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Article Review

Agriculture, Food Systems, and Sustainable Development in Asia: Challenges and Pathways

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Abstract

This review analyzes different aspects of agriculture, food systems, and sustainable development in Asia, a geographically variable, economically booming, and ecologically very diverse continent. The review considers progress as well as regional systems regarding sustainable development, organic crop, and livestock farming systems along with cropping. It also addresses the consequences of climate change on fish and aquaculture, the control of soil and carbon sequestration, and the effects on the availability of food. Further, the review discusses microbial science in supporting the development of sustainable and resilient food systems, food diversity and quality, while also critically examining the challenges and gains of implementing sustainable agriculture. Asian countries are confronting important development challenges and need to move toward sustainable and resilient food systems immediately. While significant progress has been achieved in reducing poverty, ensuring food security, and modernizing agricultural, numerous challenges still remain, including the impacts of climate change, environmental degradation, loss of biodiversity, and malnutrition. The prevailing production-focused models of input intensification as well as linear resource use cannot adequately address these interlinked challenges. Sustainable agriculture and food systems in Asia can be achieved through a multi-dimensional strategy. This would include developing and instituting policy systems that make green and inclusive practice more effective, prioritizing the benefits to the smallholder farmer. Technology and social innovation, such as upscaling climate-smart agriculture, digitalization, and knowledge-sharing mechanisms, are essential for enhancing productivity and resilience. Promoting regional and global cooperation through cross-border association, emergency funds, and knowledge transfer mechanisms is essential in order to mitigate shocks and stimulate development. Also essential are strategic public and private investments to modernize infrastructure, support research programs, and grant vulnerable populations autonomy. Ultimately, an overall approach that fosters cooperation between governments and people is essential for propelling sustainable food and agriculture systems towards a more resilient world.

Keywords: *Agriculture, Food, Climate change, Sustainable Development.*

Introduction

Agriculture and food systems in Asia are at a critical juncture, confronting the dual challenge of meeting growing food demand while ensuring sustainability and resilience in the face of climate change, environmental degradation, and socioeconomic shifts. This review synthesizes recent regional insights and research to highlight progresses, challenges, and pathways toward sustainable development in Asian agriculture and food systems. Asia's agricultural sector plays a key role in global food security, economic development, and rural livelihoods. Nevertheless, traditional production-centric approaches, such as the Green Revolution, are increasingly becoming insufficient to address the complex challenges of malnutrition, environmental sustainability, and climate resilience [1]. A systemic food systems approach that integrates sustainable resource use, nutrition, and resilience is now widely advocated to transform agriculture and food systems in Asia [1–3].

Asia is the world's most populated continent and consists of 4.5 billion individuals, or approximately 60% of the global population. By 2050, the population of Asia is expected to reach 5.2 billion, making it difficult to satisfy food demands and guarantee food security in the region. Although greenhouse gas emissions are low in Asia, climate change has already hurt the region's economic growth as well as development [4], [5]. Meanwhile, China and India continue to be the two largest contributors to world carbon dioxide emissions. Figure 1 and Figure 2 display each Asian nation's proportion of cumulative global carbon dioxide emissions.

Over the last decades, despite the significant advances achieved in fields of agricultural modernization, food security enhancements, and poverty reduction, Asia still remains severely threatened by looming and dissimilar menaces, namely, the risks caused by climate changes, loss of biodiversity, environmental degradation, and chronic malnutrition, which undermining sustainable development [6–8]. Such traditional, production focus agricultural models dependent on intensification of inputs and linear resource uses including so-called Green Revolution spawned agriculture have not been adapted to address such multidimensional challenges without undermining the ecological integrity of these agricultural systems [1], [9]. Severe outbreaks of pests, especially insect pests such as rice brown planthopper and stem borers, contribute to the significant losses in yields and increased dependency on the use of agrochemicals resulting further complication of environmental and human health implications [10–12].

