tailored to individual needs can increase the nutritional intake from food. By investing in alternative proteins, functional foods, and fortified products, they can address consumer demands for diverse and personalized nutrition. This includes developing plant-based meat substitutes to offer nutritious choices for vegetarians and those seeking to reduce meat consumption.

Food Fortification. In China, deficiencies in iodine, vitamin A, and iron are relatively common, especially among children and pregnant women (Chen et al., 2022). Food fortification stands out as a cornerstone

Figure 4-1 The role of the "missing middle" in promoting health and sustainable agrifood system transition



strategy for combating micronutrient deficiencies. This approach is widely applicable, yields quick results, is easy to implement, cost-effective, and does not require altering existing dietary habits. Given its effectiveness for specific groups, such as children, pregnant women, and the elderly, this intervention is a valuable tool for improving public health.

Food fortification involves intentionally adding essential micronutrients, such as vitamins and minerals to common foods, regardless of whether these nutrients were originally present. This process aims to prevent or alleviate health issues stemming from nutrient deficiencies, especially in those with increased dietary needs. There are two primary methods of fortification: traditional fortification and biofortification. Traditional fortification takes place during food processing and includes adding specific nutrients to staples like flour, salt, or oils—often referred to as industrial fortification. Biofortification, a newer technique, utilizes agricultural and biotechnological methods to enhance nutrient levels in crops, focusing on developing new varieties that are naturally enriched with specific micronutrients through breeding or genetic engineering.

Whole Grains. Increasing whole-grain[2] consumption is considered one of the most important and feasible paths to transforming into a sustainable and healthy food system (Milani et al., 2022). The EAT-Lancet Planetary Health Diet and the "Chinese Dietary Guidelines" both emphasize this shift (Chinese Nutrition Society, 2022; Willet et al., 2019). Compared to whole grains, refined grains have about 25% less protein and 30%–60% less dietary fiber, along with reductions in other bioactive nutrients.[3] Research consistently links increased whole-grains consumption to reduced risk of type 2 diabetes, cardiovascular diseases, and colorectal cancer, potentially saving billions in healthcare costs (Abdullah et al., 2021; Ghanbari-Gohari et al., 2021; Martikainen et al., 2021; Murphy and Schmier, 2020; Reynolds et al., 2019; Zhang et al., 2024).

Producing more whole-grain foods also enhances the edible utilization of grain resources and reduces carbon emissions. Whole grains have a higher extraction rate and lower carbon emissions compared to refined grains. In China, carbon emissions from refined rice and flour are estimated to be 1.23 and 1.34 times higher, respectively, than those from brown rice and whole-wheat flour (Zhang et al., 2024). In 2020, China processed 114.02 million tons of paddy rice and 100.548 million tons of wheat with an average extraction rate of 63% and 73%, respectively. If 30% of the rice and wheat were converted into whole grains with a 98% extraction rate, 19.51 million tons of grain could be saved (Tan and Zhai, 2024), potentially reducing carbon emissions by 26.37 million tons (Zhang et al., 2024).

4.2.2 Conservation of Food and Nutritional Resources

FLW occur throughout the food supply chain, spanning from harvesting and storage to processing, retailing, and consumption. Globally, there is a concerning trend of increasing macronutrient losses due to FLW, notably carbohydrates and proteins, posing a serious threat to food security (Gatto and Chepeliev, 2023).

From 2014 to 2018, China experienced an average annual FLW of 350 million tons of food within its supply chain, resulting in economic losses totaling $263.5 billion (equivalent to $188.48 per capita per year). Notably, 45% of these losses occurred during post-harvest handling and storage stage (Wang et al., 2023; Xue et al., 2021). It is estimated that the nutrients lost or wasted per capita annually in China could provide sufficient nutrition to sustain a person for 66.2 days (Wang et al., 2023). The loss and waste of meat, vegetables, and fruits lead to considerable nutrient depletion, especially of vitamin K, copper, and vitamin C, accounting for over 74% of the Dietary Reference Intake (DRI) (Wang et al., 2023). By curbing losses in the food supply chain, we can boost the availability of nutritional sources (Figure 4-1). Studies indicate that implementing institutional reforms and technological innovations focused on reducing FLW could save approximately 50 million tons of food in China over the short term (Xu and Zhang, 2023). Furthermore, opting

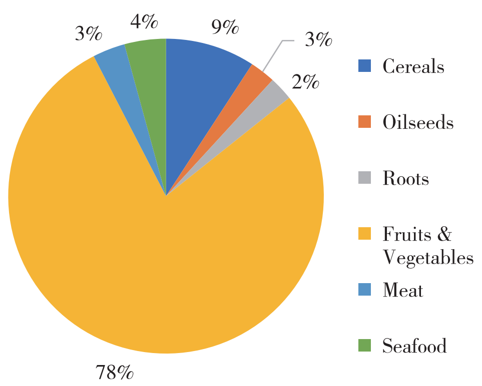
[2]The "General Rules for Determination and Labeling of Whole Grains and Whole Grain Foods" define whole grains as grain kernels that are either unprocessed, retaining their full caryopsis structure, or processed (milled, crushed, extruded) while keeping the original proportions of bran, endosperm, and germ. Whole-grain foods include brown rice, oats, sorghum, whole-wheat flour, and oatmeal (Chinese Nutrition Society, 2021). Foods are considered whole grain if they contain at least 51% whole-grain content by dry weight.

[3]Calculated according to the China Food Composition Table 2017.

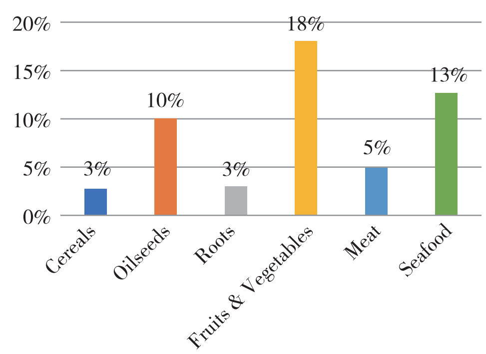
for whole grains over refined grains can substantially reduce losses of food and nutrients during processing, effectively creating what can be termed as "invisible farmland" (Tan et al., 2021).

Food Loss. (1) Characteristics of Food Loss. In China, significant food losses primarily occur during post-harvest handling and storage, processing, transportation, and retailing stages, with the midstream stages contributing the highest quantities. According to Xue et al. (2021), over 170 million tons of food loss occurred during these stages. Vegetables and fruits comprise the most food loss, at nearly 140 million tons, which account for about 78% of the total losses in the food supply chain. Cereals follow at 9%, while oilseeds, tubers, meats, and seafood have lower loss rates, ranging from 2% to 4% (Figure 4-2a). Loss rates, which represent the proportion of food loss during midstream stages to total production, vary by food types, from 3% to 18% (Figure 4-2b). Fruits and vegetables experience the highest loss rates at 18% during midstream stages. Seafood and oilseeds have loss rates of over 10%, meats are at 5%, and grains and tubers have the lowest rates, around 3%.

Figure 4-2 Food losses by different food groups



(a) Proportion of total food loss by different groups



(b) Proportion of food loss during midstream stages relative to totalproduction by different groups

Analyzing the stages individually reveals significant losses during post-harvest handling and storage stage. For instance, vegetables and fruits incur a 77% loss rate, with oilseeds exceeding 30%, showcasing substantial challenges at these stages. In contrast, loss rates for tubers and oilseeds during the retailing stage are notably lower, likely due to improved preservation methods. These variations underscore the considerable divergence in loss rates across various food categories, posing significant sustainability challenges to the food system.

(2) Nutrient Loss Due to Food Loss. Food loss affects both quantity and nutritional value. Food loss across four stages results in nearly 7.5 million tons of protein loss and about 5.2 million tons of fat loss. Nutrient loss varies significantly depending on the food category. Notably, vegetables and fruits contribute the most to protein loss, constituting over 46% due to their vulnerability during post-harvest handling and transportation stages. Seafood and meat follow, with protein loss ranging from 13% to 18%, reflecting their importance and susceptibility in the food supply chain. Oilseeds and cereals have a protein loss of 10%-11%, while tubers have minimal loss, less than 1%, due to their stable characteristics during production and processing stages. For fat loss, oilseeds rank first, accounting for nearly 49% due to their significance as a fat source and susceptibility during processing. Meat follows with over 24% of fat loss, whereas seafood and cereals have fat loss of around 7% and 2%, respectively.

(3) Land Footprint of Food Loss. Based on the yield levels across different food types, the land footprint of food loss across four stages exceeds 16 million hectares. There are significant differences in the land footprint among various food categories. Specifically, vegetables and fruits account for the largest share, exceeding 40%. Meat follows with 23%, while cereals and oilseeds range between 13% and 16%.

During post-harvest handling, processing, transportation, and retailing stages, the land footprint of food loss varies significantly. The post-harvest handling and processing stages experience the highest losses, resulting in a larger land footprint. Apart from fruits, vegetables, and meat, other food categories exhibit smaller land footprints at the retailing stage. Tubers have minimal losses during processing and transportation due to their simple processing and low transportation losses. Conversely, oilseeds experience over half of their total loss during processing, indicating potential technical and managerial issues that need further attention and improvement.

(4) Potential of Food Loss Reduction. Reducing food loss will directly decrease nutrient loss and reduce the land footprint. Aligning with the UN Sustainable Development Goal 12.3, this study references the research findings of Xue et al. (2021), which employed material flow analysis and environmental footprint methods to analyze the potential for reducing food loss. The study indicates that a 50% reduction in food loss across various stages can decrease the land footprint by over 9 million hectares. This would result in more efficient use of limited farmland, reduced environmental impacts from land cultivation, and enhanced land productivity.

From a nutritional perspective, halving food loss in these stages could save over 3.7 million tons of protein and 2.6 million tons of fat. This reduction would better meet residents' nutritional needs, reduce health issues related to malnutrition, and lessen the socioeconomic burden of nutritional imbalances. These improvements can enhance the population's quality of life and health levels.

Furthermore, reducing food loss will have positive economic and social impacts. It will improve the efficiency of the food supply chain, reduce resource waste, lower production costs, and create more job opportunities. This, in turn, promotes economic growth and reduces poverty, laying a solid foundation for achieving sustainable development goals.

