

Global food security and climate change adaptation efforts

الأمن الغذائي العالمي وجهود التكيف مع آثار التغير المناخي

Kouadra Hocine*, University of Oum El Bouaghi

kouadra.hocine@univ-ueb.dz

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Abstract:

This study analyzes the profound impacts of climate change on global food security and adaptation strategies to mitigate its effects on food systems worldwide. It proposes methods to lessen the detrimental impacts that threaten the stability and sustainability of global food supplies. The study employs a multidimensional approach, utilizing a multi-method methodology that combines quantitative and qualitative analyses. The findings reveal that staple crops have experienced a significant decline in average yields over the past two decades in regions affected by climate change. Furthermore, rural communities, particularly in developing countries, face considerable challenges in maintaining food access due to rising prices and dwindling water resources. The study emphasizes the importance of adaptation policies and measures to promote the diversification and sustainability of production systems.

Keywords: food security, climate change, global context, adaptation, food sustainability.

Introduction:

Ensuring food security is a fundamental necessity for the national well-being of any country and a cornerstone of social harmony and stability. However, global food security has faced numerous crises in recent years. The COVID-19 pandemic and its spread have impacted global agricultural markets, supply chains, and trade; food transport channels have been disrupted; and some countries have imposed export restrictions to ensure domestic food supplies, affecting the global food market and thus making it difficult for most of the world's population to access sufficient and nutritious food.

Furthermore, the Russian-Ukrainian conflict and the recent war that began on February 24, 2022, have damaged wheat production and reduced exports in both Russia and Ukraine. Due to the uncertainty surrounding the conflict and the unclear outcome of the Russian-Ukrainian war, in the worst-case scenario, the conflict could lead to a sharp decline in global trade, a rise in wheat prices, a 30% decrease in wheat purchasing power, and severe food insecurity, especially for countries heavily reliant on wheat imports from Ukraine.

In addition to the repercussions of both the COVID-19 pandemic and the Russia-Ukraine conflict, which were both incidental events that significantly exacerbated the global food crisis, global food security is also affected by the lasting, long-term, and profound impacts of climate change. In this context, the threat posed by climate change to global food security cannot be ignored.

Food security, as defined by the Food and Agriculture Organization of the United Nations (FAO) (1996), is a state in which all people, at all times, have access to sufficient, safe, and nutritious food—physically, socially, and economically—to meet their dietary needs and food preferences for an active and healthy life. It is typically summarized in four dimensions: food production, access, utilization, and stability. However, climate change affects all dimensions of food security, resulting in challenges at various levels (societal, political, and economic).

* Corresponding Author

The impact of climate change on global agriculture is uneven and varies by region and crop. As global temperatures rise, yields may increase in higher latitudes, while crop yields will decrease in lower latitudes, such as in sub-Saharan Africa, South America, the Caribbean, South Asia, Western Europe, and Southern Europe.

To mitigate the impact of climate change on global food security, the international community and individual countries have made significant efforts to address climate change and ensure food security through a range of policy responses. These include climate action strategies, food security policies, and initiatives to promote agricultural and food transformation in response to the climate crisis. Therefore, the following research question will be addressed: How can global adaptation to the consequences of climate change be achieved to enhance global food security?

To achieve the study's objectives and requirements, a multidimensional approach was adopted, examining global and local data related to the relationship between climate change and food security. A multi-method approach was also employed, combining quantitative analyses with qualitative assessments based on studies of some of the most vulnerable regions. To fully understand the subject, the study was divided according to the following plan:

- 1- Climate Change Pathways and the Challenges facing Global Food Security.
- 2- International and national responses to climate change to ensure food security.
- 3- Climate change adaptation measures to ensure global food security.

1- Climate Change Pathways and the Challenges facing Global Food Security

The paths of climate change and its impact on global food security will be traced by focusing on a range of factors and dimensions that are at the heart of food security, such as food production, access, supply sustainability, and the food system.

1.1- The Impact of Climate Change on Sustainable Global Food Production

Climate change often manifests as alterations in water and temperature resources, such as rising average temperatures, extreme temperature increases, and increased variability in rainfall; more frequent extreme weather events such as droughts, floods, heavy rainfall, hurricanes, and heat waves; and a cascade of negative interactions such as soil degradation, desertification, salinization, and sea-level rise.

