CHAPTER 3

From Food Availability to Nutrition and Sustainable Food Systems

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Abstract

There has been a major transition of focus from calorie-dense food to nutrition security. However, this transition is not merely a shift in production priorities but reflects a broader transformation in global food systems governance and sustainability thinking. Merely increasing the production of yield to nutrient rich foods is now the objective by optimizing food systems that are not only sustainable but also environmentally friendly. This shift is prompted by the rising burden of both forms of malnutrition and non-communicable diseases, and global warming. Global warming and malnutrition both exert long- and short-term consequences. There is a dire need for sustainable multisectoral approaches that prioritize diet quality, nutrient-rich foods, climate health, and quality of life. Recent evidence also emphasizes the integration of climate-resilient agriculture, dietary transition policies, and food systems governance frameworks to address these interconnected challenges. Establishing sustainable dietary guidelines, eliminating subsidies for commodity crops, and adding cost to the foods with high environmental degradation will ultimately benefit the environment and reduce the risk of non-communicable diseases among the people. Changes in public policy that have double- or triple-duty actions that target all forms of malnutrition and climate need to be addressed. Climate change mitigation must be prioritized within national and global agendas. This chapter explores the opportunities, pathways, and challenges towards sustainable food systems using a systems-based analytical perspective.

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1. Food availability and nutritional security

Recently, emerging nations have experienced significantly faster growth than industrialized countries. The convergence of growth may have significant consequences for global food consumption and agriculture due to the rising need for agricultural resources as diets transition from starchy staples, as well as for our capacity to meet the sustainable goals. From a political economy perspective, these shifts also reflect structural inequalities in global food systems and uneven access to productive resources. The primary objectives of Sustainable Development include eradicating poverty and hunger, fostering inclusive economic growth, and diminishing inequality both within and across nations, which are strongly related to the issues of convergence and food demand. Researchers determined that the predominant characteristic of economic growth during the 19th century has been 'income divergence, significantly,' with initially less affluent countries seeing markedly slower growth than their more developed counterparts (Fukase and Martin, 2020).

This divergence continues to influence present-day disparities in food availability, nutrition outcomes, and agricultural productivity. Food access is the process of acquiring specific commodities (urban-produced) and encompasses educational, cultural, geographic, and economic dimensions. It is closely associated with the term food safety. In the food access literature, researchers identify challenges and opportunities for the expansion of healthful food access in low-income communities, with a particular emphasis on the utilization of urban-produced foods. Food access is therefore not only a logistical issue but also a structural outcome of governance, income distribution, and market systems. It is crucial to consolidate the literature on the production, access to, and utilization of urban-produced commodities in order to identify the effective strategies that urban farms implement to address the food access requirements of urban communities (Siegner *et al.*, 2018).

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Food and nutritional insecurity persistently impact society in both rich and developing nations, even during years of abundant harvests. This evidence affirms that the availability of food does not inherently equate to food safety and nutritional security. At times, food is abundant and available, but it is unacceptable or unsustainable. All such circumstances represent possible food and, particularly, nutritional vulnerability. Availability is characterized by researchers as the tangible presence of accessible food, whether sourced from personal agricultural production or acquired from external markets. National food availability includes commercial production, home production, food imports, foreign donations, and domestic food reserves. Food availability predominantly pertains to the accessibility of food at the household or regional levels (Riely *et al.*, 1999). The terms of food security and nutrition recognize that nutrition is an important part of food security, but it keeps the usual focus on food availability, stability, and access. Food and nutrition security stresses combine nutrition and food security in policies, programs, and studies (El Bilali *et al.*, 2019). However, the conceptual overlap between food security and nutrition security often leads to policy fragmentation, which this chapter addresses in later sections**.**

2. Determinants of food availability

Food supply depends on how much food is farmed or cultivated in a local area, how much food is exchanged in that area's markets, how much food is stored by traders or the government, and how much food is distributed by the government or other groups. So, the amount of food that is available in an area is closely related to how easy it is to grow food and how many places there are to buy food, including markets and food supply facilities. Some of these essential considerations are price, flavor, regional customs, and how easy it is to get.

Table 3.1. Determinants of Food Availability.

Factor	Description	Example
Agricultural production	Crop yield, farming systems	Rice and wheat production
Market access	Transportation	Rural and urban markets
Imports/exports	Trade policies	Food imports
Storage Government reserves	Government reserves	Grain silos

A person's socioeconomic status and how simple it is for them to access food also affect the kinds of foods they buy and the nutrients they get. People's choices have a direct impact on nutrition and sustainability. The amount of money people have and the kinds and amounts of food that are available also have an effect on these things (Cohen and Lucero Prisno, 2025).