4.3 China's Experience in Developing Nutritional Resources in Midstream Sectors

4.3.1 Developing Fortified Foods to Expand Nutritional Sources

Food Fortification Programs. Since the successful development of 5410 infant formula in 1951, China's food fortification programs have evolved significantly over nearly 70 years. The country has made substantial progress in policy formulation, regulatory establishment, standard setting, and implementation in the field of food fortification.

Food fortification aims to increase the nutritional value of food and is categorized into three types: Nutrient restoration—adding nutrients to replace those lost during processing; nutrient enhancement—adding nutrients that are naturally lacking or present in low amounts, and nutrient enrichment—increasing the overall nutrient levels in food.

Early food fortification projects in China addressed specific nutrient deficiencies through fortified condiments such as iodized salt, iron-fortified soy sauce, and vitamin A-fortified cooking oil (Table 4.1). In 1994, China mandated the iodization of table salt and implemented the Universal Salt Iodization (USI) plan in 1996. Studies show that after implementing the USI plan, the goiter prevalence rate decreased from 22.8% (95% CI: 15.3%, 30.3%) to 12.6% (95% CI: 9.4%, 15.8%) (Zhao et al., 2022).

The iron-fortified soy sauce project began in 1997 and was officially promoted in 2002. Research shows that after one year, anemia rates at national monitoring points dropped by 30%, with an estimated productivity gain of 14.11 billion yuan after three years (Cai et al., 2015; Sun et al., 2008; Wang et al., 2011). Since 2010, China has been promoting the vitamin A-fortified cooking oil project. The promotion of vitamin A-fortified cooking oil has improved students' vitamin A nutritional status, reducing marginal deficiency rates from 20.2% to 7.5% (Li et al., 2014; Sha et al., 2013;). These projects demonstrate the effectiveness of food fortification strategies in preventing and controlling specific nutrient deficiencies.

In the early 21st century, the Chinese Center for Disease Control and Prevention's Food Fortification Office and the National Center for Public Nutrition and Development, under the guidance of the Ministry of Health and the National Grain Bureau, collaborated on nutritional fortification research for wheat flour. From 2002 to 2006, a pilot project for fortifying subsidized flour was conducted in west China where farmland had been converted to forests. The study found significant improvements in anemia rates, serum retinol, and serum zinc levels among women in the intervention group after three years (Huo et al., 2011). From 2006 to 2008, an intervention project in Zhongyang County, Jiaokou County, and Liulin County, Shanxi Province, demonstrated that fortified flour effectively improved micronutrient

Table 4-1 Review of Representative Food Fortification Programs in China

Fortified food	Year	Agency	Regulations/Standards	Effect
Iodized salt	1956	State Council	Included prevention of endemic goiter in "National Agricultural Development Outline (Draft)"	Eliminated cretinism in covered areas and effectively controlled iodine deficiency disorders in the population
	1993	State Council	Enacted mandatory iodization of salt policy	
	2011	Ministry of Health	Issued "GB 26878–2011 National Food Safety Standard Iodine Content in Edible Salt"	
Vitamin A- fortified edible oil	2007	Ministry of Health	Issued "GB/T 21123-2007 Nutrient Fortified Vitamin A Edible Oil"	Effectively increased vitamin A levels in children's serum, addressing vitamin A deficiency
	2010	National Center for Public Nutrition and Development	Launched vitamin A-fortified edible oil project	
Iron- fortified soy sauce	1997	Chinese Academy of Preventive Medicine, Nutrition and Food Hygiene Institute	Conducted research on iron-fortified soy sauce to prevent iron-deficiency anemia	Effectively reduced anemia rates in the population
	2003	State Council, Global Alliance for Improved Nutrition	Conducted research on "Improving Iron Deficiency and Anemia in China with Iron Fortified Soy Sauce"	
Fortified flour	2000	Chinese Academy of Preventive Medicine, Nutrition and Food Hygiene Institute, UNICEF	Conducted research on wheat flour fortification technology	Effectively improved immune function in residents, addressed micronutrient deficiencies in women, and reduced incidence of neural tube defects in newborns
	2003	State Council, Global Alliance for Improved Nutrition	Launched "Wheat Flour Fortification to Improve Micronutrient Deficiency" project	
	2007	Ministry of Health	Issued "GB/T 21122-2007 Nutrient Fortified Wheat Flour"	
Fortified rice	2003	National Center for Public Nutrition and Development	Established the basic formula for nutritionally fortified rice	Lack of studies of effectiveness
	2010	China Cereals and Oils Association, National Development and Reform Commission Public Nutrition and Development Center	Held a press conference for the market launch of nutritionally fortified rice, officially promoting fortified rice	

Source: Author's compilation.

status in women of childbearing age and reduced the incidence of neural tube defects in newborns (Huang et al., 2009). Additionally, Zhao et al. (2004) found that lysine-fortified flour significantly improved immune function, particularly in children.

The development of multi-nutrient fortified rice[4] represents a significant advancement in nutritional fortification research. In September 2003, the National Public Nutrition and Development Center, drawing on international experience and wheat flour fortification experiments, established a basic formula for fortified rice. Nutritionally fortified rice can be categorized into two types based on processing technology: artificially fortified rice, which adds vitamins and minerals such as vitamin A, vitamin B, and iron to rice grains, and surface nutrient spray-fortified rice, which sprays vitamins and minerals onto the outer surface of the rice. China's involvement in artificially fortified rice began relatively late. On April 26, 2010, the China Cereals and Oils Society, along with the Public Nutrition and Development Center of the National Development and Reform Commission, held a press conference in Beijing to officially promote fortified rice (Meng et al., 2021; Zhang, 2010). However, current research in China primarily focuses on processing technologies such as soaking, spraying, or infiltration to fortify rice with nutrients like vitamin B1, lysine, and calcium. There is still a lack of research on the effectiveness of these interventions (Hu et al., 2010; Jin and Su 1992; Wu Yang, 2008; Zhang et al., 2001). Further studies are needed to evaluate the impact of fortified rice on nutritional status and health outcomes.

Biofortification Program. China also has significant progress in the research and application of biofortification,[5] utilizing biotechnological and modern agricultural methods such as selective breeding to create new crop cultivars with enhanced nutritional content. Notable examples include iron and zinc-enriched wheat, vitamin A-enriched sweet potatoes, and folate-enriched rice and corn. The HarvestPlus-China project,[6] established in 2004, has developed more than 20 nutrient-enhanced crop varieties over the past two decades. The project has conducted comprehensive research across the entire production and processing chain for major staples such as rice, wheat, corn, and potatoes, as well as vegetables such as tomatoes and cucumbers. Additionally, since 2009, the project has expanded its research to include other nutrients such as anthocyanins and folate.

Biofortification, as a strategy to enhance the nutritional value of crops, offers distinct advantages over traditional food fortification. It is cost-effective, as it enhances crop varieties to naturally accumulate nutrients, eliminating the need for expensive processing and additives. Once developed, these nutrient-rich varieties can be broadly disseminated, reducing long-term costs for nutritional improvement. For example, the cost–benefit ratios[7] of biofortified crops are significantly higher than those of industrial fortification: iron-rich wheat ranges from 1,117 to 1,940 (Li and Zhang, 2016), folate-enhanced rice ranges from 39 to 198 (Liao et al., 2021), and every $23 to $96 invested in multi-nutrient rice reduces one disability-adjusted life year (DALY) (De Steur, 2012). Additionally, Sight and Life (2016) noted median cost–benefit ratios for iron fortification at 8.7, iodized salt around 30, and folate fortification from 11.8 to 30, compared to about 9.5 for iodine and iron fortification through food processing (Horton et al. 2008).

In addition, promoting biofortified crops boosts their nutritional value and increases agricultural yields and farmer incomes, thereby indirectly enhancing rural nutrition. Studies indicate that using crop nutritional enhancement techniques can raise farmers' incomes by about 15% by planting zinc-rich wheat (Zeng, 2022). Additionally, biofortified foods are more easily accepted by residents due to their similarity in taste and appearance to non-fortified foods. For example, De Steur (2014) conducted experimental auctions with 126 women of childbearing age in Shanxi Province and found that consumers were more willing to purchase folate-rich rice and willing to pay a 36% premium compared to folate supplements. Liu et al. (2018) found that zinc-rich flour produced via biofortification was more popular than traditionally fortified flour among consumers in the northern regions. These advantages indicate that biofortification not

[4] Nutrient-fortified rice is a nutritionally enhanced food made by adding specific nutrients to regular rice.

[5] Biofortification, also known as biological nutrient fortification, enhances food's nutritional value through crop breeding techniques. Unlike traditional fortification, it increases specific nutrient content during crop growth using selective breeding or genetic engineering. This method boosts nutritional value at the source and reduces nutrient loss in processing, offering a more natural and healthy nutrition source.

[6] https://bri.caas.cn/xwdt/mtbd/150366.htm

[7] Cost–benefit ratio, which is the value of benefits received for every unit of cost invested.

only complements traditional food fortification methods but also can provide superior alternatives in certain scenarios.

4.3.2 Promoting the Whole Grains

Many developed countries such as the United States, the Netherlands, Denmark, and Singapore have recognized the importance of developing the whole-grain industry. They have made substantial efforts to promote the substitution of whole grains for refined grains in diets. Their governments have enacted various measures, including the precise definition and labeling of whole-grain products, financial support for processing businesses, the establishment of nutrition programs targeted at specific groups, and public education on the benefits of whole grains. Such comprehensive strategies have effectively spurred the growth of the whole-grain industry. Additionally, the food industries in these countries have contributed to creating a consumer-friendly environment for whole-grain products by setting industry standards and launching educational campaigns about the benefits of whole grains.