Crop growth is highly dependent on weather and climate conditions and is extremely sensitive to climate change. On the one hand, continuous changes in temperature and rainfall will affect the growing conditions suitable for crops and the physiological processes necessary for crop growth and development, which may ultimately lead to reduced crop yields. Failure of key plant enzyme systems can easily lead to plant death, and the thermal environment is closely linked to plant enzyme systems¹.

At the same time, high temperatures or heat stress can also damage plant cells and affect crop yields. Wheat and other crop yields are significantly reduced under high temperatures. In India, the wheat growing season is limited due to high temperatures during sowing and ripening. Because wheat grows on a wide scale, it is often exposed to temperatures above the heat stress threshold. For example, rainfed wheat depends on soil moisture after the September monsoon rains, but the increase in maximum and minimum temperatures in September harms seedling health, accelerates premature vegetative growth, and reduces canopy cover, tillage, and yield. High temperatures also reduce the productivity of wheat sown in December or January, as essential physiological processes, including carbon assimilation and leaf chlorophyll content, are highly sensitive to extreme temperatures². As for rice, heat stress during flowering prevents anther dispersal and pollen shedding, thus reducing pollination and grain yield. This significantly decreases anther dispersal, pollen fertility, and overall crop components³.

On the other hand, extreme weather events, such as droughts, floods, and hurricanes, cause crop loss and damage to crops and food system infrastructure, further undermining food system

stability and food security. The frequency of extreme weather events today is three times higher than it was in the 1980s. In this context, Leske et al. compiled approximately 2,800 reports of severe weather disasters and found that national grain productivity declined significantly by an average of 10.1% during periods of drought, while years of extremely high temperatures can cause losses in national grain productivity of up to 9.1%.⁴ Furthermore, climate change is estimated to cause \$0.5 trillion and \$1.1 trillion in welfare losses for agriculture in sub-Saharan Africa and South Asia, respectively, between 2020 and 2050.⁵ Bellowen also assessed the impact of extreme weather on crop yields in 17 European countries. He found that heavy rainfall and high temperatures from March to August 2018 caused multiple crop failures in northern and eastern Europe. However, favorable spring rainfall meant that above-average yields in southern Europe almost offset the sharp decline in crop yields in northern Europe⁶.

Changes in temperature and rainfall will also alter the distribution of agroecological zones, potentially causing shifts in food production belts. In mid- and high-latitude regions, higher temperatures will benefit mid- and high-latitude countries by extending the growing season and expanding crop production areas toward the poles, but less fertile soils at higher latitudes may also undermine the benefits of a longer growing season. However, at lower latitudes, rising temperatures have detrimental effects on crop growth conditions, particularly in areas where temperatures are close to or at optimal growth levels.⁷ Some researchers estimate that the most severe losses from future climate change are expected to occur in sub-Saharan Africa and South Asia due to the large increase in temperatures relative to changes in rainfall, limited crop management strategies, and the dominance of staple food crops, which are less sensitive to the effects of carbon dioxide.

In addition, climate change will also affect crop quality and safety. Crop quality encompasses the impact of climate change on crop growth, harvesting, transportation, and storage. Protein and mineral nutrient concentrations will decrease, and lipid composition will change. Furthermore, changing climatic conditions and extreme weather have promoted the growth and emergence of fungi, molds, pests, and diseases, and altered the survival and dispersal methods of bacteria, viruses, and pathogens. This can lead to contamination of irrigation water and crops, impacting crop safety and food quality. Consequently, spoilage and food safety risks are increasing at all stages, from initial production to harvesting, transportation, processing, distribution, and consumption⁸.

Therefore, the shift in agricultural production areas due to climate change means that future food consumption may originate from different parts of the world. Given variations in crop varieties, soil types, growing conditions, harvesting methods, processing, and storage, the source of food may influence the composition of macronutrients and micronutrients. While climate change adaptation strategies can help maintain food production, the introduction of new crops, new farming methods, and changes in pesticide use also lead to unfamiliar risks of foodborne illnesses.

1.2- Impact of Climate Change on Food Supply and Access

Climate change will lead to price volatility in global food markets. By affecting global food production, and consequently reducing the global supply of key food crops, particularly through the impact of extreme weather events during crop growing months, it will increase year-to-year fluctuations in food supplies and exacerbate food price instability⁹.