Figure 3.1. Key Determinants of Food Availability

2.1 Agricultural production systems

Around the world, agricultural production systems are facing big problems, such as climate change, a lack of water for irrigation, rising production costs, and a general drop in farm labor over the last few decades.

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Anyway, the most recent problem, the COVID-19 pandemic, could make it hard for everyone to grow and give food. These things put at risk the economic and natural stability of food supply systems now and in the future. Thanks to progress in science, we now have a better idea of how different parts of agriculture work together, from the level of the cell to the level of the land. Genetic tools have come a long way in the last few decades, but until recently, we didn't have a good way to accurately check large groups of crops in the field. New technologies like remote tracking and AI can make agricultural systems more resilient. We will also create a unique chance to create the tools needed to solve the next ten years' worth of food and farming problems (Jung *et al.*, 2021).

2.2 Role of fisheries, livestock, and crop sectors

In the last 50 years, the main sources of food around the world have changed from grains to animal protein. This has led to a huge rise in livestock and fish production, but it also makes energy use more efficient. Proteins, vitamins, and micronutrients that aren't found in as large amounts or types of crops or other animal goods can be found in fish and shellfish. With the world's population growing quickly, it's hard for global agriculture to produce enough food to meet rising demand while also dealing with climate change. In the past 70 years, modernization, industrialization, and mechanization in agriculture have put a lot more pressure on land used for farming. This has made environmental issues worse. Using an integrated crop and livestock system on a farm can help farmers make a lot of money and provide a wide range of food for their families if it is handled correctly. ICLS can change the variety of foods that people eat, help small-scale subsistence farms make more money, and lower economic risks (Sekaran *et al.*, 2021).

2.3 Impact of Climate change on food supply

Food production systems are now facing more hurdles because of climate change, limited land and water, and most recently, a pandemic. Developing countries' farming systems are at greater risk because of global warming. To make the agricultural system more resistant to changing weather, adaptation steps and the use of new technologies need to be practiced. Even though there are agricultural methods that can help farmers adapt to climate change, the institutions that can put these technical solutions into action and spread the word about them need to be strengthened. To make the necessary institutional changes, get the money to spend on these changes, and come up with dynamic policies for lifetime climate variation modification in related fields (Aryal *et al.*, 2020).

Table 3.2. Impact of Climate Change on Food Security (Wijerathna-Yapa and Pathirana, 2022).

Sr. No	Climate Factor	Important Changes	Impact on Food Production
1	Increase in temperature	Heat waves increase the temperature beyond the normal range	Reduced the yield of crops like wheat and maize
2	Irregular Rainfall	A change in pattern causes floods and drought in the environment	Disturbance in planting cycles causes lower production
3	Drought	Water scarcity	Crop production is lower due to a shortage of water resources
4	Global Warming	Carbon dioxide levels increase in the atmosphere	Temperature increases due to carbon dioxide. High temperature damages protein structure and lowers crop production
5	Pest production	The environment favors the growth of pathogens.	Pesticides demand increases

2.4 Post-harvest losses and food wastage

A very important part of farming is post-harvest management, which includes several tasks and practices that are meant to keep and improve the quality and worth of crops that have been harvested from the fields. As the number of people grows, so does the demand for fresh-cut fruits and veggies. At the same time, popular vegetables are available all year round the world. This means that post-harvest losses, which can be big, need to be kept to a minimum in a world with complicated markets and supply lines. When sweet corn is picked before it's physiologically mature, the seed has a lot of water and sugar in it. This makes it very

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perishable fresh food that needs to be handled properly after harvest to keep it fresh and prevent loss of quality. The most important things to keep are the taste, smell, and color, since those are the things that customers like the most. Loss of sweetness and dryness are two of the problems that can happen to sweet corn after it has been picked. Implementing effective post-harvest methods not only protects farmers' hard work but also makes a big difference in lowering hunger and malnutrition (Nishad *et al.*, 2024).

3. Determinants of Food Access and Utilization

3.1 Socio-economic determinants of food access

Since each region in a country has its own culture and socioeconomic position, putting all of those differences into one region may lead to mistakes and wrong results, which is what most studies do. People from racial and ethnic minority groups and lower socioeconomic class (SES) are more likely to not have enough food, live in places that don't have enough food resources, and continue to have the most diet-related chronic diseases. It's hard for about 13.5 million people in the US to get to big grocery stores, which means they can't get fresh food. A recent longitudinal study found that a better diet was linked to being close to and having a lot of food shops, as well as to having a high-socioeconomic status (SES) in the neighborhood and thinking that the area had healthy food options. These links were stronger in racial and ethnic minority groups (Odoms-Young *et al.*, 2024)

3.2 Household food distribution

Household food insecurity is becoming increasingly recognized as a global health issue, particularly in Sub-Saharan Africa. The imperative necessity of addressing food insecurity in order to achieve human rights by 2030 has been underscored by the Sustainable Development Goals (SDGs). The primary objective is to end poverty in all its forms, while the secondary objective is to remove hunger and achieve food security. Food security is achieved when all individuals have constant physical and economic access to a sufficient amount of safe, nutritious food for a healthy existence (Drammeh *et al.*, 2019).

