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REVIEW

TRANSFORMING CHINESE FOOD AND AGRICULTURE: A SYSTEMS PERSPECTIVE

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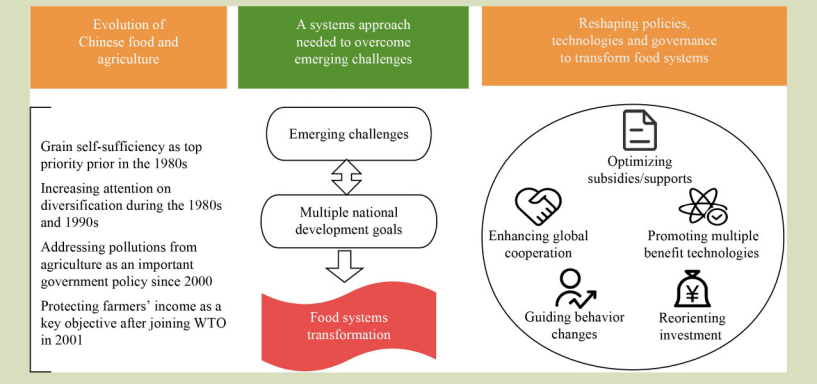
KEYWORDS

food systems, food security, nutrition, climate change

HIGHLIGHTS

- The goals of Chinese food and agriculture have shifted from grain self-sufficiency to diversified goals, including protecting natural resources, reducing pollution and greenhouse gas emissions, and improving food safety and nutrition.
- Addressing the challenges and achieving future goals requires a systems approach to transforming the Chinese food and agriculture sector.
- The nexus of food, nutrition and the environment is at the core of food systems.
- Pathways are proposed, which include repositioning subsidies/supports, promoting multiple benefit technologies, reorienting investment and finance, guiding consumer behavior, and catalyzing global cooperation.

GRAPHICAL ABSTRACT



ABSTRACT

After decades of development, China has made significant progress in ensuring national food security. However, the country currently faces multiple challenges, including the double burden of malnutrition, i.e., micronutrient deficiencies and overweight/obesity, climate change, resource stress and environmental degradation, and an increasingly complex global market. This paper reviews past developments in food and agriculture, and offers initial insights into transforming the Chinese food system for achieving multiple national development goals using a systems approach. Strategies and solutions from China can also inform the design and implementation of food system transformation in other emerging economies.

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1 INTRODUCTION

Remarkable achievements in global food security have been made over the past several decades. Since the 1960s, global growth in agricultural production has outpaced population increase[1]. However, a perfect storm of multiple risks and threats, such as climate change, COVID-19, environmental degradation, trade frictions and regional conflicts has reversed some progress already achieved and added unprecedented global food security and nutrition challenges[2]. As many as 828 million people accounting for 10% of the global population, suffered from hunger in 2021, and nearly 30% faced moderate or severe food insecurity[3].

After decades of development, China has made significant progress in ensuring national food security. China's grain

production reached 483 kg per capita in 2021, which exceeds the international food security standard of 400 kg per capita or by 21%[4]. The consumption of animal products has also increased. For example, the 2021 consumption of red meat (pork, beef and mutton) per capita and poultry per capita was 32.9 and 12.3 kg, respectively, an increase of 26% and 46% compared with the consumption in 2015. China ranked in the top 30% of 113 countries in the 2021 Global Food Security Index, which measures food affordability, availability, quality and safety, natural resources and resilience[5]. The Chinese food system, however, currently faces many challenges. First, unbalanced diets, the coexistence of overweight/obesity and micronutrient deficiency and the rise in chronic diseases have been rapidly emerging. The intake of edible oil and salt is much higher than recommended for the Chinese population, while the consumption of whole grains, green leafy vegetables, fruits, milk, fish, shrimp and beans is inadequate[6]. Second, agricultural production has imposed increasing pressure on resources and the environment, and climate change and extreme weather events have adversely impacted food systems. Evidence has shown climate change has reduced food production, increased the price of agricultural products, and reduced China's food self-sufficiency[7]. Third, domestic and international markets are becoming more closely linked than ever, and complex international situations and emergencies have exacerbated food and agricultural trade risks. China imported 7.4 Mt of meat, which exceeded 31 billion USD in 2022[8]. China's imports of soybean was about 91 Mt in 2022, which accounts for 82% of total domestic demands.