Table 1 shows the projected impact of climate change on the prices of major crops in the global market. Peanuts, fruits, and vegetables have the highest prices in the global market.

Table 1. Forecast of the impact of climate change on global market prices of major crops (2005 US\$/ton)

Crop	2010	2030	Compared to 2010, what is the percentage increase in prices by 2030?	2050	Compared to 2010, what is the percentage increase in prices by 2050?
Barley	172	187	8.72	198	15.12
Maize	149	215	44.30	301	102.01
Millet	282	364	29.08	413	46.45
Rice	359	455	26.74	567	57.94
Sorghum	147	183	24.49	194	31.97
Wheat	221	261	18.10	317	43.44
Groundnuts	788	1030	30.71	1283	62.82
Soybeans	333	449	34.83	517	55.26
Palm oil	522	657	25.86	687	31.61
Cassava	117	140	19.66	165	41.03
Potato	269	384	42.75	439	63.20
Sweet potato	694	815	17.44	958	38.04
Yams	692	823	18.93	1035	49.57
Fruits and vegetables	869	1086	24.97	1311	50.86

Note: USD 2005/ton means the price is adjusted based on the USD value in 2005 to eliminate the impact of inflation and to study long-term price trends.

Source : Timothy Sulser et al, Climate Change and hunger: Estimating costs of adaptation in the agrifood system, Food Policy Report, Washington, DC : IFPRI, June 2021, p.p.30-35, available at : <https://h1.nu/1jdXJ> (accessed 11/11/2025).

The table shows that the prices of various crops are trending upward in 2030 and 2050. The crop expected to see the largest increase is maize. Compared to 2010 prices, the price of corn is projected to increase by 44.3% in 2030. By 2050, the price of corn is expected to rise by 102.1%, followed by potatoes. Compared to 2010 prices, the price of potatoes is projected to increase by 42.75% by 2030. By 2050, the price of corn is also projected to increase by 42.75%. Therefore, the annual price increase is 63.2%. Peanuts and rice ranked third and fourth in terms of percentage increase. The increase in barley prices was the smallest among all products. Compared to 2010 prices, the price of barley is projected to increase by 8.72% in 2030 and by 15.12% in 2050.

Furthermore, researcher Porfirio et al. predict that by the middle of the 21st century, supply shocks caused by climate change will increase maize price volatility by 10% in some net maize-importing countries in Africa, Asia, and Latin America¹⁰. Projections regarding future grain production and supply have already led to higher global grain prices. During a food crisis, food prices rise, which can easily lead to famine, food riots, and social unrest.

A global food crisis began in late 2010. Food prices rose by 40% between January 2010 and February 2011, peaking in the summer of 2011 and triggering famine in the Horn of Africa. Simultaneously, rapid increases in food prices have been linked to social unrest in almost every region of the world¹¹.

Climate change also affects agricultural trade. In an open market economy, the impact of climate change on agriculture in any one country cannot be considered in isolation from other regions of the world. Climate change is impacting national agricultural productivity and output, and the geographical pattern of major food crop production is shifting globally, with an increasing number of mid- and high-latitude regions and a decreasing number of low-latitude regions. This

shift in production potential necessitates the flow of agricultural products such as grains and livestock from mid- and high-latitude regions to low-latitude regions, reshaping the global food supply chain through trade.

Furthermore, with rapid population growth and urbanization, future food demand will increase, and food imports will also rise. In this context, Fischer et al. estimated that by 2080, developing countries' grain imports will increase by 10% to 40%.¹² However, given the impact of climate change on national agricultural productivity and rising global food prices, some countries have adopted export restrictions and policies to subsidize agricultural products to ensure domestic food supplies and stabilize food prices.

For example, during the peak of the global market in 2007–2008 and 2010–2011, many governments intervened in the agricultural export market. Regarding wheat, 15 countries imposed export restrictions in 2007–2008, including major wheat exporters such as Argentina, Kazakhstan, Russia, and Ukraine.

The OECD indicated that from 2020 to 2022, governments would provide an average of US\$630 billion annually in subsidies to producers, and some emerging economies would impose implicit taxes on their producers averaging US\$179 billion annually.¹³ Furthermore, the production and trade of all products based on food inputs, such as food, feed, fuel, and fiber, will also be affected.