Figure 3.2. Key Determinants of Food Access and Utilization

3.3 Cultural and behavioral factors

People of a certain area or social group eat in a certain way. Cultural dietary routine includes the things they eat and the way they think about food. Material factors include methods for growing, transporting, and distributing food; money; place and time to prepare meals. Kids learn how to handle food by watching their parents do it. Mealtime schedules, where and when to eat (at the table, with other people, etc.), and how to eat (e.g., proper eating habits and enjoying food) are all taught by social groups like families, schools, and peers. The same experiences that shape learning also shape how people think about and feel about food and eating. This passing on is one reason why food practices have stayed mostly the same over time. When immigrants are introduced to new foods and different ways of cooking and getting food, their cultural food habits change. This is called acculturation (Monterrosa *et al.*, 2020).

4. Food safety and quality considerations

Quality of food is simply how well the natural qualities of a food product or service meet customer needs. It is a changing part of food that determines how important or acceptable it is to customers. The scientific idea of food safety is talked about under the heading of food quality. This section goes into detail about how to handle, prepare, distribute, and store food so that it doesn't get contaminated and people don't get sick. As a matter of public health, it's growing more important. There is a difference between food quality and food safety. Food safety is about making sure that safe food is eaten by everyone. Both of these ideas require that food be made that is safe and healthy for people to eat. Because food quality and safety are so important, major focuses on different quality systems and food safety management systems, how they get approved according to the latest standards, and the requirements that need third-party checks (Farooq *et al.*, 2021).

5. Food Security to Nutritional Security

Food and nutrition security (FNS) does not always mean that food is available. Even if food is available, it might not be easy for everyone who needs it to get it. Also, food that is available and easy to get might not always have all the nutrients the body needs to grow, develop, fight off sicknesses, and meet its normal physiological needs. Food is sometimes easy to get and plenty, but it's not always good or viable. Food and nutrition security can only be reached when everyone has the physical and financial means to get enough healthy food to meet their dietary needs and make healthy lifestyle decisions (Simelane and Worth, 2020).

Table 3.3. Comparison of Food Security and Nutrition Security

Parameter	Food Security	Nutritional Security
Definition	Food access to sufficient quantities	Accessibility to adequate food fulfilling nutritional requirements
Area of focus	Food quantity Quantity of food	Quality and nutritional aspects of food
Key Concern	Food scarcity and hunger	Malnutrition and micronutrient deficiencies
Objective	To make sure people are not hungry	People are well nourished and nutritionally secure
Example	Availability of enough staple food (wheat or rice)	Access to a balanced diet with macro and micronutrients
Indicators	Food supply, food prices, and income	Nutritional status (Body mass index, stunting, wasting, etc.)

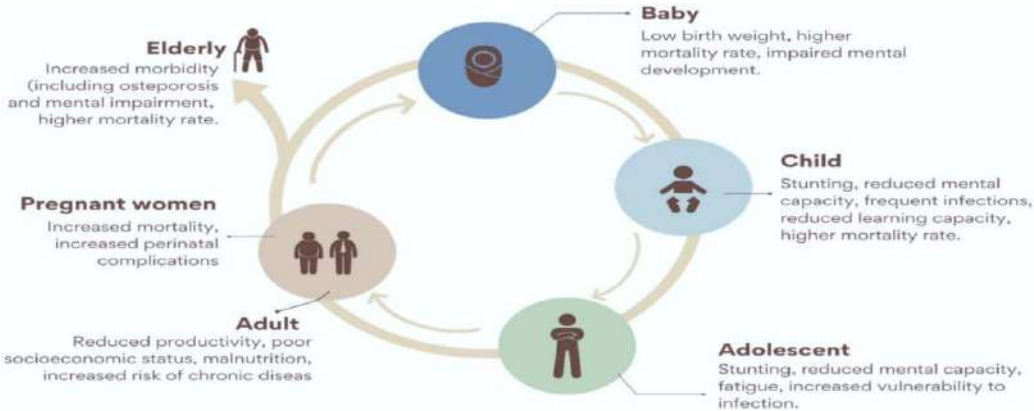

Figure 3.3. Effects of Nutrient Deficiency through the Developmental Cycle (Ofori *et al.*, 2022)