It is clear that food systems must be transformed globally including China, but it is also an opportune time for this to happen. The 2021 United Nations Food Systems Summit, the 2021 United Nations Climate Change Conference (COP26), and the Fifteenth Conference of the Parties to the United Nations Convention on Biological Diversity (COP15) all regard the food system transformation to be essential. In 2022, China's No. 1 Central Document, the first document issued by the central government at the beginning of the year, emphasized the promotion of green and high-quality agricultural development. At the Two Sessions of 2022 (the National People's Congress and the Chinese Political Consultative Conference), President Xi Jinping demonstrated the need to establish the "big food" concept, which aims to improve livelihoods further while pursuing food from different sources including farmland, grassland, forestry, ocean and even novel science and technology. While ensuring a steady supply of grains, it also needs to develop food resources and categories that guarantee an adequate supply of various foods, including meat, vegetables, fruits, aquatic products and other food items, to achieve a balance of food supply and demand. In October 2022, the report of the Twentieth National Congress of the Communist Party of China re-emphasized establishing the big food concept and consolidating the foundation of food security comprehensively. In the new development stage, the Chinese government has proposed higher development goals; these include Healthy China 2030, Rural Revitalization, Ecological Civilization, Common Prosperity, and Carbon Neutrality. The Chinese food system is foundational to achieving these goals.

This paper reviews past development in food and agriculture in China, and how transformation has already happened using a systems approach going beyond food and agriculture. It also offers initial insights for the transformation to achieve the multiple national development goals. This study aimed to contribute by integrating various development goals into a unified framework and examining their interlinkages. Strategies and solutions based on China's food system transformation can also provide valuable insights into the design and implementation of policies in other emerging economies.

The three sections that follow give a brief description of the evolution of Chinese agriculture and food systems, argue that new challenges and development goals facing China's food and nutrition security requires a systems approach to transform food and agriculture, and explore pathways to transform the Chinese food system and possible implications for policy design and implementation. The paper concludes with critical implications and recommendations arising from this analysis.

2 EVOLUTION OF CHINESE FOOD AND AGRICULTURE

This section summaries the development of Chinese food and agriculture, highlighting priorities and sequences of goals and related policies. The goals have shifted from grain self-sufficiency to diversified goals, including protecting natural resources, reducing pollution and greenhouse gas emissions, and improving food safety and nutrition.

2.1 Grain self-sufficiency as top priority prior to the 1980s

From the founding of the People's Republic of China in 1949 to the 1980s, the Chinese government attached great importance to grain production and focused on grain-based food security. In the 1950s, the per capita grain production was only 209 kg, far below the subsistence level. To change the food shortage

situation, the Chinese government took the development of agricultural production as the central task and formulated the first Five-Year Plan in 1953. The document was required to ensure the necessary increase of grain and other crops every year. The National Agricultural Development Program (draft) from 1956 to 1967 also clearly targeted at implementing measures to increase production and crop yield[9]. From 1949 to 1978, China's grain output was on the rise. The grain production was 30.5 kt in 1978, about 2.69 times the level of 1949. However, the grain supply was still inadequate, and hunger was common[10]. In 1983, the household contract responsibility system was formally established, which increased the incentives to farmers to grow grain significantly and promote the enhancement of comprehensive grain productivity. In the same year, China's per capita grain output exceeded the food security line for the first time.

2.2 Increasing attention on diversification during the 1980s and 1990s

With the rapid development of China's grain production, the focus of the food agriculture in the 1980s and 1990s began to evolve into non-grain production. As income rose, the demand for meat, eggs and milk had gradually increased. Determine how to adjust the agricultural production structure to meet the population's new food needs became the key challenge. While increasing grain production remained an important policy goal, economic crops and aquaculture had developed rapidly[11]. The supply of economic crops with relatively high income, such as oil crops and peanuts, vegetables and fruit, as well as feed grains such as corn and soybean, had gradually become the focus. The planted area of soybean rapidly expanded, with an annual increase rate of 4% from the 1980s to the 1990s. The area of oil crops in the 1990s increased by 37.5% compared to the 1980s. However, the production structure of agricultural products in China had yet to be able to adapt to the change in the food consumption structure of residents, which was reflected in the increase in the import of non-grain food. For example, the import of edible vegetable oil increased from 90 kt in 1980 to 1.12 Mt in 1990, a 12-fold increase.