Natural catastrophes, which include severe temperatures, storms and wildfires (23%), floods (37%), drought (19%), and insect and animal disease infestations (9%), are the primary causes of agricultural productivity (crop and livestock) losses in Asia, amounting to $10 billion [13]. The frequency and intensity of tropical cyclones in the Pacific have grown over the past few decades. South Asia is the world's most insecure region, with 262 million people suffering from malnutrition [10], [14]. Climate-driven extremes such as floods, droughts, heat waves, storms, and cold waves, as well as temperature and rainfall variability, have several deleterious effects on the agricultural industry in Asia. In particular, cropping systems are crucial to food security and have contributed to Asia's problems and challenges. Climate change has a negative impact on rice and wheat, along with crop yields and quality. The production of crops is in danger in Asia and in developing nations. For instance, Pakistan's geographic position, with dry to semiarid environmental conditions, makes it extremely vulnerable [9], [14]. Climate change is having a significant impact on the biology, ecology and distribution of pest, and beneficial insects resulting in more outbreaks, ecological imbalances between natural controls, and more pest management problems. Increased temperatures and changed precipitation regimes increase pest habitats and life cycles, lessen the effect of natural control factors, heighten threats to the sustainability of food production. To reduce these effects, there is a need to employ adaptive integrated pest management (IPM) plans with the aid of enhanced monitoring and predictive technologies that would make the agricultural system resilient to dynamic climatic environments [15–17].

There have been reviews covering various elements such as development and regional patterns, sustainable development and organic agriculture, cropping system modifications, environmentally sound animal production, soil conservation and carbon sequestration, climate change effects on fisheries, aquaculture, and food supplies, contribution of microbiology to sustainable food, food quality and diversity, as well as the implications and advantages of sustainable agriculture in Asia. Nevertheless, there is a need for an overall assessment which integrates all of these elements so that a holistic snapshot can be presented in terms of these topics. Accordingly, this paper has been planned to this end.

Materials and Methods

The review presents an overview of various areas including progress and regional schemes, organic agriculture and sustainable development, cropping system improvement, environmentally sustainable animal farming, soil health and carbon sequestration, impacts of climate change on fisheries, aquaculture, and food supply, contributions of microbiology to sustainable food systems, food quality and diversity, as well as the challenges and benefits of sustainable agriculture in Asia. Meanwhile, an in-depth analysis bringing all these together is necessary to gain a holistic perception of these ideas. A thorough and methodical search was performed in key academic databases, using specifically selected keywords pertaining to food security, climate resilience, and rural livelihoods. In order to supplement academic literature, gray literature from leading organizations was also included. The collected materials were then systematically categorized based on themes and carefully reviewed as well as analyzed.

The research employed a qualitative integrative review method that is applied to investigate existing trends in agriculture, food, and sustainable development in Asia. It was found out that the selection of the relevant literature was determined by its compliance with Sustainable Development Goals (SDGs) 2 (Zero Hunger), 12 (Responsible Consumption and Production), and 13 (Climate Action) and the geographic focus of South, Southeast, and East Asia. Systematic and exhaustive search was done in well-known academic platforms, such as Scopus, JSTOR, web of science, and Google scholar using preselected keywords covering food security, climate resilience, and rural livelihoods. Complementing the academic sources, gray literature in the form of the Food and Agriculture Organization (FAO), Asian Development Bank (ADB), International Food Policy Research Institute (IFPRI), United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), United Nations Environment Programme (UNEP), and World Bank is taken to give practical considerations and contextualization in terms of statistics. The inclusion criteria were constricted into publications in English strictly dated to 2010-2024, so that they can be clearly relevant to the Asian region. Extracted materials were coded according to key thematic categories such as the agricultural production, as well as the environmental sustainability, governance structures, and technological innovation. Its data include more than 80 peer-reviewed publications, policy materials in the regions, and national statistics. Also, progress reports and exemplary case studies, like digital agriculture in China and adopting agroecology in Bhutan gave conceptual clarity and context in a subtle way. Thematic matrices allowed the achievement of a comparative analysis with regard to subregions, which allowed one to recognize similar patterns, problem areas, and best practices. All the sources and information were properly arranged through the Zotero software in order to facilitate effective cross-referencing and synthesis. This methodological framework enabled the policy-relevant synthesis of sustainable agricultural pathways with varied Asian contexts in a comprehensive way [18].

Progress and regional frameworks

Significant efforts have been made to promote sustainable agriculture and food security in Asia. The ASEAN region, for example, has adopted the ASEAN Integrated Food Security Framework and Strategic Plan of Action on Food Security (2021–2025), with the aim of enhancing food security while improving farmer livelihoods. Further, cooperation frameworks such as the ASEAN–Japan MIDORI Cooperation Plan facilitate the transfer of advanced agricultural technologies to ASEAN countries, promoting innovation-driven sustainability [19].