The most important parts of a good diet are macronutrients and micronutrients. Protein, carbs, fats, vitamins, and minerals must be in the right amounts for a healthy body. Different people have different daily needs because of their age, gender, weight, level of exercise, and overall health. Micronutrients are things that the

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body needs, like vitamins and minerals. They do more than one thing and often work better together. Macronutrients are made up of carbs, fats, and proteins, and they make up most of the body's soft tissues. Macronutrients, which are made up of fat, protein, and carbs, give you energy and important building blocks for your body. Micronutrients are needed to keep this process of building and rebuilding going repeatedly. Because of this, each person's micronutrient needs will be different because of their different biochemical states at different times in their life. High demand for tiny nutrients is vital during conception. If there isn't enough of them, it could affect physical and even cognitive growth (Gush *et al.*, 2021).

Malnutrition is defined by the absence of micronutrients, which leads to undernutrition and obesity, particularly in adolescents. Hidden hunger is the insidious and clinically undetectable absence of micronutrients. Healthy eating is one of the recommended actions in caregiving, which includes the prevention of nutritional deficiencies. According to data from the Food and Agriculture Organization (FAO), 852 million individuals in developing countries experienced chronic starvation in 2005. Hunger affected 16.4% of the Caribbean population, 8.4% of the population in Mesoamerica, and 7.9% of the population in South America between 2019 and 2021. Researchers estimated that over 2 billion individuals across the globe are at risk of experiencing micronutrient deficiencies. Over one billion individuals suffer from micronutrient deficiencies, which manifest as anemia, vitamin A deficiency, or even cognitive impairment, as a consequence of nutritional deficiencies that began during childhood (Weffort and Lamounier, 2024).

5.1 Dietary diversity and balanced nutrition

Diversity in food consumption is a general measure of food consumption that shows how easy it is for households to get different kinds of food and how good the food that is eaten is. Eating a variety of foods is thought to provide all the essential nutrients, but it is important to check one's nutritional status. Toddlers and kids younger than five years old have problems with eating every day because they aren't getting enough food. Not getting enough of certain nutrients because of limited food choices has been linked to low birth weight, under-nutrition, starvation, stunting, and other nutrition issues. Therefore, steps need to be taken to ensure a healthy diet that provides food and nutrition security for everyone in a way that doesn't hurt future generations (Ardianti *et al.*, 2021).

5.2 Public health implications

Metabolic diseases have risen significantly over the past two decades. Diabetes, heart disease, and hypertension are among the most common disorders. Sedentary lifestyle and high-fat diet are the common but modifiable risk factors. Another common disease, such as severe periodontitis, is the sixth most common disease and affects about 11.2% of the world's adult population. This makes it a big problem for healthcare, society, and the economy. New scientific findings explain the links between periodontitis and other diseases (Genco and Sanz, 2020). People of all ages around the world often don't get enough sleep. This is seen as a public health epidemic that isn't fully noticed or reported, and it costs a lot more money. Not getting enough sleep can interfere with the body's normal processes, which can lead to heart disease, diabetes, obesity, and other neural problems. The problem is getting worse because more people are using smartphones and other electronics (Chattu *et al.*, 2018). Since the 1990s, globally, the economy and people's habits have changed. At the same time, the prevalence of obesity has risen. According to Chinese standards, about half of adults and one-fifth of children are overweight or obese. China is in a good position to look for a way to deal with the obesity problem. But the national and local governments need to be very committed and take the lead. All relevant parts of society and individual citizens also need to be involved (Wang *et al.*, 2021).

6. Sustainable Food Systems

A sustainable food system is one that fulfills current food needs with healthy food while maintaining healthy ecosystems that can also provide food for future generations. Sustainable Development Goals (SDGs) are a set of global goals aimed at making the future sustainable for future generations. Note that changing food systems is very important because the way they work now can't last forever. Sustainability is now a main goal and a guiding concept for human progress. Concerns around the world include environmental damage, social unrest, and changes in the economy. These issues are challenging traditional ideas about growth and

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making us rethink how we act every day. Food technology and governmental science are both important parts of making the transition to a sustainable food system easier (Hariyadi, 2024).

6.1 Environmental sustainability

There are two reasons why the food we consume today is unsustainable: the food system is depleting non-renewable resources and causing unacceptable environmental damage. Our food is classified as residual food due to its dependence on fossil fuels, non-renewable mineral resources, the depletion of groundwater reserves, and the excessive loss of soil. Global endeavors to regulate and manage the human food supply are fundamentally rooted in the concept of sustainable food systems. Eco-friendly development is the conservation and waste management of the natural resource base, and an assessment of improvements in technology and institutions in such a manner as to ensure the achievement and uninterrupted satisfaction of human needs for all future generations. It also conserves land, water, plant, and animal genetic resources. Modifications require the use of internet technology, specifically in the form of food from the internet. This technology provides the opportunity to more effectively utilize international resources, to establish systems of resilience, and to promote responsible governance through education and trade, which are not constrained by knowledge and access (Holden *et al.*, 2018).