Moreover, climate change is impacting the smooth supply chain of agricultural products. Natural disasters such as heavy rains, floods, and hurricanes, exacerbated by climate change, will directly damage infrastructure such as roads, ports, communications, and networks, reducing the efficiency of agricultural product handling and disrupting the smooth flow of supply chains. It is worth noting that one-third (1/3) of the world's ports are located in areas prone to tropical storms, and climate change may exacerbate the impact of future natural disasters on ports. In addition to extreme events, rising sea levels, waves, and salt erosion will increase erosion rates, which will have a lasting negative impact on port facilities and supply chains.

Given the impact of climate change on non-renewable resources (such as oil, coal, and natural gas) and mineral ores, this will have a significant impact on manufacturing and transportation industries, with the consequences of climate change particularly affecting global logistics. This will further disrupt food transport and trade.¹⁴ Therefore, the risks posed by climate change to cold chain operations will hinder the circulation of fresh and perishable agricultural products and reduce food diversity. Even if processed agricultural products can alleviate some food transportation problems, they still raise concerns about the nutritional value of food.

1.3- The Impact of Climate Change on Food Demand and Utilization

Climate change affects the livelihoods and incomes of agricultural populations. Its impact on agriculture will significantly affect agricultural income and the livelihoods of farmers, especially in countries with a high percentage of agricultural production and rural households that rely on a single crop. At the same time, the negative impact of climate change on agricultural production may lead to a direct decrease in the demand for agricultural labor, resulting in direct losses in labor income and food resources. For example, in Nigeria, agriculture contributes approximately 41.73% of the GDP. Agricultural-related activities account for a substantial 95.67% of the sector's contribution.¹⁵ Agriculture is considered one of the most dominant sectors in Nigeria's economic structure.¹⁶ The agricultural sector employs more than 30.1% of the country's workforce and is also the largest employer in the country. This dominance of the agricultural sector means that even very minor climate instability can have devastating socioeconomic consequences.¹⁷

Furthermore, food price volatility caused by climate change will also affect producers and consumers, altering the profitability of agricultural production and the share of income spent on food. Climate change will also increase the health risks and illnesses to which agricultural populations are exposed and will affect the productivity and capacity of the agricultural workforce.

The increased temperatures resulting from climate change will pose a threat to occupational health, particularly for manual laborers working outdoors in areas with high temperatures. Extreme climate variability will also have short- and long-term effects on mental health. The decline in agricultural employment and labor rates has led to a decrease in household income, impacting families' ability to purchase sufficient, nutritious, and healthy food.

Higher food prices and lower incomes will harm diet quality and reduce dietary diversity. On the one hand, higher prices for staple food crops may reduce spending on non-food products, thus decreasing dietary diversity. On the other hand, rising food costs may lead to fewer and smaller daily meals, skipping meals, consuming less nutrient-rich foods, and eating more high-energy foods high in fat, sugar, and salt to satisfy hunger. These latter foods are much cheaper than foods rich in protective nutrients, such as fruits and vegetables.

Delayed cropping seasons or changes in seasonal rainfall patterns due to climate change may also exacerbate seasonal fluctuations in food and nutrient intake. Furthermore, climate change impacts the health, food consumption, and nutrition of women, infants, and young children. In resource-poor regions, climate change has a greater impact on women's health, particularly pregnant women. Food insecurity and malnutrition during pregnancy can lead to micronutrient deficiencies in mothers, depression, anxiety, gestational diabetes, and hypertension.¹⁸

1.4- The Impact of Climate Change on Food System Stability

Climate change will exacerbate the scarcity of critical natural resources, such as freshwater, and lead to widespread population displacement due to extreme weather events like drought, desertification, and rising sea levels. This will trigger a series of challenges and conflicts, further fueled by pre-existing conditions such as poverty and economic shocks.¹⁹ For example, violence, regional conflicts, displacement, and the erosion of vulnerability and resilience to climate change will not only affect food production, access, and utilization but also the stability of the entire food system, exacerbating global food insecurity.