Results and Discussion

Sustainable development and organic farming system

Implementation of sustainable development requires reinterpretation and rebasing of the most significant goals as well as management methods of the majority of the economy's branches. This development is crucial in economic branches where natural factors exert a key influence on the processes. Among such branches are agriculture since it has a direct impact on the environment, food safety, and condition of rural regions [20], [21].

Other crop and farming systems that play critical roles in performing sustainable development include low-input agriculture, integrated crop management, precision agriculture, and organic agriculture. The role of organic agriculture, according to the International Federation of Organic Agriculture Movements, lies in agriculture, processing, distribution, or consumption to preserve and enhance the health of the ecosystems as well as living organisms [22–24]. While organic farming has numerous advantages such as better soil, quality food and environment, it is also associated with small farm size, absence of infrastructure, and lower production of certain crops. Imperfections notwithstanding, adoption of organic farming is an essential step towards ensuring sustainable future food output [25–27].

Table 1. Organic Farmland Area and Its Share of Total Farmland by Region in 2022: A Comparative Overview of Sustainable Agriculture.

Region	Year	Organic area (farmland) (ha)	Organic area share of total farmland (%)
Asia	2022	8830990.40	0.54
Europe	2022	18'693'328.44	3.76
Africa	2022	2'735'006.30	0.24
Latin America	2022	9'537'386.55	1.44
Northern America	2022	3'627'818.38	0.78
Oceania	2022	53'194'638.56	14.14

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Benefits of a system of environmentally sustainable livestock production

Promoting environmentally sustainable livestock production

Livestock farming is growing rapidly, adopting new processes and procedures to boost productivity and profitability. Meanwhile, it is essential to consider environmentally friendly processes in livestock rearing [28], [29]. It involves putting in place practices that mitigate the impact on the environment without sacrificing productivity. Principal approaches are modifying grazing habits, improving the variety of animals and forage, controlling frequency and location of animal grazing, as well as integrating livestock and crop production systems. In order to further enhance climate change sustainability, there is a need to feed the livestock balanced nutrition, enhance waste management of animals, integrate trees and shrubs using agroforestry, and utilize supplementary feeding techniques [14], [30], [31].

Cropping system adaptations and crop management

Adaptation strategies can lower the adverse effects of climatic variability by conserving water through management of irrigation quantity, timely application of irrigation water, as well as efficient water harvesting and conservation technologies [32], [33]. Crop-specific cultivation practices include sowing timing regulation [34]. Indeed, crop intensification and diversification have significantly improved as adaptation strategies [35], [36].