6.2 Climate-resilient agriculture

Climate Resilient Agriculture for Achieving Food Security fully tackles critical aspects of climate-vulnerable agriculture for food security through the implementation of mitigation and adaptation approaches. The issue of future food safety is likely to be exacerbated by the pressure on agriculture that climate change and increasing variability will exert. Structure of the atmosphere gas has undergone substantial changes over the past few decades, primarily due to higher greenhouse gas emissions from industry, and agricultural farms, as well as deforestation and methods of land management. To enhance food security and adapt to changing weather and natural resource pressures, agriculture and food systems must also contribute to climate change mitigation. Climate-resilient agriculture is a sustainable approach to increasing agricultural productivity and incomes, adapting and constructing resilience to climate change, and reducing emissions of greenhouse gas (Meena *et al.*, 2026).

6.3 Integrated aquaculture and livestock systems

Integrated farming systems are an acceptable choice for strengthening sustainability in the face of environmental pollution, climate change, and soil degradation. The multidimensional effects of these various forms of environmental destruction of the environment deform the foundation of agricultural production.

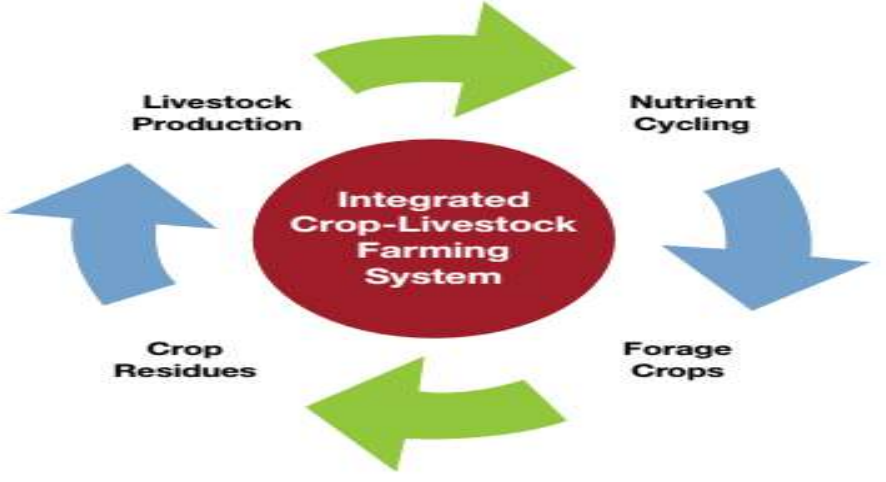

Figure 3.4. Integrated Farming System including Crops, Livestock, and Nutrient Cycling.

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The socio-ecological capacities of farmers to sustain their livelihoods are improved by the integrated agricultural systems strategy. Consequently, the most advanced approach of environmentally friendly agriculture is farm management systems, which depend on the integration of key components of agriculture, including crops, livestock, and aquaculture. The mixed system of livestock management provides a variety of advantages and a more effective response to climate change by enhancing the production of crops and livestock and reducing greenhouse gas emissions. Modification levels are broadly categorized as food-based, DNA-management, and the use of communication technology (Bhattacharyya *et al.*, 2020).

6.4 Resource-efficient food production

The food and beverage industry is currently highly inefficient due to the significant amount of food scraps it produces, as well as the significant amounts of water and energy it consumes. This issue is further exacerbated by the tightening of regulations regarding the treatment and elimination of food waste, greenhouse gas emissions, and wastewater discharge, as well as the increased economic costs. Consequently, resource efficiency is essential for the development of a sustainable food system. It is imperative to implement transparent and precise real-time monitoring to mitigate food waste, energy consumption, and water consumption in order to comprehend the genuine causes of their generation and utilization. These factors would facilitate the innovation of food production mechanisms and the attainment of operational enhancements. Smart items like the Internet of Things, a relatively new manufacturing concept within Industry. :The performance of production systems can be significantly impacted by the information technology infrastructure (Jagtap, 2019).

6.5 Circular economy in food systems

The circular economic system replaces the concept of end-of-life. Its major objective is to replace the prevailing model of linear economics. This model involves the extraction of raw materials from the environment and their processing into final products. These products are intended for a single purpose and have a short lifespan. The concept of the circular economy is to minimize the environmental impact of these products by extending their life cycle. It operates at different levels for achieving balanced development. Industrial systems should follow the idea of a zero-waste economy (Hamam *et al.*, 2021).