2.3 Addressing pollution from agriculture as an important government policy since 2000

Since 2000, shortage of arable land and freshwater resources per capita in China has become more evident. Also, the excessive use of mineral fertilizers and synthetic pesticides to achieve a high yield of crops over the last two decades has caused a large amount of agricultural pollution. Therefore, agricultural pollution control and sustainable food production have become increasingly important as a policy issue. The excessive use of mineral fertilizers and synthetic pesticides has caused soil pollution, water eutrophication, and land degradation, affecting the quality and safety of agricultural products and threatening human health and life. The livestock and poultry sectors have contributed the most COD (chemical oxygen demand) and TP (total phosphorus) emissions, mainly from livestock and poultry manure. In 2007, the COD and TP emissions from these sectors were 12.7 Mt and 160 kt, respectively, accounting for 96% and 62% of agricultural pollution. In addition, agricultural pollution is non-point source and is difficult to regulate due to asymmetric information, uncertain emission routes and cross-emission by multiple polluters.

To tackle these challenges, China set specific targets for agricultural pollution control and emission reduction in the twelfth Five-Year Plan for agriculture and rural areas. China's No. 1 Central Document is the first document issued by the central government in the beginning of the year. In 2016, this document noted that the green development of agriculture should be promoted comprehensively. The Opinions on Innovating System and Mechanism to Promote Green Development of Agriculture, issued in 2017, guided promoting resource conservation and environmental friendliness in agricultural development.

2.4 Protecting farmer income as a key objective after joining WTO in 2001

Since joining the World Trade Organization (WTO) in 2001, China's agricultural market has opened further to the international market. However, the lack of comparative advantages in grain production and the small scale of farm size and operation increased risks faced by individual farmers. Therefore, the use of agricultural subsidies to protect farmer income and stabilize agricultural production has become a key focus of the food systems.

Since 2004, the State has successively implemented subsidies for grain production. The total amount increased rapidly from 100 million yuan in 2002 to 127 billion yuan in 2009, which included subsidies for improved soybean cultivars and agricultural machinery purchase, direct income support to grain farmers and subsidies for agricultural materials[12]. The sum of direct production support and general services support for agriculture in China increased from 368.7 billion yuan in 2010 to 613.9 billion yuan in 2020 (at the 2010 constant price), with an average annual growth rate of 5.23% and accounting for an about 10% share of agricultural GDP[13]. At the same

time, the abolition of the agricultural tax in 2006 further alleviated the pressure on farmers. To comply with the WTO rules, the central government began to reform agricultural subsidy policy.

3 A SYSTEMS APPROACH NEEDED TO OVERCOME EMERGING CHALLENGES

3.1 Emerging challenges facing food system in China

China has made remarkable achievements in food security, and the population's dietary and nutritional status has been dramatically improved. However, the Chinese food system faces multiple challenges, such as malnutrition, stretched natural resources, environmental degradation, unbalanced urban and rural development, and an unstable international market.

3.1.1 Double burden of malnutrition

Despite significant progress in eliminating poverty and hunger, unbalanced food intake persists and has even worsened for certain population groups. Chinese residents consume substantially more edible oil, salt and animal products than recommended. They consume inadequate fruits, vegetables, whole grains, beans, and milk, and their diet has deviated significantly from nutrition and health goals[14]. Unbalanced diets are notably worse in rural areas[13].

Currently, China is suffering from the double burden of malnutrition, that is the coexistence of micronutrient deficiencies and overweight/obesity. In 2020, more than half of Chinese adults were overweight or obese, as well as 10% and 19% of children and teenagers, respectively[15]. Meanwhile, deficiency in key micronutrients, including vitamin A, calcium, and omega-3 fatty acids, has increased among rural inhabitants, leading to diet-related chronic disorders such as anemia, hypertension and stroke[6]. In 2017, over 3 million deaths were related to diet-related diseases such as diabetes and heart disease in China.

3.1.2 Resources stress and environmental degradation

China is increasingly facing land degradation, water stress, and climate change challenges. Excessive mineral fertilizer use has caused severe soil and water pollution. Of more than 133 Mha of arable land in China, more than two-thirds is considered low-quality (Ministry of Agriculture and Rural Affairs, 2020). In addition, China is stressed about domestic water supplies. In 2021, China's total freshwater consumption was about 592.02 billion m^3, and 61% was consumed by agriculture[16]. Also, under global climate change, the annual average temperature in China has risen significantly over recent decades, and this warming trend along with the increasing fluctuation in precipitation is expected to continue[7]. It is estimated that there is about 10 Mha of contaminated farmland in China, and a third of this contaminated land is unfit for crop production[17]. The crop germplasm resources in China had decreased from 11,590 in 1956 to 3271 in 2014, with an extinction rate of 72%[18].