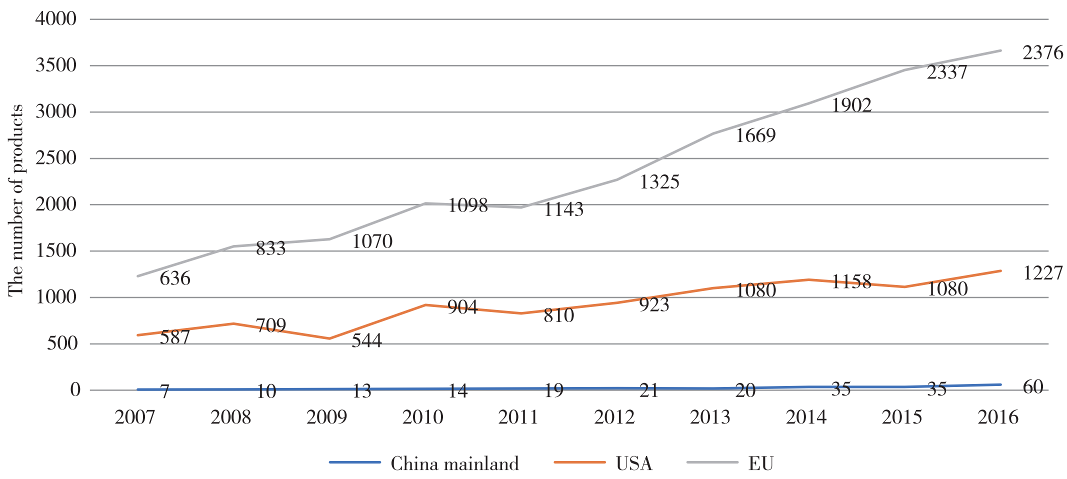
Compared to these countries (Table 4-2), China has introduced certification marks for whole-grain products and is in the process of improving its national standards for whole-grain foods. The Chinese Dietary Guidelines promote the health benefits of whole grains and recommend specific daily intake amounts. Despite these efforts, further development is needed. For example, China has not implemented measures such as financial support for whole-grain suppliers; the provision of whole-grain foods in nutrition programs for special populations

Table 4-2 Measures to Promote Whole-Grain Industry Development in China and Developed Countries

	Intervention measures	Implementing countries	Status of measures in China
Standards	National standards for whole-grain foods	US, Canada, the Netherlands, Denmark, Iceland, Norway, Sweden	National standards are currently under development and refinement, with standards already implemented for whole-wheat flour and sprouted brown rice
Financial support to businesses	Government financial subsidies for R&D and sales of whole-grain product suppliers and retailers	Singapore	NA
Labeling	Government regulations on whole-grain food labeling	Singapore, Iceland, Norway, Sweden, Denmark	NA
	Industry-regulated labels, such as whole-grain stamps	US, Australia, the Netherlands	China issued its first certification for whole-grain foods in 2021
Special nutritional programs for vulnerable groups	Special nutrition supplement programs for women, infants, and children, including whole grains in school lunch and breakfast programs	US, Singapore	NA
Education on Whole Grains	Whole-grain nutrition and health claim standards	US, Canada	NA
	Dietary guidelines recommending whole- grain intake	US, Canada, Denmark, Sweden	Chinese Dietary Guidelines recommend 50–150 g of whole grains per day.
	Development of educational materials for retailers and consumers	Danish Whole Grain Partnership	NA

Source: Author's compilation based on Wang et al. (2023) and Tan and Zhai (2024).

Figure 4-3 Statistics of products claiming to be "whole wheat" launched annually in China mainland, the United States, and Europe, 2007–2016



Source: Mintel New Products Database.

is lacking; and the strategies for disseminating information about whole grains could be more diverse and widespread. Addressing these aspects could significantly enhance the impact of China's whole-grain initiatives, aligning them more closely with the comprehensive strategies seen in other developed countries.

The whole-grain industry in developed countries has experienced rapid expansion due to comprehensive intervention measures. These include an increased supply of products, more stringent labeling standards, rising consumer acceptance, and larger market size. For example, in the United States, since the Whole Grains Council launched the Whole Grain Stamp in 2005, the number of stamped products increased from 250 in 2005 to 10,700 by 2020. The diversity of whole-grain stamp products outside the United States has also increased significantly since 2009, with quick-cooking oats, for example, growing 60% from 2009 to 2020 (Sluyter et al., 2022).

In many countries, consumers increasingly perceive whole-grain foods as healthier and more nutritious dietary choices, with sales of new whole-grain products surpassing those of refined-grain products (Rikard et al., 2021). In 2023, the global market valuation for whole grains and high-fiber foods reached $48.8 billion and is expected to grow to $74.8 billion by 2030, with the U.S. market comprising one-third of this global market share.[8]

In contrast, China's whole-grain industry is still in the early stage, with a limited range of products mainly consisting of bakery foods and breakfast cereals (Zhao et al., 2018). For instance, in 2016, China mainland introduced only 60 new whole-wheat products, significantly fewer than the 1,227 in the United States and 2,376 in Europe. This highlights the potential for market growth and the need for further development and diversification of whole-grain products in the Chinese market.

4.3.3 Midstream Actions for Food Loss Reduction

Since the 18th CPC National Congress, the central government has prioritized food security, highlighting the importance of minimizing food waste and loss General Secretary Xi Jinping has consistently stressed the importance of frugality and opposing waste, urging comprehensive actions to minimize food loss and waste. The government has advocated for a societal attitude in which wasting is considered shameful and saving is deemed honorable.

Over recent years, the National Development and Reform Commission, the Ministry of Commerce, and the State Administration of Grain and Material Reserves have implemented various measures aimed at "saving food and reducing losses [and] opposing waste." These measures include new legislation, enhanced infrastructure, and public awareness campaigns. As a result, significant progress has been made in reducing food losses. The main achievements are detailed in Table 4-3.

[8] https://www.strategyr.com/market-report-whole-grain-and-high-fiber-foods-forecasts-global-industry-analysts-inc.asp

Table 4-3 Food Loss Reduction Measures and Actions

Year	Department	Document	Content
2013	National People's Congress Standing Committee	"Agriculture Law of the People's Republic of China"	Advocates cherishing and saving food.
2018	National People's Congress	"Constitution of the People's Republic of China"	Article 14 establishes principled regulations on "practicing thrift and opposing waste."
2020	National Food and Strategic Reserves Administration	"Notice on Innovating Measures to Further Enhance Food Saving and Loss Reduction Work"	Emphasizes the importance of food saving and loss reduction, enhances legislation and regulation, strengthens management according to law, builds a comprehensive system to continuously reduce post-harvest food losses, and promotes new technological achievements in food saving and loss reduction.
2021	National People's Congress Standing Committee	"Anti-Food Waste Law of the People's Republic of China"	Specifies the responsibilities and obligations of governments, enterprises, and individuals in food production, storage, transport, processing, and consumption phases; requires all parties to implement effective measures to reduce food loss and waste.
2021	Central Committee of the Communist Party of China, State Council	"Food Saving Action Plan"	Proposes strengthened food-saving and loss-reduction measures across the entire food production chain
2021	National Development and Reform Commission, Ministry of Commerce, State Administration for Market Regulation, National Food and Strategic Reserves Administration	"Anti-Food Waste Action Plan"	Focuses on advancing food-saving and loss reduction measures (including promoting loss reduction in pre-consumption stages, improving standards for food saving and loss reduction, and conducting investigations and evaluations on waste in food storage).
2021	Ministry of Agriculture and Rural Affairs, Ministry of Finance	"Notice on Comprehensive Promotion of Cold Storage Facilities Construction for Agricultural Products at Production Sites"	Focuses on construction of facilities in 31 provinces, targeting vegetables and fruits, and considering locally advantageous specialty varieties.
2022	Ministry of Agriculture and Rural Affairs, Ministry of Finance	"Notice on Ensuring Good Work on Cold Storage Facilities Construction for Agricultural Products at Production Sites in 2022"	Focuses on major production areas of fresh agricultural products and areas with advantageous specialty agricultural products, strategically clustering construction of cold storage facilities.
2023	Ministry of Agriculture and Rural Affairs	"Notice on Continuing Good Work on Cold Storage Facilities Construction for Agricultural Products at Production Sites"	Focuses on major production areas of fresh agricultural products and areas with advantageous specialty agricultural products, improves facility layout, and promotes the extension of cold chain logistics services to rural areas.

Source: Author's compilation.

4.4 Challenges in Developing Nutritional Resources in the Midstream Sectors

4.4.1 Urgent Need for Innovation Breakthroughs in Food Processing Technology

China's food processing industry is currently characterized by low market concentration, with numerous small enterprises and overall limited research and development capabilities. This is particularly evident in key processing technologies, equipment, and inspection instruments, alongside storage equipment, especially in nutrition-oriented areas (China Association of Food Science and Technology, 2022; Liu et al., 2022). Deficiencies are noticeable in various aspects, including nutritional fortification technology, whole-grain processing technology, and cold chain logistics.

In terms of nutritional fortification, although China has introduced some fortification programs such as iodized salt, fortified flour, fortified rice, and iron-fortified soy sauce, there is still a lack of precision nutrition and personalized regulation technologies based on individual nutritional needs and health conditions (Yin et al., 1998; Yu et al., 2006). Research on whole-grain processing has focused on taste, cooking time, and shelf life while maintaining the nutritional characteristics of products during whole-grain processing, but further advancements are needed. These include improvements in whole-grain processing technology and equipment, innovation in whole-grain bioprocessing technology and raw materials, and the application and promotion of whole-grain foods in different populations and scenarios (Tan and Zhai, 2024). Additionally, the cold chain logistics system for storing and transporting food has not been fully popularized, especially in rural and remote areas where inadequate infrastructure leads to higher rates of food loss during transportation.

4.4.2 Improvement Needed in Food Industry Standards and Regulatory Systems

China's current food standard system is incomplete, lacking standards and adequate regulation, which hinders the healthy and orderly development of the nutrition-oriented food industry. Despite the enactment of a series of food safety laws and regulations, there is a lack of clear guiding documents, specifically targeting the field of nutritional fortification, apart from the "Regulations on the Management of Iodine Deficiency Elimination by Iodized Salt." Currently, the management of nutritional fortification primarily relies on GB 14880, "National Food Safety Standard-Use of Food Nutritional Fortifiers." However, there are no specific standards for fortified products (Liu et al., 2022).

Furthermore, there is also a lack of standards and specialized institutional supervision for the addition of trace nutrients, which may result in inconsistent product quality in the market, affecting consumer trust and willingness to use (Liu et al., 2022; Smith, 2015). China's whole-grain food industry also suffers from inadequate relevant standards and labeling. The limited adoption of existing product standards and labeling results in uneven product quality in the market, impeding the industry's healthy growth (Liu et al., 2021).

4.4.3 Lack of Effective Policy and Institutional Incentives for Participants in the Midstream Sectors

Most participants in the midstream segment of China's food industry are small and medium enterprises with primary focus on short-term profits and lack consideration for long-term and social benefits. To incentivize these enterprises to produce more nutritionally healthy foods, the government needs to provide external policy incentives.