Climate disruptions influence the likelihood of conflict by directly impacting physiological and psychological factors, as well as by increasing resource scarcity. Warmer temperatures, in particular, can increase hostility and violence by raising levels of aggression.²⁰ Unfavorable climatic conditions, such as rising temperatures or declining rainfall, coupled with population growth, reduce the resources needed to sustain human livelihoods and intensify competition for resources, thus fueling conflict. For example, Hsiang et al. found that during El Niño years, the probability of civil conflict in tropical regions was twice as high as in normal years, assuming that El Niño can lead to either negative economic or psychological effects, thus increasing the likelihood of conflict. Moreover, the impact of El Niño may exceed the sum of these individual effects because it is a global process that generates simultaneous and interconnected conditions worldwide.²¹ For instance, between 1981 and 2002, rising temperatures led to a significant increase in civil wars in sub-Saharan Africa, and it is estimated that if this trend continues, the incidence of civil wars will increase by about 50% by 2030.²²

Some argue that climate indirectly affects conflict by reducing economic output and agricultural income, raising food prices, and increasing migration flows, but this is constrained by other social and political factors. Indeed, the correlation between lower per capita income and a higher probability of civil war is one of the strongest empirical relationships in the economic literature.²³ Given that declining wages and job opportunities lead to increased crime rates and heightened motivations for violence and rebellion.

Furthermore, climate change is causing large numbers of people to migrate from their regions. Consequently, the influx of large numbers of "eco-migrants" will strain the economic and resource base of the receiving region, leading to competition for scarce resources. At the same time, when migrants and local residents belong to different ethnic and cultural groups, the arrival of new migrants may disrupt the fragile ethnic and political balance, exacerbating tensions and leading to conflict.²⁴

2- International and National Responses to Climate Change to Ensure Food Security

The international community's response to climate change, and specifically to global food security, has taken the form of a series of policy measures, proposing specific goals, visions, and action strategies, thus providing a framework for climate action by all stakeholders. Table 2 outlines the international community's objectives in addressing climate change and ensuring global food security. In this context, the Food and Agriculture Organization of the United Nations (FAO) launched its "FAO Climate Change Strategy (2022-2031)" in 2022, supporting the 2030 Agenda by transitioning to more efficient, inclusive, resilient, and sustainable agricultural and food systems, with the aim of achieving better production, better nutrition, a better environment, and a better life, leaving no one behind.²⁵

Table 2. Action Goals of the International Community in Addressing Climate Change and Ensuring Global Food Security

International Organizations / International Conferences	Year	Subject	Goals / Vision
International Food Policy Research Institute (IFPRI)	2022	Global Food Policy Report: Food System Transformation and Climate Change	Transforming food systems to adapt to and mitigate climate change by accelerating innovation, reforming policies, resetting market incentives, and increasing financing.
Food and Agriculture Organization of the United Nations (FAO)	2022	Climate Change Strategy 2022–2031	By shifting to more efficient, inclusive, resilient and sustainable agri-food systems, the 2030 Agenda is supported for better production, better nutrition, a better environment and a better life, leaving no one behind.
World Food Programme (WFP)	2023	Climate Action in Vulnerable Environments	Prioritize climate action in vulnerable and conflict-affected regions.
International Fund for Agricultural Development (IFAD)	2018	Environment and Climate Change Strategy and Action Plan 2019–2025	Enhancing the resilience of smallholder farmers and rural communities to the impacts of environmental degradation and climate change.

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World Trade Organization (WTO)	2023	Trade policy tools to promote climate action	By easing food trade restrictions and improving the functioning of food and agricultural markets, while simultaneously promoting climate action.
World Food Security Summit	2023	-	To inspire support for lasting solutions to turn the tide and prevent famine, wider food insecurity, and malnutrition.
28th Conference of the Parties to the United Nations Framework	2023	UAE Declaration on Resilient Food Systems, Sustainable Agriculture and Climate Action	Pledge to integrate agriculture and food systems into national climate action by 2025.
Convention on Climate Change (COP28)	2023	Transforming Food Systems for Humanity, Nature, and Climate: A Call for Joint Action	Focusing on the global food system as a basic betting for achieving significant and tangible changes for humanity, nature and climate by 2030.

Source : Prepared by the researcher based on data obtained from policy reports on the websites of various international organizations and conferences, which were discussed.