Figure 3.5. Integrated Framework for Sustainable Food Systems

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7. Food Systems Approaches

7.1 Components of food systems

Food systems comprise the individuals and activities that are responsible for the production, transportation, supply, and consumption of food. The food supply chain encompasses the following stages: agricultural production, transportation and distribution, manufacturing, packaging, and retail. The activities within the food supply chain are intricately linked to one another. Ecosystem services and feedback mechanisms are influenced by drivers that regulate food system operations. A balanced food system is the ability of a system and its components to function at different levels to provide sufficient and reachable food to all. Complex food systems are necessary to prevent disruptions and to develop the adaptive capacity to adapt to the changes in the operating environment, which is characterized by multidimensional changes (Rimhanen *et al.*, 2023).

7.2 Food production, processing, distribution, and consumption

An integrated strategy balances optimal production with changes in food utilization. It is necessary to establish balanced food systems. Main points for enhancing the food resilience of an area that seeks to increase its efficiency: (i) Enhancing technical solutions, (ii) Increasing community engagement, (iii) Enhancing agricultural variety, and (iv) Implementation of an integrated system in food planning. The interests of stakeholders in the food chain must be coordinated in order to ensure the sustainability of the consumption and production areas (Menconi *et al.*, 2022).

7.3 Role of technology in food systems

Sustainable food systems need new and advanced technologies. These technologies can help us find answers to some of the most important questions we need to ask in order to change SFSs and learn more about world food safety and nutrition protection. New technologies have an effect on how SFSs change. Some innovations include better ways to use farming land, process food, make production systems work better, change people's diets to fit their needs, and deal with waste. What are some new technologies being used in digital agriculture? The Internet of Things (IoT) is AI and machine learning devices like drones, self-driving cars, and advanced materials like gene technology. Right incentives, rules, and social permits are very important for getting more people to use current technologies to support the sustainable food systems (Khan *et al.*, 2021).

7.4 Urbanization and changing food patterns

Africa's food and environmental systems are being greatly affected by rapid urbanization. As cities grow, agricultural or natural lands may be taken over, and these could diminish food production and biodiversity. Land-use displacement effects can either make up for lost agricultural production or cause even more biodiversity loss. Changing lifestyles, jobs, and incomes in cities are quickly affecting people's food choices and supply, such as the modernization of food systems and environments (de Vos *et al.*, 2024).

8. Role of Policy and Governance

8.1 National and international food policies

The world has a lot of people who don't have enough food, and hunger and malnutrition are still going to be big problems, especially in developing countries with low incomes. It is expected that the effects of environmental change will be especially hard on agriculture in those countries over the next 30 years. International markets are used for trading basic agricultural goods in the future. Countries with free trade policies can use their comparative advantages in the economy to boost average per capita incomes, long-term growth rates, and their ability to pay for social safety nets for the poor. So, the challenge for policymakers is to find a balance between the best lifetime policies and temporary efforts to improve food security (Smith and Glauber, 2020).

8.2 Institutional frameworks

Theoretical frameworks of food system governance may make complicated things easier to understand, but they might not take into account things that happen outside of their frameworks or the practical issues that

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affect actual governance efforts. Frameworks include different food networks, bioregions, and food sheds. They also use examples from real-life experiences to show what practical factors are used in these kinds of initiatives. It comes to the following conclusions: a) localized complaints shape how governments act; b) globalization and localization don't have to be separate; and c) different points of view are important, but markets are necessary for food systems (Arthur *et al.*, 2022).

8.3 Nutrition-sensitive agriculture

There are major nutrition problems in almost every country in the world today, 70 years after the end of the last major war. Nutrition is seen as both a part of and a result of sustainable development. Food production is also an important part of this. Nutrition-sensitive agriculture (NSA) programs have sprung up to support things like changing crops, teaching people about nutrition, and giving women more power. A lot of research has been done on whether or not NSA programs affect nutrition indicators. But not as much research has been done on whether or not these programs are fair in terms of distribution, process, and recognition (Nichols, 2020).

8.4 Food system transformation strategies

Food system transformation needs scientific understanding and analysis of the interactions between system components. The objectives of food systems challenge socio-political policies. Different systems emphasize specific types of interventions for achieving system change. They argue that food systems are best viewed as multi-directional systems. Based on these insights, researchers have identified critical governance strategies and principles employed to affect the variation of the food system as a long-term and non-linear process of negotiation, reconfiguration, and competition. Governance interventions need a significant reorientation of investments in the dairy system, and a reevaluation of the role of policymakers in either modifying or perpetuating undesirable systemic outcomes (Leeuwis *et al.*, 2021).