In its top-level design of policies, the Chinese government has already addressed issues related to promoting the development of the nutritionally healthy food. For instance, the "Opinions of the State Council on Accelerating the Promotion of Agricultural Supply-Side Structural Reform and Vigorously Developing the Grain Industry Economy," issued by the State Council in 2017, calls for the "promotion of moderate processing of rice, wheat flour, and edible vegetable oil, and the vigorous development of new types of nutritionally healthy foods such as whole grains."

Despite these directives, targeted policy support measures are still needed. In the whole-grain industry, for example, companies lack the motivation to develop new whole-grain products that cater to consumer taste preferences due to factors such as incomplete regulations on labeling an health claims, poor stability of whole-grain raw materials, and weak consumer demand. To address these issues, targeted policy measures are of paramount importance. This includes offering financial incentives, revising labeling regulations to allow health claims, improving raw material safety and stability, and boosting consumer demand through education and marketing campaigns. By implementing these measures, the government can foster an environment conducive to producing and consuming nutritionally healthy foods.

Additionally, China needs to strengthen consumer nutrition education and awareness to foster behavioral changes. There is a notable knowledge gap regarding food nutrition and health, resulting in low demand for healthier options such as fortified foods and whole-grain foods. Furthermore, public awareness about the importance and the daily practices to reduce food waste is still insufficient. Consumers often prefer visually appealing and freshness over quality, prompting many lead retailers to refuse to sell perfectly edible but imperfect-looking produce.

Urbanization and lifestyle changes have also altered consumption habits, with a tendency toward purchasing convenient, processed foods, often delicately packaged. This trend contributes to food waste due to overstocking and short shelf lives. Solving the food waste problem requires joint efforts from the government, enterprises, and the public. To mitigate these issues, the government should implement educational campaigns to raise consumer awareness about nutrition, the benefits of fortified and whole-grain foods, and the importance of reducing food waste. Retailers and food producers can also play a role by promoting and selling imperfect-looking but safe foods, and by improving packaging to extend the shelf life of products. Enhanced public education and targeted policies will be instrumental in driving the necessary changes in consumer behavior to support a healthier and more sustainable food system.

4.5 Conclusion and Policy Implications

The big food concept necessitates diversified food supply in the future, prioritizing not only food resources but also the supply and guarantee of nutritional resources. In developing a diversified food supply system and addressing food safety and nutrition issues, the importance of the midstream segment becomes increasingly prominent. Despite its pivotal role in connecting producers and consumers, facilitating information flow, and product distribution, the potential of the midstream segment has not been fully tapped.

This chapter emphasizes the role of the midstream segment in addressing food safety and nutrition issues through specific cases of nutritional fortified foods, whole-grain foods, and food loss reduction. By showcasing these examples, it underscores how the midstream segment can enhance food safety, improve nutritional quality, and reduce waste, ultimately contributing to a more sustainable and health-oriented food supply chain. In the future, the potential of the midstream segment of the food supply chain to improve food and nutritional resource utilization levels and reduce waste and losses can be further explored through the following three aspects:

4.5.1 Standardize Industry Practices and Strengthen Regulatory Systems

(1) Standardizing industry practices can significantly reduce information asymmetry, enhance market transparency, and improve overall supply chain efficiency. It is crucial for these standards to encompass not only food safety and quality but also nutritional content and environmental impact.

(2) A comprehensive regulatory system must be established to ensure that enterprises adhere to standards for production and distribution, thereby minimizing violations and unfair competition. This system should be adaptable to market changes and technological advancements. Examples include implementing storage standards, establishing loss and waste assessment and monitoring mechanisms, and providing "best before" labels to guide consumers on timely consumption. Additionally, regulatory bodies should prioritize training to enhance participants' awareness and skills in reducing food loss, ensuring continuous improvement in food quality.

4.5.2 Strengthen Policy Guidance and Institutional Incentives

(1) Comprehensive Legal Framework: Develop and

refine laws and regulations to regulate the whole-grain and nutritionally fortified food markets. This initiative aims to provide enterprises with a more stable operating environment and to reduce market uncertainty.

(2) Promoting Sustainable and Nutritious Food Development: Implement incentive measures, such as financial subsidies and tax breaks, to encourage enterprises to invest in developing sustainable and healthy food products. These measures can include adjustments to existing financial support programs or the introduction of new subsidies tailored to the specific needs of enterprises.

(3) High-Level Strategy for Nutritionally Fortified Foods, Whole Grains, and Food Loss Reduction: Enhance the government's strategic planning for nutritionally fortified foods, whole grains, and food loss reduction. Define the responsibilities of all stakeholders, reinforce policy direction, and ensure enduring policy consistency and transparency. This will help to establish a robust framework for enterprises to develop sustainable long-term plans and investment strategies.

(4) Technical Assistance and Funding for Food Loss Mitigation: To address food loss, the government should offer technical support and financial assistance to guide processing enterprises in adopting efficient methods, improving production efficiency, and minimizing losses. Additionally, encourage research institutions to develop loss reduction technologies, promoting technological innovations and their practical implementation.

4.5.3 Enhance Technological Support and Collaborative Innovation

(1) Augmented R&D Investment: For optimal nutrient utilization in food, technological advancements are key. Therefore, boosting investments in fundamental and applied research is paramount, particularly in key areas such as whole-grain processing, nutrition fortification technologies, and cold chain logistics. Prioritizing R&D efforts will foster technological breakthroughs and industry upgrades.

(2) Encouraging Innovation: Create dedicated research funds, provide R&D subsidies, and implement incentive mechanisms to inspire researchers' innovative drive, catalyzing technological breakthroughs and industry-wide innovation.

(3) Promoting Collaborative Innovation: Foster close collaborations among agricultural research institutions, enterprises, universities, and government agencies. Encourage joint research, knowledge exchange, and resource pooling to facilitate technological advancements and broad adoption. Establishing cross-departmental and cross-industry innovation alliances will faciliate to address complex technical challenges in the food supply chain. By integrating resources from diverse stakeholders, overall technological capability could be enhanced, thereby bolstering adaptability to market shifts.

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Chapter 5

Promoting Diversification of Food Imports and Ensuring Food Supply Security

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Key Findings

● In recent years, as the impact of the COVID-19 pandemic has gradually diminished, global food production, logistics, and trade have progressively stabilized. However, the global food trade still faces challenges from extreme weather, natural disasters, fluctuating trade policies, geopolitical conflicts, and disparities in food safety standards.

● As the world's largest food importer, China has seen an expanding food trade deficit, an unbalanced import structure, and overly concentrated imports, leading to potential instability. China's dependence on imported soybeans is particularly significant, highlighting an urgent need to diversify its food imports.

● Given the current complex international situation, China should actively explore trade potential with partner countries for preventing future food production and trade crises while gaining a strategic advantage in food imports. China has considerable potential for diversified food trade cooperation with countries involved in the "Belt and Road" initiative, Russia, African nations, and Regional Comprehensive Economic Partnership (RCEP) member countries.

Policy Recommendations

● China should continue to maintain stable trade relations with major food-importing countries and reduce trade barriers and uncertainties through long-term cooperation agreements. Additionally, the food trade diversification strategy should be further optimized by actively expanding trade cooperation using international mechanisms such as the Belt and Road initiative and the RCEP agreement to broaden the sources of food imports.

● China should guide enterprises to integrate domestic and foreign capital, technology, and agricultural resources through international cooperation. Encouraging the establishment of large-scale, competitive global agricultural companies and major grain merchants will enable these companies to play a more significant role in leading food trade and enhance China’s influence in the global food supply chain and pricing.

● Furthermore, China should engage more deeply in WTO agricultural negotiations and South-South agricultural cooperation, participating extensively in the global food supply system governance to ensure the diversification of food supplies. Promoting the inclusion of food trade facilitation goals in WTO negotiations and reducing export bans or restrictions on agricultural products by WTO member states will help secure both China’s and the global food supply safety.

5.1 Introduction

This chapter offers strategic guidance for stabilizing and diversifying food supplies both globally and within China. It assesses the challenges and risks to global and Chinese food import diversification and supply chains, proposing measures to enhance import stability through diversification, elevate the import potential of Belt and Road initiative countries, and maintain stable food trade policies to minimize trade barriers. Additionally, it encourages Chinese corporate participation in the global food industry chain and involvement in international food governance through WTO negotiations and South–South agricultural collaboration.

5.2 Challenges to Food Import Diversification and Supply in China and Globally

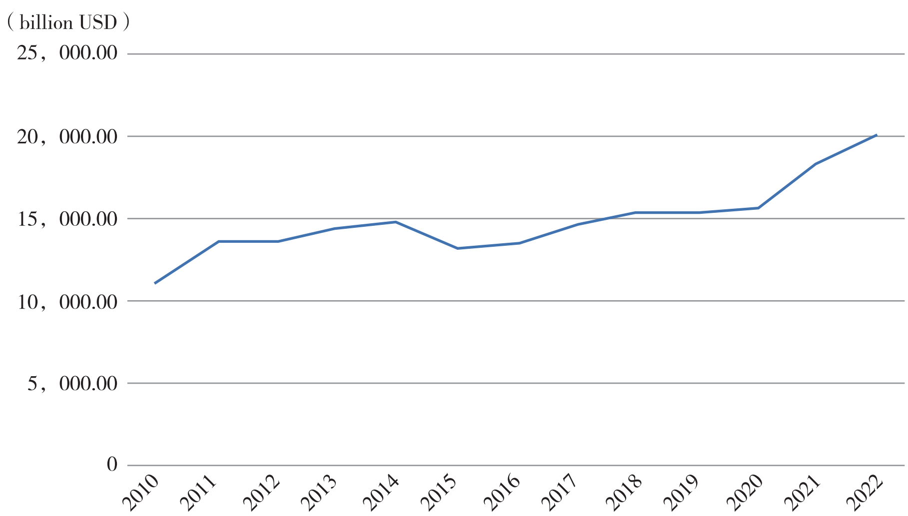
With the diminishing impact of COVID-19, global food production, logistics, and trade have progressively stabilized. Despite this progress, the global diversified food trade faces ongoing challenges from extreme weather, policy volatility, geopolitical conflicts, and disparities in food safety standards. As the leading global food importer, China is experiencing a widening trade deficit, imbalanced import structures, and high concentration in specific imports such as soybeans, underscoring the important need for diversification.