In 2018, the International Fund for Agricultural Development (IFAD) released its "Environment and Climate Change Strategy and Action Plan 2019-2025," focusing on strengthening the resilience of smallholder farmers and rural communities to the impacts of environmental degradation and climate change.²⁶ Furthermore, the International Food Policy Research Institute (IFPRI), in its 2022 World Food Policy Report, "Transforming the Food System and Climate Change," systematically explained the relationship between the two, proposing to promote food system transformation to adapt to and mitigate climate change through accelerated innovation, policy reform, readjustment of market incentives, and increased financing.²⁷

It must be pointed that the climate action of international organizations highlights the pivotal role of transforming agricultural and food systems in addressing climate change and ensuring global food security. However, given the different natures and objectives of various international organizations, their focus on climate action varies. For example, the World Trade Organization emphasizes the role of trade instruments in climate action, promoting climate action by easing restrictions on food trade and improving the functioning of food and agricultural product markets. The World Food Programme prioritizes climate action in vulnerable and conflict-affected areas. Furthermore, the United Nations Food Systems Coordination Centre was established on January 1, 2022. Its vision is to promote and support food systems transformation actions based on the Sustainable Development Goals to accelerate the achievement of the 2030 Agenda; its mission is to translate national commitments into effective actions to achieve sustainable food systems by 2030.

Furthermore, climate change and global food security are hot topics at international conferences. The 2023 World Food Security Summit will focus on four key pillars: nutrition, science and technology, early humanitarian action, and climate-resilient agricultural and food systems. The summit aims to focus international attention on the worsening global food security crisis, help advance efforts to eradicate hunger and malnutrition (Sustainable Development Goal 2), and emphasize support for durable solutions to combat famine and food insecurity more broadly.

As for national-level responses and actions, they primarily involve two aspects. On the one hand, most countries actively participate in international conferences on climate and food security, sign climate commitments, set climate targets, and submit Nationally Determined Contributions (NDCs) to address climate change. On September 23, 2022, the 193 Parties to the Paris Agreement submitted their NDCs, along with 166 updated reports on these contributions. All Parties also provided information on mitigation targets or adaptation action plans. Mitigation targets included absolute targets for reducing emissions at the economic level, as well as strategies, policies, plans, and actions for low-emission development, including agriculture. Furthermore, 74% of Parties strengthened their commitment to reduce or limit greenhouse gas emissions by 2025 or 2030 in their new or updated NDC reports, and 92% of Parties reported on the implementation period of their NDCs up to 2030.²⁸

At the 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change in 2023, 134 countries and regions, including China, signed the UAE Declaration on Resilient Food Systems and Climate Action, pledging to integrate agriculture and food systems into their national climate actions by 2025. On the same day, more than 150 non-governmental actors issued a "Call to Action for Transforming Food Systems for People, Nature and Climate," hoping to bring about significant and tangible changes to the global food system for the benefit of people, nature and climate by 2030. This declaration illustrates the shared commitment of agriculture, businesses, cities, civil society, philanthropies and other non-governmental entities to action on climate change.²⁹

At the same time, countries are individually developing short- and long-term climate action strategies, agricultural policies, and various supportive policies, including climate finance. For example, the Vietnamese government, in its Nationally Determined Contribution (NDC), pledged to reduce emissions by 9% across the economy by 2030 and achieve net-zero emissions by 2050. In agriculture, it committed to reducing emissions by 20% every 10 years and signed the Global Commitment on Methane.³⁰ Domestically, it implemented the National Climate Change Adaptation Plan 2021–2030 and approved the Agricultural Plan and the Rice Sector Restructuring Plan, aiming to reduce greenhouse gas emissions while ensuring annual rice production. Vietnam's rice exports reached US\$3.1 billion in 2021, making rice a major draw for Vietnamese agricultural exports.³¹

Furthermore, regional organizations, acting as alliances, have jointly issued a series of climate strategies and action plans. For example, the Association of Southeast Asian Nations (ASEAN) issued the "Establishment of a Climate Change Adaptation Network (2018)" in the area of climate strategy; the "ASEAN Multi-Sectoral Framework on Climate Change and Food Security," and agricultural standards and guidelines (Good Agricultural Practices and Good Livestock Practices) in the area of agriculture; and the "ASEAN Guidelines on Promoting Responsible Investment in Food, Agriculture and Forestry" in the area of finance (investment in food, agriculture and forestry).