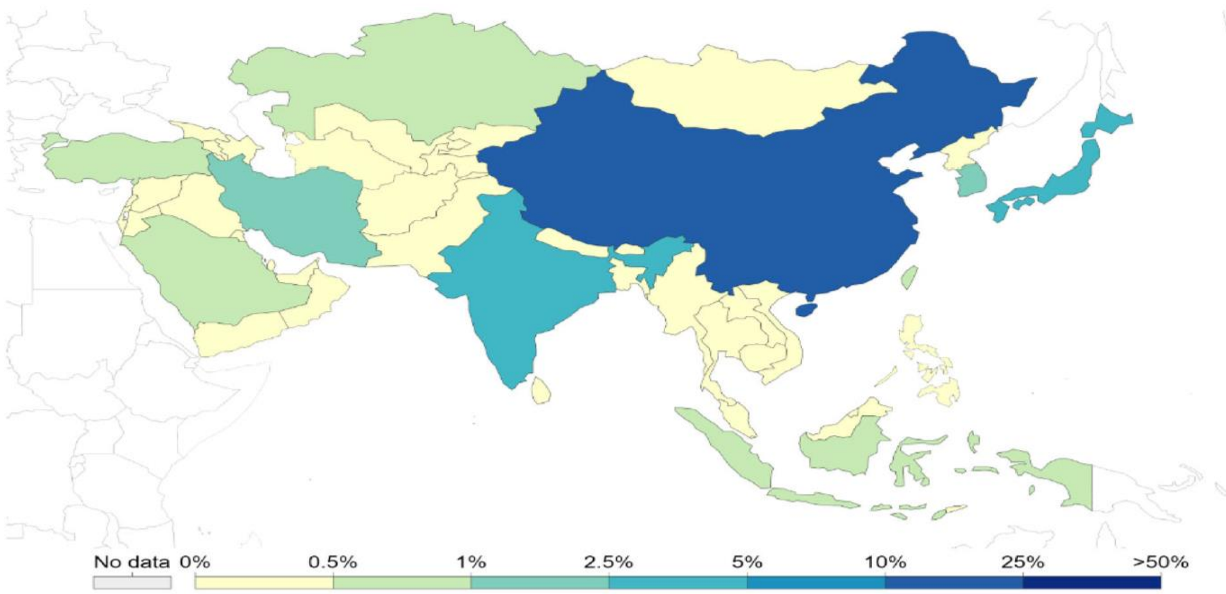

Figure 1. The proportion of each Asian nation's total carbon dioxide emissions (OWID, based on the Global Carbon Project and CDIAC) [14].

Management and carbon sequestration

Climate variability is caused by the livestock production sector, accounting for 14.5% of global total greenhouse gas emissions [37]. Unfortunately, there are negative impacts of climate change on forests at different levels such as altered vegetation in Asian countries, resources for soil loss, productive traits, and carbon dynamics. Three hundred million people in India are dependent on forests for many purposes such as providing food for 300 million people, rural dwellers' up to 40% of their energy requirements, and shelter for one-third of the animals [38–40].

Impacts of climate change on aquaculture and fisheries

Climatologically forced extremes such as cyclones, floods, global warming, ocean acidification, irregular and unpredictable rainfall, salinity, and sea level rise have negatively influenced aquaculture in South Asia. Meanwhile, climate variability has had many negative impacts on forests, such as altering carbon dynamics, changing vegetation, and productive properties. Climate variability, in South Asian nations, while also leading to drought, heat stress, and loss of land resources [14].

The effect of climate change on food supplies

Much research has already begun analyzing how households and communities react to climatic shocks [41]. In order to know how local societies could be impacted as well as the covariate risks of climate change affecting large areas, micro- and macrolevel analysis are required. Significant changes in the areas of farmland or pastureland, for instance, may be owing to climate change [42], which would have a serious impact on access to food, trade, and prices. Climate change may affect physical access to food through effects on transport infrastructure and physical health [43].

Food quality and variety

Food safety throughout the supply chain along with the health effects of climate change, including nutritional status, are the two main ways in which climate change affects food consumption. Climate change may reduce the safety of food since rising temperature promotes bacterial growth [44]. Climate change impacts on water, such as diminished water supply for sanitation [45], or higher water contamination owing to more intense and more frequent floods [46], may threaten food safety and health. There has also been concerns over increased incidence of disease, which will cause excessive use of veterinary medicines and pesticides, particularly in the fishery industry [47].

Climate variability and change have also been found to threaten the social and economic bases of farming systems. Marginal and resource poor communities are the most vulnerable to climate change. Meanwhile, threats to such communities may destabilize community resource policy and promote conflict [8].