5.2.1 Dynamics and Challenges of Global Diversified Food Trade

In recent years, intensified globalization has led to increased food trade cooperation. From 2010 to 2022, global food trade surged by 80% from USD 1,115.79 billion to USD 2,007.66 billion. In 2022, global trade included 469 million tons of grains, 42.6 million tons of meat, and 8.383 million tons of dairy products. By 2023, as the effects of COVID-19 waned, the stabilization of global food production, logistics, and trade improved the food trade environment. However, natural disasters, policy shifts, geopolitical tensions, and food safety standards continue to pose significant risks to the stability of the global food trade.

(1) Extreme Weather and Natural Disasters Jeopardize Global Food Production and Trade. Extreme weather events such as droughts, floods, and hurricanes have devastating impacts on agricultural production, significantly reducing the capacity of the global food system. For instance, the La Niña phenomenon from 2020 to 2022 led to the most severe drought in 40 years in the Horn of Africa, depleting local water sources and destroying thousands of acres of crops. Moreover, extreme weather conditions exacerbate pest and disease threats to crops. According to the FAO, pests and diseases reduce global crop production by approximately 40% annually. For example, extreme heat

Figure 5-1 Trend of global food trade total, 2010–2022



Data source: WTO STATS.

in India and Pakistan in March 2022 decreased crop yields, prompting India to ban wheat exports and restrict rice exports, thereby posing threats to global food trade.

(2) Uncertainty in Global Trade Policies Affects the Stability of Global Food Trade. Frequent adjustments in tariffs and other trade policies by governments directly affect the cross-border flow of food and trade costs, introducing uncertainty into global food trade. During the pandemic, restrictive food trade measures by various countries hindered agricultural exports, disrupting the established food trade patterns and contributing to a rise in global food prices. Additionally, upcoming elections, such as the 2024 US presidential election, European Parliament elections, and the UK general election, could further increase trade policy uncertainty, potentially affecting the stability of China's food imports.

(3) Geopolitical Conflicts Negatively Impact Global Food Trade. Since 2022, geopolitical tensions such as the Russian–Ukrainian conflict, the Israeli–Palestinian conflict, and the Red Sea crisis have emerged as significant risk factors for global food trade. Ukraine and Russia, key global food exporters of grains and vegetable oils, hold important positions in the market. Together, their grain exports account for nearly 20% of the global market share, and their sunflower oil exports comprise more than 60%. The outbreak of conflict directly affects the production, supply chain, and trade logistics of grains and oilseeds in these countries, adversely impacting global food supply and trade.

(4) Differences in Food Safety Standards Affect Global Food Trade. Global disparities in food safety and quality standards lead to compliance issues that severely affect international food trade. Countries and regions often have different standards and regulations for food safety and quality, forcing manufacturers to adhere to multiple standards simultaneously, significantly increasing production costs and management complexity. For instance, substances such as ractopamine and benzoyl peroxide, permitted in food processing abroad, are banned in China. Discrepancies in food safety standards also cause compliance issues, such as the differences in genetically modified (GM) food standards between the United States and the European Union (EU). The United States has a more lenient regulatory approach to GM foods, while the EU employs stricter labeling and approval procedures, significantly affecting trade between these regions.

5.2.2 China's Food Trade Deficit Widens Annually, Trade Risks Await Mitigation

Food security is fundamental, and ensuring it has always been a paramount concern for national welfare and livelihood. Over more than four decades of reform and opening-up, China has made remarkable strides in food security, thanks to the continual enhancement of domestic agricultural production capabilities and its leading role in global agricultural trade. International food markets and overseas agricultural resources have become significant for supplementing domestic production and bridging the gap between production and consumption. However, China's widening food trade deficit and associated trade risks need urgent attention and mitigation.

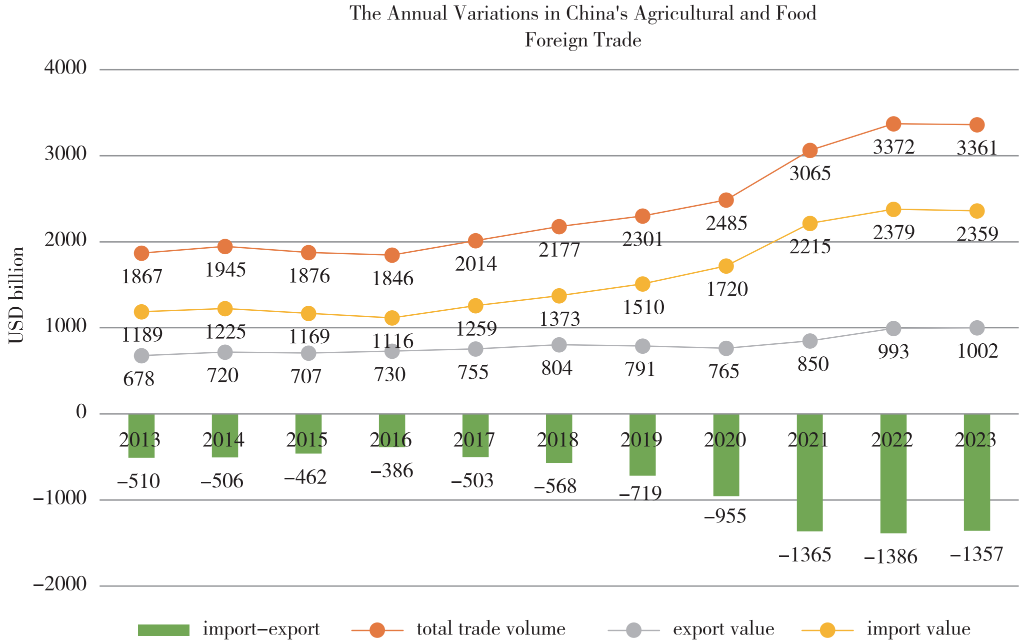
(1) High Concentration in China's Food Trade. According to WTO statistics, in 2023, China's total food imports reached $235.9 billion, maintaining its position as the world's largest food importer since 2022. Figure 5-2 illustrates the annual changes in China's foreign food trade, showing a sharp increase over the past decade, from $194.5 billion in 2013 to $336.1 billion in 2023. This growth primarily stems from a rapid increase in import expenditure, which nearly doubled from $122.5 billion in 2013 to $235.9 billion in 2023. In contrast, export amounts have changed relatively little, resulting in a pattern of "fast imports, slow exports," with the trade deficit showing an annual expansion trend.

Regarding the sources of imports, in 2023, the top five countries from which China imported food were Brazil, the United States, Thailand, Australia, and Indonesia, collectively accounting for 54% of the total import volume. Brazil and the United States accounted for 24.85% and 13.96% of the total imports, respectively. Although the overall concentration of China's imports remains high, there has been a shift in the regional distribution of import sources. Dependence on the United States has decreased, while reliance on Brazil, Russia, and ASEAN countries has continuously increased.

In 2023, oil-bearing crops accounted for the largest share of China's total food import volume, with soybeans alone comprising one-fourth, totaling $61.236 billion. While the overall growth trend in imports remained steady, significant changes were observed in the types of imports: grain imports decreased by 4.3%, cotton and sugar dropped sharply by 20%, and oil-bearing crops surged by 50%. The import volume of staple foods also significantly exceeded quotas, with notable changes in product structure. Rice imports decreased by 58.3%, wheat imports increased by 37.7%, corn imports decreased by 2.2%, and overall staple food imports increased by 29.1%.

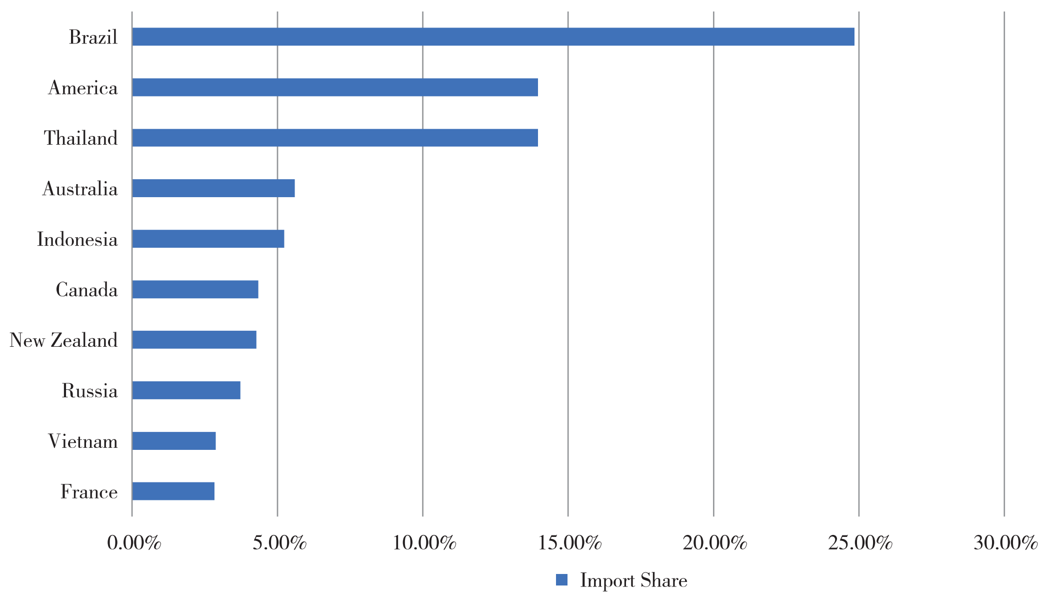
In summary, China's food imports are substantial, with an increasingly pronounced trade deficit, particularly evident in soybeans. China's soybean production accounts for less than 10% of the world's total output, resulting in a very low self-sufficiency rate. China has the highest demand and import volumes for soybeans globally.