Increased environmental pressures undermine domestic food production capability. Natural disasters and extreme weather events (e.g., floods, droughts, and unseasonably high or low temperatures) due to climate change can cause a significant loss in domestic agricultural and food production. In 2018, about 140 million people were affected by natural disasters, with a total loss of 4 billion yuan, while in 2019, about 20 Mha in China were affected by natural disasters[19].

3.1.3 Increasing global risks

China has experiences increased reliance on imports and was the second largest importer and fifth largest exporter of agricultural products in terms of value in the world[20]. From 2001 to 2020, China's imports of grain, including soybean, increased rapidly; WTO disputes and international litigation have also increased[13]. In 2022, China imported 147 Mt of grain, accounting for 21% of the total grain consumption[21]. In particular, China's imports of soybean accounts for 82% of total domestic demand in 2022. The import of beef was 2.69 Mt in 2022, which surpassed the total import volume in 2021 (2.33 Mt), with an annual increase of 15%, contributed 27% of the total supply[22].

Global food supply chains have been disrupted due to COVID-19, natural disasters, regional conflict and trade disputes. They increased food price volatility and decreased the food production. Trade distortions further induced volatility of world agricultural prices by around 22% during the pandemic[23]. In addition to trade and price risks, the regional conflict leads to increased uncertainty in the global food market. The grain export restriction policies of Russia and Ukraine and the possible grain export restriction measures taken by various countries have forced the adjustment of the grain production and trade patterns, further increasing the uncertainty of the global grain market and trade.

3.2 Multiple national development goals in China

China has entered into a new stage of development and is moving toward the second centenary goal of building itself into a modern country in an all around. The Chinese government has proposed ambitious development goals; including Healthy China 2030, Rural Revitalization, Ecological Civilization, Common Prosperity, and Carbon Neutrality. The food system is key to achieving these goals, which goes far beyond grain self-sufficiency.

3.2.1 Food security

Since the Eighteenth National Congress of the Communist Party of China, food security has been a top priority in governance, ensuring basic self-sufficiency in grain and the absolute safety of essential staples. The big food concept was re-emphasized at the Two Sessions held in 2022 and the Twentieth National Congress of the Communist Party of China. It pointed out that to better meet the population's needs for a better life, China should acknowledge the changing trends in the food consumption and ensure an adequate supply of meat, vegetables, fruit, aquatic products among others. A food system is at the core of guaranteeing and stabilizing diversified supply of food beyond grains for its population.

3.2.2 Healthy China

The Chinese government launched the Healthy China 2030 initiative in 2016 and released a corresponding action plan, *Healthy China Action* (2019–2030), in 2019. Such action sets up targets of cutting dietary oil, salt and sugar nationwide, reducing obesity and preventing chronic diseases. Food is directly linked with human nutritional health, and the functioning of the food system determines the quantity, structure and quality of various food items.

3.2.3 Carbon neutrality

At the United Nations General Assembly and the UN Biodiversity Summit in September 2020, the Chinese government pledged to reach national peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. China commits to extend its nationally determined targets by adopting more vigorous policies and measures. Such policy ambition aligns with China's vision of becoming an ecological-based society. China's food system generated over 1 Gt of CO_2 equivalents in 2018, the third annual highest level[24]. So for achieving carbon neutrality, the nation's food system must feature prominently in the overall national plan to address climate change.

3.2.4 Common prosperity

The goals of 2035 and 2050 proposed in the report of the Nineteenth National Congress of the Communist Party of China reflect the requirements of improving people's lives, narrowing the gap and achieving common prosperity. The Gini coefficient of national per capita income still remains at a high level of 0.46. To improve people's living standards, narrowing the gap between urban and rural areas is critical. China has made a historic achievement in poverty elimination. However, small farmers need more ability to connect with large markets and a solid ability to resist risks to further increase their income beyond the poverty line. The proportion of the food system in the national GDP and employment is as high as 23% and 37%, respectively. The sustainable development of the food system is essential to prevent a large-scale return to poverty and further enhance living standards among low-income people, especially in rural areas.

3.3 Food systems approach

3.3.1 Food systems

The food system concept was first proposed in the 1970s and has been deepened over time by different disciplines. Marion[25] defined food systems as the sum of various relationships between agriculture and downstream economic entities. Its definition gradually expanded to include organizations or individuals involved in food production, processing, circulation, raw materials and equipment inputs[26], and their impacts on the economy, environment, health and society[27]. An ideal food system should be beneficial to human and earth health, making it easier for consumers around the world to obtain and afford better food and become more resilient and inclusive of supporting livelihood security[2,28].