9. Emerging Innovations

9.1 Biofortification

Micronutrient insufficiency causes a serious and difficult problem. Biofortification is seen as an effective and long-term way to deal with this problem because it manages nutrients. Biofortification uses many different methods, including agronomic practices (like adding minerals or microbes) and molecular and genetic engineering techniques, along with traditional plant breeding. All of these methods add important nutrients to plants, like provitamin A, vitamin C, iron, zinc, calcium, iodine, and selenium, while lowering harmful substances and trypsin inhibitors in basic foods (Labuschagne, 2023).

Figure 3.6. Importance of Biofortification in the Food Chain (Walsh *et al.*, 2025).

9.2 Green nanotechnology in food production

Nanotechnology has led to a lot of research in the last few decades, especially in engineering, biotechnology, food technology, medical sciences, and agriculture. The bulk material is broken up into tiny particles with one or more dimensions in the nanometer range or even smaller. These particles have surprising properties that are different from those of the bulk material. Nanomaterials have unique properties that make plants more resistant to disease, help find mycotoxins in food, make better use of nutrients, and boost plant growth. Bio-Nanotechnology uses biological ideas along with chemical and physical methods to create very small particles that have specific jobs to do. This is also a cheaper alternative to using chemicals or physical methods to make nanoparticles. Nanotechnology is a new technology that is getting a lot of attention in the food system because it can help with processing, safety, and packaging food. Nanotechnology can be used in food production to improve the overall quality of food, such as its taste, flavor, and bioavailability (Mohammad *et al.*, 2022).

9.3 Precision agriculture

Precision agriculture (PA) uses computers to better manage the production of crops and animals. It is seen as another way to improve food privacy around the world. Precision agriculture (PA) to boost output, make better use of resources like water, feed, and labor, pesticides, and fertilizers, make production more stable, and lower the damage that farming does to the environment. PA, on the other hand, can look very different depending on the type of crops and animals raised, the size of the farm, how it is managed, how easy it is for the farm to get technical help, and the age and education level of the operator (Erickson and Fausti, 2021).

9.4 Smart aquaculture and fisheries management

The world is facing labor shortages in agriculture because young adults aren't working enough, and the agricultural population is getting older. This will have an effect on aquaculture production. Aquaculture farming has some problems that can be fixed by creating a smart aquaculture-based fish tracking and control system with various smart devices that can collect data in real time. This way, the quality of the water in fishponds and other system parameters can be easily checked, changed, and evaluated from afar. AIoT-based aquaculture systems can check the water quality and microclimate at the same time. Another thing that an AIoT system can do is collect data from sensors and feed data that can help make aquaculture more accurate and smarter. Smart aquaculture cuts down on work, keeps water quality stable, saves energy, and makes sure fish are fed correctly (Chiu *et al.*, 2022).

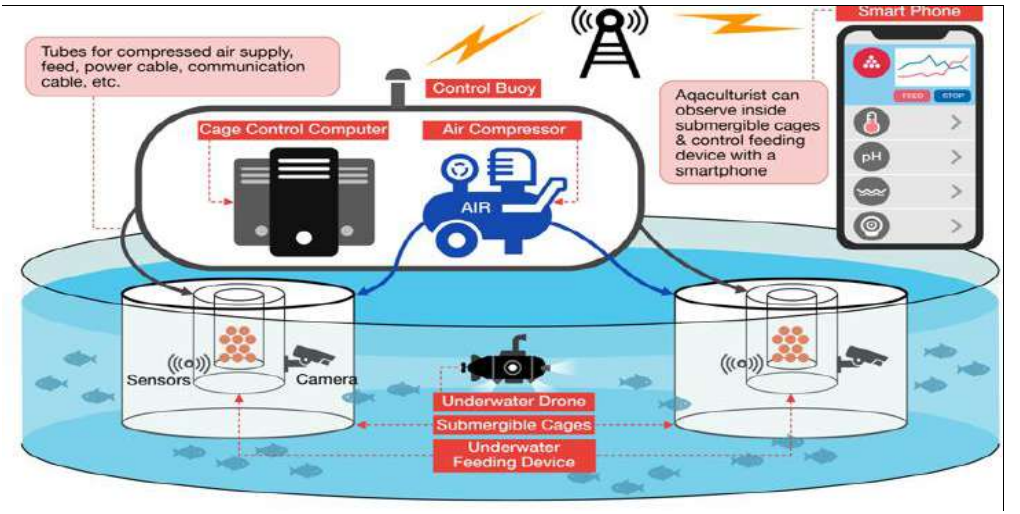

Figure 3.7. Smart Aquaculture System (Vo *et al.*, 2021).