Figure 5-2 Annual changes in China's foreign food trade



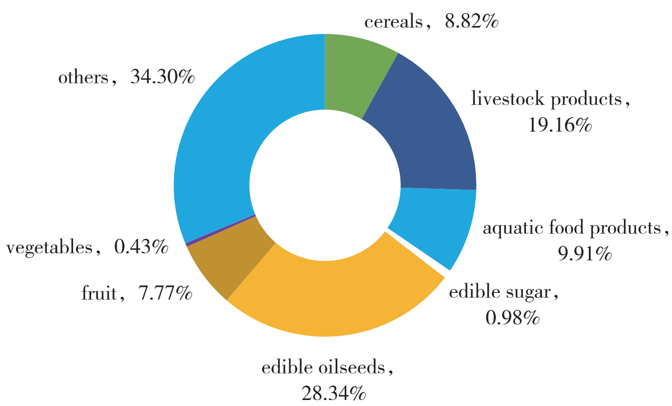
Source: General Administration of Customs of the People's Republic of China.

Figure 5-3 Sources of China's food imports in 2023



Source: General Administration of Customs of the People's Republic of China.

Figure 5-4 Proportions of China's food imports in 2023



Source: General Administration of Customs of the People's Republic of China, US Department of Agriculture.

(2) Imbalance in China's Food Import Structure and High Concentration of Import Sources. China's agricultural product imports face two main issues: an imbalanced import structure with a heavy reliance on a few high-volume agricultural products and highly concentrated import channels. The former issue, which is the reliance on a limited range of products, and the latter, which is the concentration of sources, together introduce significant market risks. These challenges are particularly important amid geopolitical tensions and the strategic competition between China and the United States, underscoring the importance of diversifying import sources to ensure food supply security.

First, there is an imbalance in China's food import structure, with key agricultural products such as grains, oil-bearing crops, and meats accounting for over 60% of total import expenditure. These products primarily meet domestic consumption demands and national food security, highlighting China's insufficient self-sufficiency in these areas and posing risks to the diversification of China's food supply. The issue with soybeans is particularly pronounced. As a major global consumer, China's rapid economic development has led to continuously increasing demand in downstream sectors such as animal feed, soy products, and cooking oils. Over 80% of China's soybean consumption is for oil extraction, relying heavily on imported genetically modified soybeans. The by-product of soybean oil extraction is soybean meal, which is used as feed. , The remaining less than 20% of soybean consumption is used in soy food products.

Despite policy support, advancements in agricultural mechanization, and increases in soybean planting area and yield, domestic soybean production has shown some growth. In 2023, production reached approximately 20.84 million tons, up by 2.8% year-over-year. However, strong domestic demand persists. Foreign soybeans used for oil extraction are cheaper and have higher oil content than domestic varieties, necessitating large imports to meet market needs.

According to the General Administration of Customs, in 2023, China imported 99.409 million tons of soybeans, costing 419.89 billion yuan, up 11.4% and 4.8% year-over-year, respectively. China imports one-third of international soybean production, accounting for over 60% of the global soybean trade. This substantial import volume impacts the prices in the domestic soybean market and related industries, squeezing the domestic soybean market. While domestic soybeans are primarily used for food processing, they can also enter the oil extraction market to balance supply and demand when domestic processing demand is weak. However, competition from low-cost imported soybeans with high oil content limits this option, as domestic consumption needs for soy foods are only about 15 million tons. Additionally, the separation between production and sales of domestic soybeans further drives down domestic prices.

Apart from soybeans, barley also merits attention. Although the total volume of barley imports to China is not high, China's dependency on foreign sources has risen significantly, from 22% in 1995 to 93% in 2021. Barley has even surpassed soybeans to become the most import-dependent agricultural product. This high dependency on imports increases domestic supply risks.

Second, the concentration of some of China's food import sources limits the stability and reliability of imports. The Ministry of Agriculture and Rural Affairs recently released a report on China's main agricultural product import sources from January to December 2023, revealing that Brazil, the United States, Thailand, Australia, and Indonesia are the top five sources, accounting for over half of the total import value. China's substantial domestic food demand and its significant share in the international market mean that any export restrictions by these source countries could place China in an unfavorable position. The high concentration of imports increases the risk of restrictions, emphasizing the need for diversification in China's food imports.

Optimizing the regional distribution, varieties, and transportation channels of imports could help diversify food supplies. For instance, China's dependency on soybean imports exceeds 80%, primarily from Brazil and the United States. In 2023, Brazil remained the largest supplier, with imports reaching 69.95 million tons, accounting for 70.4% of China's total soybean imports, followed by the United States with 24.17 million tons, representing 24.3%, and Argentina third. However, in the complex international environment, China's soybean imports face numerous risks. According to the statistics of WTO and the Ministry of Commerce, since 2010, these countries have been among the top 10 in cases involving trade remedies against China. Trade disputes and conflicts could directly affect the stability of China's food imports.

Moreover, barley imports are also highly concentrated from Australia. In 2017, 73% of China's barley imports came from Australia, which remained the largest source in 2018 and 2019. After implementing a diversification strategy, the concentration of imports eased. Particularly after the implementation of anti-dumping and countervailing duties in 2020, the cost of Australian barley exports surged, leading Chinese traders to reduce imports. From 2021 to the first nine months of 2023, there were no records of Australian barley imports in China Customs' import and export data system.

In 2023, barley imports in China were mainly from Canada, France, and Australia, accounting for 80%. Ukraine was once a major source of barley for China, but the Russian–Ukrainian conflict significantly impacted import stability. Following the cancellation of the anti-dumping and countervailing measures, China imported a total of 2.71 million tons of barley in the first two months of 2024. Nearly 1.6 million tons were from Australia, accounting for 60% of China's total barley imports, making Australia once again the largest source of barley imports to China after more than three years.

5.3 Directions for Resolving Risks in China's Diversified Food Imports and Supply

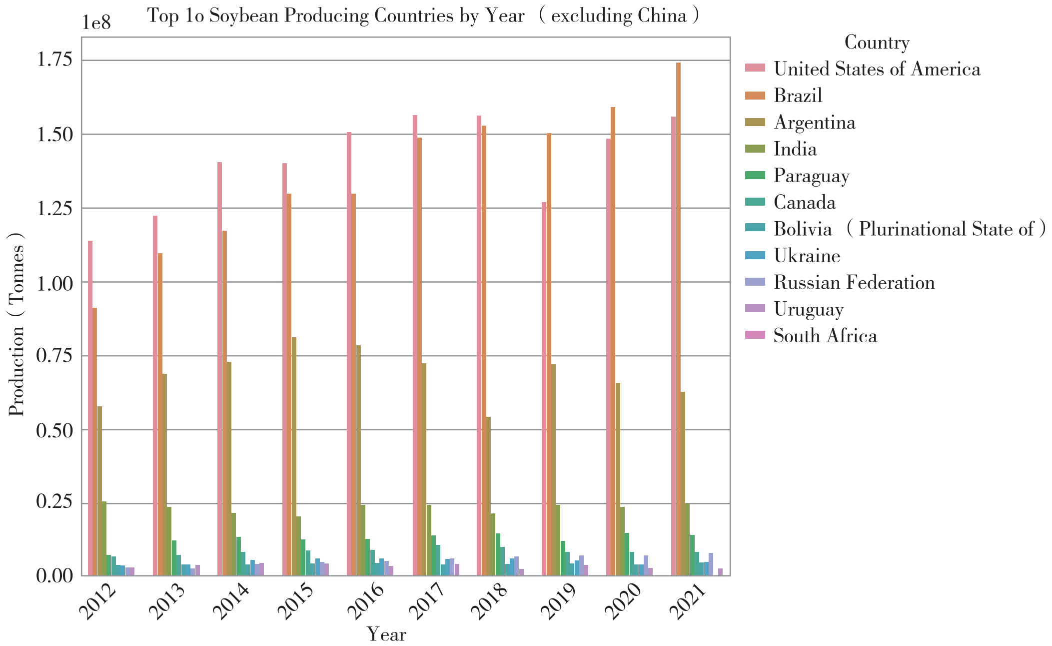
5.3.1 Promoting Diversified Food Imports to Enhance Import Stability

Given the current state of China's food imports, a prominent feature is the high concentration of imported varieties and sources. This report uses the international supply markets of soybeans (Figure 5-5), beef (Figure 5-6), and raw milk (Figure 5-7) as examples to analyze the stability of future diversified food imports in China.

Looking at the soybean international supply market (Figure 5-5), over the past decade, the United States, Brazil, and Argentina have consistently been the top three global producers, together accounting for over 80% of the world's total production. China's soybean imports primarily come from these three countries, while the supply from other international markets such as India, Paraguay, and Canada are relatively insufficient. Since the onset of the US–China trade frictions, China's soybean imports focus has shifted from the United States to Brazil, increasing the proportion of Brazilian soybeans and stimulating production in Brazil. However, as China's demand for soybeans continues to rise and Brazil's production capacity nears its limit, China may increasingly consider importing more soybeans from Argentina. At the same time, it is also advisable to stabilize the US market and moderately increase purchases of US soybeans.

Establishing overseas soybean cultivation bases in Central Asia and the Russian Far East is another potential strategy. Following the Russian–Ukrainian conflict, China has become a strategic partner in developing Russia's Far East economy. A joint statement by the leaders of China and Russia outlined key directions for Chinese–Russian economic cooperation before 2030, highlighting eight major areas, including "effectively enhancing agricultural cooperation to ensure food security for both countries, deepening agricultural trade cooperation, steadily

Figure 5-5 Soybean production statistics for the top 10 countries in the world, 2012–2021 (excluding China)



expanding mutual access to agricultural products while ensuring safety, and increaseing investment cooperation in agriculture."

The two countries have signed over 80 major project cooperation agreements covering important agricultural areas. China is Russia's largest importer of agricultural products, with approximately 80% of Russian soybeans exported to China. In 2022, Russian soybeans accounted for 56% of China's non-GMO soybean imports. There is a strong foundation for cooperation between China and Russia in soybean trade. The Russian Far East, with its abundant arable land resources (25% of the region's total area), is ideal for large-scale mechanized production and non-GMO soybean cultivation. Additionally, China can access the Pacific and Arctic regions through ports in Russia's Far East, enhancing regional security and stability, which is significant for China's food security.

According to the international market situation for live cattle stocks (Figure 5-6), Brazil and India are the leading countries, demonstrating their pivotal roles in the global beef supply chain. In contrast, countries such as Ethiopia, Argentina, Pakistan, and Mexico show minor fluctuations in live cattle stocks, contributing to the overall stability of global live cattle inventories. In recent years, China's beef trade partners have included Brazil, Argentina, Uruguay, Australia, New Zealand, and the United States, aligning with global beef supply trends and reflecting the continuous stability of China's beef import policies.