More specifically, food systems encompass food and agricultural products from agriculture, forestry, animal husbandry, fishery, industry and service industries. It also includes all actors and their interconnected roles in the whole process of technology innovation, inputs, production, storage, transportation, processing, sales, consumption and disposal, as well as the broader economic, social and natural environment[13]. The big food concept is used here to cover all foods, including plant and animal products, and other food products for human consumption. The food system makes a vital contribution to the national economy and employment, far exceeding agriculture[29,30]. Food systems should ensure food security and nutrition in an environmentally sustainable manner, and be resilient and inclusive in supporting the

livelihoods of all people.

The conceptual framework of food systems is shown in Fig. 1, which has various components, including driving factors, core relationships, constraints and goals. First, driving factors are forces that bring changes to the food system and demand new equilibrium. They include the population size and structure, changes in institutions and organizations, economic basis, climate change, extreme weather, and global markets. Second, the nexus of food, nutrition and the environment is the core of the food system. The sectors, food, nutrition and the environment, are interdependent. On one side, food provides a basis for human nutrition and affects health, and on the other, the whole food supply chain requires environmental resources and produces various wastes for the environment. Therefore, a sustainable food system needs to maximize synergies and minimize trade-offs of desired goals among the three sectors of food, nutrition and the environment. In this context, the critical food systems segment must be identified, evaluated, and managed to pursue cross-department and dynamic equilibrium. Various stakeholders are essential in food systems. The food system is beyond the food sector, covering fields from technology innovation and inputs to food consumption. The main stakeholders include farmers, firms, governments, consumers, food transporters, agricultural and food scientists and researchers. Third, the constraints of the food system are from the carrying capacity of resources, environment, ecology and climate. All the activities of the food system should be within the limit of global boundaries. Finally, the goals are the output of the food system. The food system provides a basis for achieving the national primary strategic goal of food security, nutrition, carbon peaking and neutrality, and common prosperity.

3.3.2 Goals of food system transformation

The multiple challenges and the key national strategic development goals discussed above require that the Chinese food systems urgently be transformed for achieving the following five goals (Fig. 2).

Nutrition. The food system should provide nutritional foods to everyone with a balanced diet. With the continuous increase in income, meeting of the population's demand for high-quality, nutritious, and healthy food is becoming increasingly urgent. Food systems must be transformed to improve people's diet, nutrition, and health. Increasing production of nutritious food through research and development (R&D), investment and value chain development can reduce the production cost and price and effectively improve the accessibility of residents to nutritious food[31,32].

Sustainability. Sustainability is an essential dimension of food system transformation. The food system must consider its impacts on resources and the environment, including land, water, greenhouse gas emissions and the ecosystem. Producing more environmentally-friendly and sustainable foods is needed to adapt to the limitations of resources and the environment[33]. Land and water degradation, emissions and environmental pollution must be tackled during the whole supply chain including production, transporting, processing

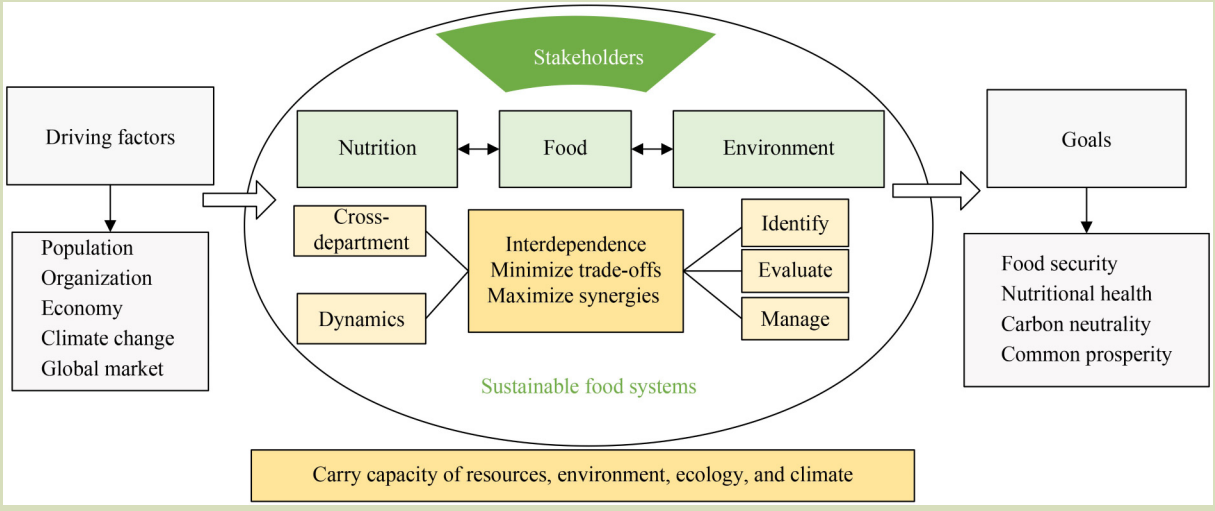

Fig. 1 Conceptual framework of food systems.