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10. Challenges and Future Perspectives

10.1 Population growth

A significant obstacle to the attainment of global food safety is the consistent growth of the global population, which is projected to reach nine billion individuals by 2050. Consequently, it is imperative to urgently address the necessity of feeding an expanding international population and adequately addressing the consequences of climate change. The application of molecular and genetic mechanisms to the development and/or enhancement of agricultural and industrial processes may facilitate progress. Food security is the foundation of any nation. The major target of the food system is to accommodate a rapidly expanding population and to facilitate urbanization. Nevertheless, a billion individuals worldwide endure chronic hunger daily. Individuals should have access to sufficient quantities and quality of food at reasonable prices to ensure they can live without hunger and eliminate malnutrition by providing food and nutritional security from a human life cycle perspective. Additionally, scientists are exploring methods to repurpose agricultural and food waste in the emerging market (Ghosh *et al.*, 2024).

10.2 Climate variability

It is expected that atmospheric change will have a huge impact on food systems all over the world, often in ways that make existing weaknesses and unfairness worse between societies and regions of the world. The good news is that there are already a lot of practices, technologies, knowledge bases, and social networks that can help us deal with climate change positively. These include ways to both reduce its effects and adapt to them, as well as ways to make these efforts work better together and help other important goals, like protecting biodiversity and other ecosystem services. Because of this, food systems should and can be a bigger part of climate policies. Short-term, changes in policies and support systems that help the poor can quickly bring about a wide range of positive effects that go far beyond food systems. Long-term, we need to put money into research right away to make sure that future generations will have food security and a healthy ecosystem (Wijerathna-Yapa and Pathirana, 2022).

10.3 Resource scarcity

Even though the psychology of resource scarcity is a new field of study, the idea that resource scarcity happens everywhere is a basic idea in modern economics. As a result, the resources we need to meet our needs are always limited. These include labor, capital, time, and food for consumption. This means that any sensible person has to put efficiency first and talk about how to make the best use of their resources (Isler, 2021).

10.4 Food inequality

As the world's communities continue to grow, issues of human rights and the unequal distribution of food resources have become more important. New ways to look into the connection between inequality at the country level and violations of human rights in the way biophysical resources are distributed and food is made available. More research needs to be done in the future to fully understand these dynamics and start coming up with ways to help people who don't have equal access to food. It will also be important to look more closely at how trade policies affect patterns of agricultural development, crop production, and yields (D'Odorico *et al.*, 2019).

10.5 Need for integrated food system planning

No universal approach exists for planning of local food systems and sustainability. Planning must strike a balance between the necessity of being comprehensive and place-based. In part, the future of food systems is contingent upon the establishment and maintenance of a combined food system that transparently considers a diverse array of eco-friendly parameters at the national and global levels. A global food system that is integrated promotes adaptive strategies while also recognizing the unique objectives of local communities. The objective of an integrated food system is to address a variety of local needs and national and international partnerships that are mutually beneficial (Issac *et al.*, 2022).

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11. Conclusion

The food system transformation addresses safety, inequalities, hunger, and sustainability. This strategy will also support several interrelated goals, including the SDGs. In the future, it will be necessary to increase the availability of food to all citizens, regardless of their status, and to enhance national sensitivity by providing high-quality food. Numerous policy modifications and interventions that are recommended have the potential to benefit the environment, nutrition, and food availability (Hendriks *et al.*, 2023). The rehabilitation of the food crisis has been a collaborative effort between numerous nations and European Union policymakers. It has included the initiation of resource recycling and the implementation of modern techniques for the sustainability of natural food sources. Renewable livelihood strategies recognize the interactions of water, energy, and food as a single system during the assessment of the manmade and natural surroundings. Genetically modified food will contribute to the resolution of the food system issue by twenty to fifty percent, as well as the creation of employment opportunities for farmers and the establishment of sustainable food security worldwide. Horizontal gene transfer is essential for the prevention of crop disruption and the integration of new dynamic techniques to ensure global food insurance by minimizing and controlling pathogen infections. The organization is establishing a framework in developing countries to enhance the efficiency of agricultural resource systems and to ensure individuals have access to nutritious food. The regulation of food safety and security can be achieved through the enhancement of agricultural industrialization and the management of natural resources.

The evolution of broader and more integrated policies is required for addressing the multiple sectoral approach, including production, distribution, ecological effects, and social. These factors will be facilitated by the active engagement of these stakeholders. Policymakers adhere to the following guidelines during the policy-making process: The drivers of the food system and their interactions should include nutrition policy for the best achievements. In the development of nutrition policy, policymakers should capitalize on consumer health trends. The packaged food and food service sectors could be aligned in terms of nutrition policy coherence by policymakers.

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