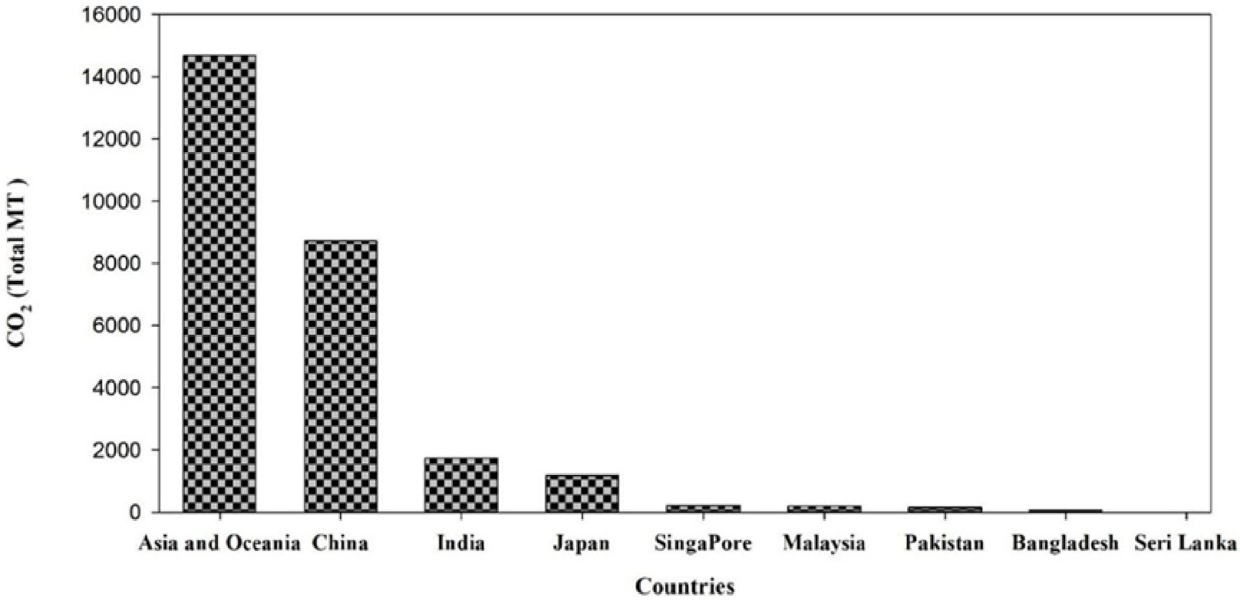

Figure 2. Emissions of carbon dioxide (CO2) from various Asian nations (source: Carbon Dioxide Information Analysis Centre, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States; International Energy Statistics https://cdiac.ess-dive.lbl.gov/home.html).

Challenges and benefits in adopting sustainable agriculture

Sustainable agriculture is promoted as an alternative to conventional farming because of environmental and economic constraints; however, its use remains low. Farmers note advantages such as improved soil fertility, cover vegetation, water supply, and job creation, resulting in improved productivity and food security. Adoption is, however, constrained by a lack of information, poor institutional support, inadequate labor, and fragmented land. Other challenges linked to sustainable agriculture include higher workloads, waterlogging, and pests [48], [49].

Table 2. Key Actions for Sustainable Food Systems in Asia.

Action Area	Description	Example/Initiative
Green Policy Reform	Reduce chemical inputs, expand organic area, lower emissions	Japan's MIDORI Strategy
Climate-Resilient Farming	Promote drought-resistant crops, efficient irrigation, conservation farming	ADB investments, ASEAN+3 Rice Reserve
Nutrition & Social Safety	Targeted food and nutrition programs for vulnerable groups	Indonesia's free meal program
Digital & Supply Chain	Use of digital tools, precision farming, supply chain modernization	India, Vietnam digital agriculture
Regional Collaboration	Policy harmonization, emergency reserves, knowledge sharing	ASEAN, FAO, UNFSS+2, South–South cooperation (Chin *et al.,* 2024)

Food system organization and transformation in Asia

They are chains of farmers, manufacturers, retailers, governments, and consumers who bring order to how food moves from farms to plates in a region. Over the last decades, food systems in Asia have fundamentally transformed owing to various interrelated determinants such as rapid economic growth, growing urbanization, advancements in technology (e.g., agriculture and logistics), and shifting consumer diet preferences (table 2) [50], [51].

Transforming food systems in Asia is critical for sustainable development, reduction of poverty, and climate resilience. Success depends on integrated policies, technological innovation, inclusive investments, and robust regional cooperation. With sustained commitment, Asia's food systems can drive sustainable growth and improved livelihoods across the region.

Table 3. Microbial applications for sustainable and resilient food systems.

Microbial Application	Function/Role	Sustainability Impact	Examples
Fermentation (Traditional & Modern)	Food preservation, flavour enhancement, probiotic enrichment	Reduces food waste, enhances nutritional value, supports local food systems	Kimchi, tempeh, kefir, precision fermentation (e.g. dairy proteins)
Biofertilizers & Biopesticides	Soil microbiomes enhance nutrient uptake and plant resilience	Reduces chemical inputs, restores soil health	Rhizobia, Bacillus spp., Trichoderma
Microbial Protein Production	Produces high-protein biomass via fermentation	Reduces land/water use, GHG emissions vs. livestock	*Quorn* (Fusarium venenatum), *Solar Foods*, *Spirulina*
Waste-to-Resource Conversion	Valorization of food/agricultural waste via microbes	Supports circular economy, reduces methane emissions	Anaerobic digestion, black soldier fly larvae with gut microbes
Synthetic Biology & Engineered Microbiomes	Tailored microbial systems for crop resilience and nutrient delivery	Precision agriculture, climate resilience	CRISPR-engineered rhizobia or soil microbes