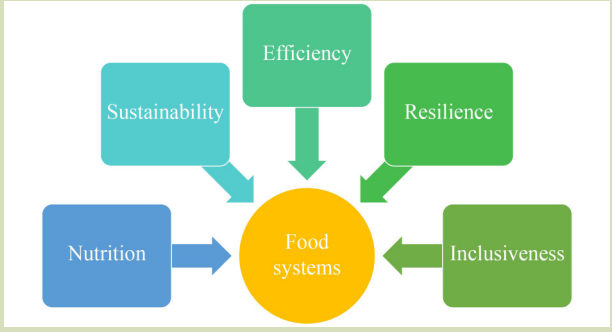

Fig. 2 Goals of food system transformation.

and input manufacturing process[34].

Efficiency. As natural and human resources are limited, food must be produced efficiently. It requires increasing the yield of crops, improving the use efficiency of inputs and energy through technology innovation (e.g., land leveling) and reducing market transactions costs (e.g., e-commerce)[35].

Resilience. China demonstrated the resilience of its food system by coping with the COVID-19 pandemic. However, the adverse impact of shocks, including natural disasters, climate change, animal and plant diseases, and other major public health events and trade uncertainties must be reduced and managed in the future.

Inclusiveness. More than a billion people are working in food systems globally. The Chinese food system also accounts for one third of total employment, including farming households and women in the general workforce. Special polices are needed to ensure that farming households, women and low-income consumers can benefit from food system transformation[13].

4 RESHAPING POLICIES, TECHNOLOGIES AND GOVERNANCE TO TRANSFORM FOOD SYSTEMS

It is clear that a systems approach must be used to tackle the emerging challenges impacting food systems. Food systems should also be transformed for achieving multiple national development goals. Therefore, changes and innovations in policies, technologies and governance should involve broader stakeholders and sectors beyond traditional food and agriculture. Reshaping policy, technology, governance, institutions and behavior will be essential to accelerating the transformation of the Chinese food system. These changes will not be linear, so certain degree of sequencing will be needed. It is noted that within each set of strategies, the design and formulation of policies and guidelines from government departments are vital to stimulate other stakeholders and should be prioritized. However, active involvement and innovation of farmers, firms, researchers and consumers are also essential.

4.1 Optimizing subsidies/supports

Subsidy and support policies could be optimized according to the big food concept to promote nutrition-oriented food production, diversify food supply and consumption, and reduce the price of nutritious food to promote balanced diets and nutritional health. Establishing a leading group across various government departments is needed to coordinate policies and investments in the national food system. In terms of policy designing, systemic approaches need to be applied to holistically analyze food production, environmental sustainability, nutrition and health as a basis for formulating significant policies. In addition, policy innovations such as taxing emission-intensive foods, investing in rural infrastructure and irrigation/drainage, providing subsidies and support to establish and expanding national disaster insurance and reinsurance systems, as well as reorienting research and development toward climate-smart food should be promoted to make the food system more resilient.

The Academy of Global Food Economics and Policy[13] explored how to reform China's agricultural support policies. Specifically, reform by increasing support to producers of nutritious food and promoting agricultural science and technology while reducing food loss, the capacity to supply nutritious and healthy food can be enhanced. As well, the structure of agricultural production support should be adjusted to the production of both nutritious and low-carbon foods, i.e., to minimize the tradeoff and maximize the synergy. Also, the expenditure structure and regional distribution of fiscal support for agriculture should be optimized to promote the goal of common prosperity. In addition, agricultural support policies should reduce distorting effects on agricultural production and trade, so the risk of agricultural trade friction can be reduced and the resilience of food systems can be improved.

4.2 Promoting multiple benefit technologies

Multiple benefit technologies, including yield-enhancing

technologies (e.g., precision agriculture), conservation technologies (regenerated agriculture), nutrition technologies (biofortification), and information and data technologies (early warning and response systems), should be supported. The integration of biological and digital technologies brings innovation breakthroughs. Innovative science and technologies such as synthetic protein and synthetic starch can be explored to improve the productivity of the whole food system. Regenerative agriculture can be used to minimize land damage, ensure soil and vegetation coverage, diversify planting and reduce the use of synthetic chemical inputs. Technology innovation can increase the production of highly nutritious food while reducing production costs, thereby increasing the accessibility of nutritious food to residents.