Looking ahead, China's beef import channels are expected to become more open, maintaining a stable supply. To diversify import routes, it is advisable to deepen trade cooperation with major beef exporting countries such as Brazil and India. Additionally, China should consider quality, price, and trade risks while exploring or strengthening trade relations with countries that have relatively stable beef supplies, such as Ethiopia, Argentina, Pakistan, and Mexico.

Regarding the international supply market for raw milk (Figure 5-7), India and the United States have maintained the highest production levels over the past decade, showing a stable upward trend. Meanwhile, countries such as Brazil, Russia, Germany, France, and Pakistan have medium production levels with gradually increasing trends but larger fluctuations. Overall, the international market for raw milk is expected to continue its slow and steady growth, with milk protein supplies remaining at normal levels.

China's current dairy import trade primarily sources high-quality dairy products from New Zealand, the EU, and Australia. This focus on quality has led to relatively high prices in the domestic dairy market. Looking foreword, China's dairy import trade policy is expected to continue emphasizing quality while also intensifying efforts to diversify import sources. This will involve

Figure 5-6 Statistics of beef stocks in the top 10 countries in the world, 2012–2021 (excluding China)

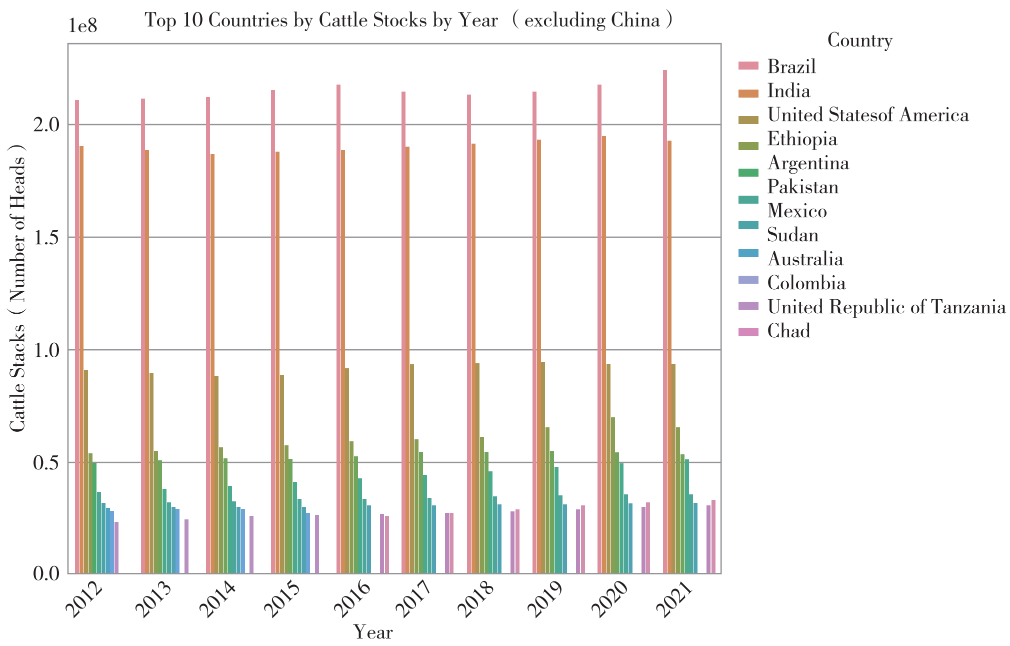
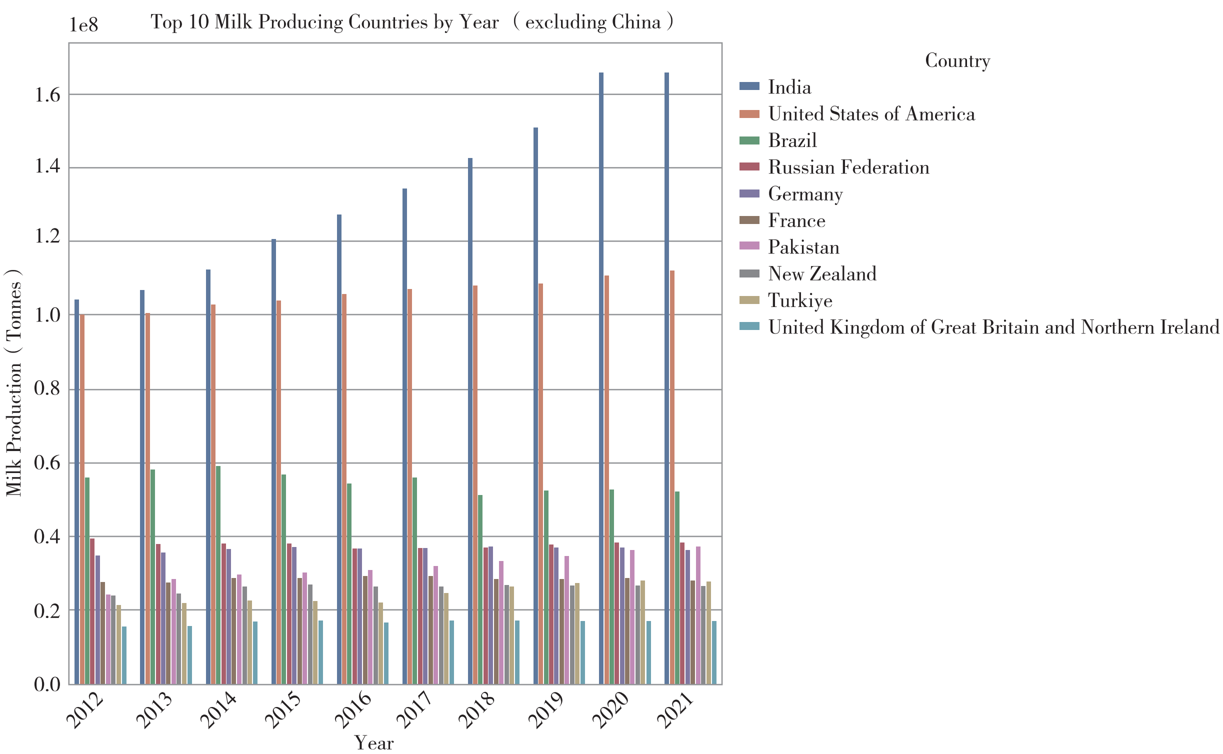


Figure 5-7 Raw milk production statistics for the top 10 countries in the world, 2012–2021 (excluding China)



expanding the range of milk supply sources, enhancing milk quality, ensuring domestic milk supply, and stabilizing domestic milk prices.

According to predictions from the US Department of Agriculture for the 2023–2024 period, the production of corn and soybeans is expected to rise, while the output of other major staple grains and primary protein sources will see minimal change or even a decline in growth rates. This trend indicates that the advantage in food resources will continue to be concentrated among a few countries.

Consequently, the globalization of the food supply chain is becoming increasingly pronounced. This concentration exacerbates issues such as international production insufficiencies and dependence on imports by economies with comparative disadvantages. It also diminishes the flexibility and autonomy of food-importing countries in managing food diversity crises. Moreover, the centralization of global food supplies raises profound concerns about food sovereignty and poses potential threats to the food security and economic stability of importing nations.

Analyzing the changes in China's import trade policies, especially those related to agricultural products, reveals that these policies are significantly influenced by fluctuations in international agricultural product prices, resulting in considerable temporal disparities and instability. According to data from the China Agricultural Trade Promotion Center, a slight increase in international rice prices in 2023 led to a significant 57.5% decrease in China's rice import volume year-over-year. Conversely, decreases in the international prices of soybeans, wheat, and corn resulted in respective import volume increases of 11.4%, 21.6%, and 31.5%. These fluctuations reflect the sensitivity of China's import trade policies to international market price changes and indicate a need for more sophisticated management strategies to stabilize national food security and guard against international food price crises.

Therefore, China's next steps to ensure the quality and safety of national food imports should focus on trends in geopolitical conflicts and fluctuations in international food prices. The goal is to maintain the stability and continuity of the existing food import trade system, ensuring national food security and mitigating the potential impacts of geopolitical risks and global food price crises.

5.3.2 Enhancing the Import Cooperation Potential of Belt and Road Initiative Partner Countries

Given the current complex international situation, actively exploring the trade potential with China's food trade partners is significant for future stability. This approach aims to avert political crises in major food-producing countries and secure a proactive stance in food imports. This section focuses on Russia, African regions, and RCEP member countries to analyze the potential and future trends of China's diversified food import cooperation.

(1) Analysis of the Potential for Diversified Food Import Cooperation between China and Russia. On October 18, 2023, at the third Belt and Road International Cooperation Summit Forum, China and Russia signed the largest food sector trade contract to date, spanning 12 years. This agreement marks a significant step in unlocking the potential for diversified food import cooperation between China and Russia.

According to the contract, Russia will supply China with 70 million tons of food, including grains, legumes, and oilseeds, which is expected to alleviate the constraints of rising international grain prices and supply shortages on China.

Additionally, Russia plans to develop the Outer Baikal region into a significant land-based grain terminal, with the China and Russia grain trade transported through the "New Land Grain Corridor" to support this trade. It is anticipated that the annual volume of grain imports from Russia to China will exceed 10 million tons, establishing Russia as an important source of wheat imports for China. Furthermore, China has actively opened new import channels from Brazil, South Africa, and Myanmar in recent years, importing crops such as corn and soybeans, further expanding the scope of cooperation in diversified food imports.

(2) Analysis of the Potential for Diversified Food Import Cooperation between China and Africa. Currently, only 16 African countries have a trade surplus in agricultural products with China, while the other 33 African countries have a trade deficit (Figure 5-8). Considering that China is one of the world's largest food consumers, with a continuously growing demand for grains, oilseeds, and fruits, African countries can improve their trade deficits by optimizing their agricultural production structures and enhancing the quality and competitiveness of their agricultural products.