Microbiology for sustainable and resilient food systems

Microbiology is central to planning sustainable food systems (table 3), influencing soil fertility, farm yields, food safety, and environmental protection [52], [53]. Microbial communities such as nitrogen-fixing microorganisms and mycorrhizae are crucial in recycling nutrients, diminishing the application of chemical fertilizers, and enhancing ecologically friendly farming. Along food processing, microbial fermentation is central to shelf-life extension, enhancement of nutritional value, and optimization of food recovery a critical advantage to low-resource regions. Microbiology is inextricably linked to agriculture, food systems, and Asian sustainable development since microorganisms play significant roles in soil health, crop productivity, nutrient cycling, and food security. Sustainable Asian agriculture seeks to boost productivity while sustaining ecosystems and ameliorating resilience to climate change and socio-economic stress, where microbiological processes are fundamental in bioavailability of nutrients, organic matter decomposition, as well as managing pests and diseases. Integration of microbiological breakthroughs, such as biofertilizers, biopesticides, and microbial consortia, benefits sustainable agriculture which lowers the use of chemicals and its impact on the environment. Studies highlight the significance of area-based interventions throughout Asia, considering socio-economic variations, smallholder production systems, and ecological diversity, to support agroecologically resilient food systems and rural livelihoods. Further, microbiological control of postharvest operations reduces wastage of food and optimizes food safety, which is critical for sustainable food security in the face of rapid urbanization and climatic stresses [54–57].

Conclusion

Asia's evolution toward sustainable agriculture and food systems is of great significance with its large population, rising economic growth, and ecological diversity, creating both extraordinary opportunities and serious challenges. While some progress has been made in reduction of poverty, ensuring food security, and agricultural modernization, unresolved issues such as climate risk, environmental degradation, and malnutrition threaten sustainable achievements. The conventional production-focused methods are inadequate to address the complexity of current issues and need a comprehensive transformation encompassing climate resilience, resource management, and nutrition-sensitive policy. This shift has to be supported by fresh policy frameworks promoting green and inclusive practices for the benefit of smallholders; social and technological change such as climate-smart agriculture and digital technologies to boost productivity and reduce vulnerability; enhanced regional and global coordination for knowledge sharing and emergency management; and targeted investment using public and private finance for improving infrastructure, enhancing research, and enabling the vulnerable. Despite such efforts, Asia still lags behind in fulfilling some of the sustainable development goals (SDGs) against hunger, poverty, and climate action owing to increasing climate-related threats, deep-seated rural poverty, and expanding nutritional disparities. The success of the region in attaining a sustainable and equitable food future relies on its effort towards combined, evidence-based strategies and shared growth. By leading on innovation, collaboration, and putting people's as well as the planet's health first, Asia can make its food systems a driver of sustainable development, a beacon to the rest of the world. Asia's shift to food and agriculture systems that are sustainable is a must with its massive population, rising economic development, and ecological diversification. Though improvements in food security, poverty, and agricultural modernization have been recently realized, underlying challenges such as climate risk, environmental degradation, and malnutrition erode sustainable development. The historical production-focused approach cannot address the complexity of today's challenges and requires a thorough transition with climate resilience, resource management, and nutrition-sensitive policy. This transformation should be enabled by new policy platforms that enable green, inclusive action to be taken in smallholders' interests; social and technological transformation such as climate-resilient agriculture and digital platforms to spur productivity and adaptation; enhanced regional and international partnerships to facilitate knowledge sharing and rapid response; and strategic investment from public and private sources of finance to upgrade infrastructure, promote research, and strengthen the most vulnerable. Despite these initiatives, Asia is finding it difficult to meet several sustainable development goals (SDGs) relating to hunger, poverty, and climate action due to increased climate-related risks, deep-rooted rural poverty, and widening nutritional disparities. The future of the region's success in meeting a sustainable and equitable food destiny hinges on how aggressively it pursues integrated, evidence-based solutions and shared growth. Through encouraging innovation, cooperation, as well as people's and the planet's well-being, Asia can position its food systems as drivers of sustainable development and a model for the world.

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