The adoption of ecologically-sustainable agriculture and low-carbon technologies, and R&D of breakthrough technologies in agricultural emissions reduction should be further strengthened. It specifically includes the promotion and application of slow and controlled-release fertilizers, deep fertilization machinery and compound organic-mineral fertilizers[13]. In addition, R&D in emerging green technologies such as intelligent fertilizer, transgenic technology, gene-editing technology, and biological carbon sequestration technology should be substantially expanded.

These multiple benefit technologies need financial support. Thus, future R&D should be directed to the new trends in international agricultural and food science and technology, such as advanced breeding, precision agriculture and digitalization, protein alternatives, sustainable packing and food waste reduction[36]. R&D spending should target both staple grains and the more nutritious non-staple grains (rich in minerals and vitamins), as well as fruit and vegetables. The stable supply of major staple crops and meat is currently the core objective of China's food security policy. However, as people have recently begun to over-consume these foodstuffs, R&D should be redirected to also include other more nutritious foods to improve production and reduce prices to achieve a more balanced diet.

4.3 Reorienting investment and finance

China needs to create a favorable financing environment for food security, environment, inclusiveness and resilience. Reorienting funding is an important step that helps ensure continuous food security in the country and achieve a healthy and sustainable food future.

First, ensuring food security needs increased agricultural and rural investment to enhance production capacity. China has introduced an investment program to promote high-standard farmland construction. These programs could be further improved to achieve multiple goals of food systems, including food security, nutrition, protection of natural resources and carbon emission reduction beyond grain security. Second, it is necessary to increase investment in restoring natural resources (e.g., land and water) and realizing sustainable food production. It calls for increasing investment in protection of land, water and other resources, strengthening the construction and enforcement of the agricultural environment, promoting the management of natural resources, and protecting the ecological environment[37]. Upgrading the agricultural production mode to circular and renewable agriculture and strengthening the agricultural ecological system is significant[23]. Third, funding reorientation should consider inclusiveness for the better livelihood of small stakeholders. The development of e-commerce has effectively boosted the connection between small farmers and the wider market. It has become essential for small farmers to share the rapidly growing demand of the big market. Therefore, increasing investment in e-commerce can benefit small farmers and small agribusinesses. Finally, resilience to risks and shocks is a significant dimension of food systems. It is necessary to reposition investment to integrate technologies with risk-informed and shock-responsive social protection systems by enhancing risk management and early response capacities to shocks and crises.

While ensuring government investment in food system transformation, China should also introduce a more diversified investment and finance strategy, and encourage more private investment in the sector. China's overall finance system can be strengthened by providing incentives for private sector innovation through financial support and tax incentives, especially for agritech startups. In addition, through financial support and improved investment, market entities should be incentivized to participate actively in food system transformation.

4.4 Guiding behavior changes

Internationally-recognized healthy dietary patterns, such as EAT Lancet diet, Mediterranean diet, and more plant-based diets, are not only beneficial to health but also reduce non-communicable diseases and mortality, as well as reduce greenhouse gas emissions[38–40]. Therefore, healthy diets should be promoted and nutrition-related diseases prevented through improved dietary guidance and nutrition education; to that end, nutrition knowledge classes should be conducted in

rural and urban areas. Environmental sustainability should also be incorporated into national diet nutrition programmatic and guidance documents such as the Chinese Dietary Guidelines, Guidelines for Food and Nutrition Development in China, National Nutrition Program, and Healthy China Initiative.

There is a need to avoid excessive meat intake for a balanced diet recommended by the dietary program. The demand side can drive the transformation of the food system toward nutritional health and environmental sustainability, and reduce the pressure of farming on resources, the environment and greenhouse gas emissions. It demands providing healthy diet knowledge in public education and implementing dietary nutrition interventions in critical geographic areas and targeted populations to reverse the rapid increase in overweight/obesity. Changing diets and reducing food loss and waste can achieve low-carbon sustainable food system development.