Using the general equilibrium model (CP model) by Caliendo and Parro (2015), simulations of the trade and welfare scenarios post-signing of a China–Africa Free Trade Agreement indicate significant potential growth. Overall, the total food trade growth for African countries is expected to increase from 0.01% to 13.4%. Specifically, for African countries with substantial food trade volumes with China, such as Réunion, Rwanda, Ghana, Guinea-

Figure 5-8 **China-Africa agricultural products bilateral trade volume (in million USD)**

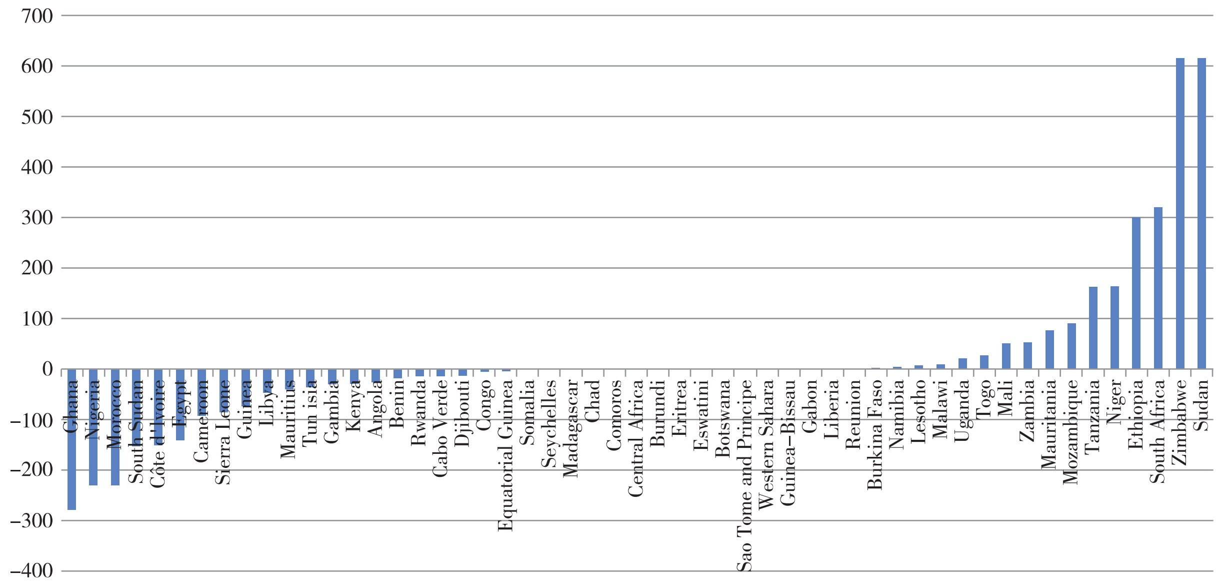
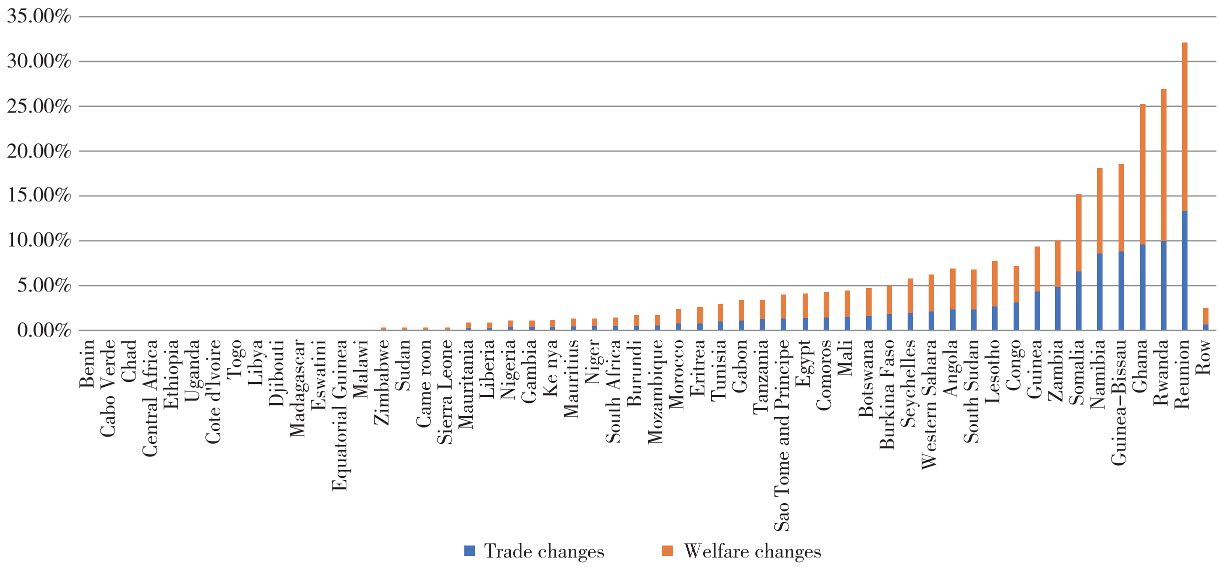


Figure 5-9 **Simulated effects on trade and welfare in African countries after signing a China-Africa free trade agreement**



Bissau, Namibia, Somalia, Zambia, Guinea, Congo, and Lesotho, the trade expansion effect is expected to range between 2.73% and 13.37%. This forecast indicates that strengthening food trade cooperation with China will likely promote the growth in food trade and help improve trade deficits for African countries.

(3) Analysis of the Potential for Diversified Food Import Cooperation under RCEP. Taking the RCEP as an example, the potential for China to import from ASEAN, Japan, Korea, Australia, and New Zealand is explored through simulation analysis based on the CP model. Using the tariff reduction schedule in the RCEP Agricultural Products Tariff Concession Table, the proportions of tariff reductions at different stages are determined, with particular focus on the proportion of zero-tariff goods in the final year of the agreement. This allows for simulation of the final tariff reduction (last year) and exploration of trade effects post-reduction. Table 5-1 reports the effects on China's agricultural trade after tariff reductions among RCEP members alone. The results show that ASEAN will significantly increase its agricultural products to China, further promoting the diversification of food imports (0.845), followed by Australia (0.229) and New Zealand (0.106).

Table 5-1 Trade effects on Chinese agricultural products after tariff reductions by RCEP members

Country	Trade effect
Australia	0.229
Japan	0.007
Korea	0.030
New Zealand	0.106
ASEAN	0.845
Brunei	0.002
Cambodia	0.264
Indonesia	0.144
Malaysia	0.105
the Philippines	0.041
Singapore	0.000
Thailand	0.124
Vietnam	0.165

Overall, Russia, African countries, and RCEP member states have significant potential to become major partners in China's future diversified food imports, ensuring the supply needs of China's diversified food.

5.4 Policy Recommendations for China and Global Food Supply from a Diversified Import Perspective

China should implement specific policy measures to effectively address the challenges of global food import diversification and supply security. First, China needs to maintain stable trade relationships with major food importing countries and reduce trade barriers and uncertainties through long-term cooperation agreements. Second, China should optimize the diversification of its food trade by utilizing international cooperation mechanisms such as the Belt and Road initiative and RCEP to expand trade cooperation with nontraditional food exporting countries.

Additionally, the government should encourage Chinese companies to participate in the global food industry chain, enhance their influence in the global food supply chain, and improve the business environment of the food industry. Last, China should actively participate in the global governance of the food supply system through platforms such as the WTO and South-South cooperation. This involves promoting the inclusion of food trade facilitation goals in WTO negotiations and avoiding the politicization of food trade, ensuring the diversification of food imports and supplies.

5.4.1 Maintain the Stability of China's Food Trade Policies, Reduce Trade Barriers in the Food Sector

First, China needs to stabilize trade relations with its current principal food import sources. By signing long-term cooperation and trade agreements, China can reduce trade barriers in the food sector and maintain stable foreign trade policies, thus ensuring the reliability of its existing food trade supply sources.

On this basis, China should further optimize the diversification of its food trade. This can be achieved by expanding trade cooperation with countries that have potential in nontraditional food production and export, utilizing international cooperation channels such as the Belt and Road initiative and RCEP. China should proactively seek food imports from a wider range of countries. Additionally, China should address high tariff barriers and export bans on food imports by negotiating trade agreements to reduce tariffs and other trade barriers. This will expand trade cooperation with potential source countries and reduce the concentration and risks associated with food imports, ensuring a diversified source for China's food imports.

5.4.2 Guide Chinese Companies in Participating in the Global Food Industry Chain, Improve the Business Environment of the Food Industry

The Chinese government can guide companies through international cooperation to integrate domestic and foreign capital, technology, and agricultural resources. Encourage the establishment of large-scale, competitive global agricultural companies and major grain merchants to lead food trade and enhance their influence in the global food supply chain and pricing rights. Additionally, actively invest in establishing food processing enterprises globally, transferring some capacity to primary product-producing countries to internationalize food production and processing.

Considering the analysis of global diversified food supply risks, investing in the backend processing and branding of food products helps to enhance the added value of agricultural products, extend the industrial chain, and, while indirectly controlling the production segment, mitigating adverse political and economic factors. Furthermore, strategic arrangements for food storage, docks, and other logistics links can enhance the capacity to transport food back to the country during emergencies, thereby better addressing severe fluctuations in global food prices.

5.4.3 Participate in the Global Governance of the Food Supply System Through WTO and South–South Agricultural Cooperation

China can strengthen the global governance of the global food supply system by actively participating in WTO agricultural negotiations and South–South agricultural cooperation, promoting the diversification of food supply. Specific actions should include advocating for the inclusion of food trade facilitation goals in WTO negotiations and encouraging WTO members to reduce agricultural and food export bans or restrictions. These efforts aim to ensure the food supply security for China and globally.

In the diversified food sector, encompassing grains, vegetables, fruits, legumes, nuts, meats (including poultry), dairy (including dairy products), eggs, and fish (including all aquatic products), it is important to persuade WTO member states to commit not to implement agricultural and food export bans or restrictions inconsistent with WTO provisions. This approach helps avoid politicizing agricultural trade and reduces overreactions to agricultural and food trade incidents. Ultimately, these efforts broaden the sources of China's diversified global food supply.

In a global context, there remains vast potential for the development and utilization of agricultural resources, especially in developing countries and regions such as sub-Saharan Africa, Latin America, Eastern Europe, West Asia, and the Russian Far East. These regions have significant potential for increasing crop yields and food exports. Therefore, it is advisable to strengthen South–South agricultural cooperation with Southern countries and those along the Belt and Road. Continuing to advance deep trade and investment cooperation will further promote the diversification of China's food types and sources. This approach not only benefits China but also contributes to the sustainable development and prosperity of agricultural sectors in these regions.

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