A dietary guidance initiative could center on developing a national program for encouraging a healthy and sustainable diet under China's recommended dietary guidelines[41]. This could be achieved by the following measures. (1) Developing a national nutrition guideline for the Chinese people that meets health requirements and sustainability requirements. (2) Strengthening awareness messaging, including package labeling, food marketing and laws. (3) Linking a healthier diet with a sustainable production scheme aimed at increasing the production of fresh fruit and vegetables by Chinese family farmers and increasing access to fresh fruits and vegetables by Chinese consumers. (4) Expanding the national Clean Plate Initiative to tackle food waste (and associated plastic waste) at retail (including the shopping environment), food service (including e-commerce), and household levels. (5) Promoting alternatives to animal protein, particularly from beef, including synthetic meat and plant-based processed protein-rich meals.

4.5 Enhancing global cooperation

Global governance mechanisms and institutional coordination capacity need to be enhanced to match the increased scope of global action required to address and respond to risks and threats in food systems. The UN Food Systems Summit in 2021 was an excellent start to addressing global food security issues through global cooperation. However, most importantly, the bold new actions launched by this summit rely on actions of committed countries. A scientific platform for the food system, similar to the Intergovernmental Panel on Climate Change, should be established to provide the basis for the transformation of the food system at the global and national levels, act as a platform for meaningful dialog, and provide evidence-based advice for different stakeholders, facilitating decision-making.

The global community should jointly improve food production capacity, prioritize food and agriculture, increase investment in agriculture and rural areas, accelerate scientific and technological progress, improve infrastructure, promote green transformation and sustainably expand the food supply. This calls to stabilize the food supply chain, actively promote trade liberalization and investment facilitation, eliminate unreasonable trade restrictions, reduce food loss and waste, and build an efficient, open and fair global food system. For example, recent discussions at the G20 have focused on food systems. In the Agriculture Working Group on the Agriculture of the G20, the three priority issues discussed were: (1) building a resilient and sustainable food and agriculture system; (2) promoting an open, fair, predictable, and transparent food trade; and (3) encouraging innovative agricultural businesses through agriculture digital technology.

Global food and agriculture governance must be improved, giving full recognition to the role of the United Nations and deepening multiple partite cooperation within developing countries and between low/middle-income countries and high-income countries. It includes increasing financial and technical support for developing countries and promoting the establishment of a more efficient and rational global governance of the food systems. For example, the European Union and the Food and Agriculture Organization of the United Nations cooperate closely on agriculture, fisheries, forestry, biodiversity, food security, food crises and food safety to transform food systems. Strengthening international cooperation can improve food security in China and the world.

To facilitate changes and to reshape policies, technologies, governance and behavior proposed and discussed above, evident-based research is critically needed. They include designing indicators to measure and track performance, collecting and analyzing data sets from various sources, innovating relevant theories, approaches, and instruments to evaluate policies and programs, and other scientific endeavors.

5 CONCLUSIONS AND RECOMMENDATIONS

After decades of development, China's food security and nutritional status have improved substantially. However, the Chinese food system faces multiple challenges, including the double burden of malnutrition, climate change, resource stress

and environmental degradation and increasing global market risks. This paper has discussed the four-stage evolution of the Chinese food system, reviewed both challenges and development goals, and provided policy recommendations for transforming the food system in China through a systematic approach.

Through the four-stage evolution, the focus of food systems in China has shifted over time. First, before the 1980s, enhancing grain production was the top priority. Second, in the 1980s and 1990s, the food system began to evolve into non-grain food security to meet increasing demands such as vegetables, fruit, meat and eggs. Third, since the beginning of the 21 century, mitigation of agricultural pollution on land and water was attached importance. Finally, after joining the WTO, ensuring and enhancing farmer income has become crucial.

Entering a new stage of development, China has proposed higher development goals; these include Healthy China 2030, Rural Revitalization, Ecological Civilization, Common Prosperity and Carbon Neutrality. The food system is fundamental to achieving these primary national strategic development goals. However, China's food system faces emerging multiple challenges, such as malnutrition, resource depletion, environmental degradation, unbalanced urban and rural development, and an unstable international market. Therefore, addressing the challenges and achieving future goals requires a systematic approach to transforming the Chinese food system.

The transformation of the Chinese food system needs the collaboration of multiple stakeholders and broad cooperation domestically and globally. This study proposes pathways to promote the food system transformation in China. First, reposition subsidies/supports toward environmentally providing nutritious foods. Second, promote multiple benefit technologies through reforming the R&D system and enhancing the adoption of these technologies. Third, reorient investment and finance in both public and private sectors to achieve a healthy and sustainable food future. Fourth, guide behavior changes among consumers toward a sustainable and healthy diet. Finally, catalyze global cooperation on food security is critical to ensure Chinese national food security and a stabilized global food market.

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Compliance with ethics guidelines

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