3. Climate Change Adaptation Measures to Ensure Global Food Security

As we have seen, climate change significantly impacts food production, access, utilization, and food system stability, exacerbating global food insecurity. The transition to a more sustainable

and adaptive food system has become an internationally agreed-upon priority. This shift towards a new system characterized by high productivity and efficiency, nutritional health, environmental sustainability, resilience, and inclusivity plays a crucial role in addressing the impacts of climate change and ensuring global food security. This can be achieved through the adoption of a range of measures and strategies that adapt to climate change and guarantee global food security.

3.1- Promoting Agricultural Innovation/Smart Agriculture to Drive the Transformation of Agri-Food Systems

Although agri-food systems provide food and nutrition, supporting more than 1.2 billion people in low- and middle-income countries and a quarter of households globally, more than 9% of the world's population will still suffer from malnutrition, and more than 3 billion people will be unable to afford a healthy diet. With global population growth, food systems will need to feed nearly 2 billion more people by 2050 compared to 2020. At the same time, agricultural production and productivity growth has slowed due to several factors, most notably climate change. As a result, global food production is projected to decline by 8% by 2050.³²

It must be pointed that, given the inability to meet the global food consumption needs of more than 8 billion people and the limited availability of arable land, the fundamental solution for stabilizing and increasing production lies in scientific and technological investment in agriculture and food. As the world's consumption needs shift from simply "having enough to eat" to "good nutrition" and "healthy, nutritious nutrition," limited water and soil resources must ensure sufficient quantity, high quality, environmental sustainability, high efficiency, and an optimal structure for agricultural production. Therefore, the global agri-food system must achieve its goals on multiple fronts. On one hand, it must feed the world, adapt to climate change, and significantly reduce greenhouse gas emissions. In response to these challenges, the concept of climate-smart agriculture (CSA) has emerged as a comprehensive approach to achieving food security and promoting sustainable development while addressing climate change issues³³.

Therefore, it is essential to establish a comprehensive vision for agriculture and food, empower agriculture with science and technology, rely on technological innovation to ensure a robust global food supply, and firmly promote the principles of in-ground grain storage and technology to meet people's aspirations for a better life.

At the 2023 UN Climate Change Conference (COP28), the Consultative Group on International Agriculture (CGIAR), the Food and Agriculture Organization of the United Nations (FAO), the International Fund for Agricultural Development (IFAD), and the Rockefeller Foundation hosted a Food and Agriculture Pavilion focused on the theme "Addressing the Food and Climate Crisis Together." The pavilion discussed the crucial role of agri-food systems in addressing the climate crisis, emphasizing the need to develop climate-smart agriculture to enhance agricultural productivity and climate change resilience. This includes implementing conservation agriculture, intercropping, microbial fertilizers, controlled-release fertilizers, organic and inorganic compound fertilizers, and deep fertilization to improve soil fertility; diversifying crop production, implementing integrated crop and livestock systems, agroforestry systems, and integrated soil and crop management systems to enhance crop resilience to climate change; and developing water-saving irrigation measures, such as controlled irrigation, intermittent irrigation, drip and sprinkler irrigation, and precision sprinkler irrigation, to improve water use efficiency.

Therefore, food security should be considered the fundamental principle of climate-smart agriculture. Climate-smart agriculture can thus be seen as a modern production approach that harmonizes food security, climate change mitigation benefits, and agricultural adaptation to climate change to achieve the Sustainable Development Goals.³⁴

Furthermore, emphasis has been placed on mitigating the impact of climate change on crop growth by adjusting regional crop production patterns, planting dates, and harvesting times. This includes promoting new breeding techniques to cultivate drought-resistant, salt-tolerant, and early-maturing varieties to address climate change and hydrothermal resource constraints. The

continuous development of bioregeneration technologies will also provide opportunities to reduce crop pests and diseases and enhance their nutritional value. Simultaneously, the development and use of digital technology, remote sensing monitoring, and big data platforms will facilitate agricultural producers' access to the latest climate, meteorological, marketing, and promotional information, as well as field monitoring and management, for the prevention and mitigation of natural hazards.

3.2-Enhancing Climate Finance and Providing Financial Support for Transforming Agricultural and Food Systems

At the 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change in 2023, the United Arab Emirates, the host country, announced that the international community would mobilize more than \$2.5 billion to support food security, address climate change, and promote innovation in the food system.³⁵ Governments can direct investment in the food system through taxes, subsidies, and regulations; innovation partnerships can encourage collaboration with the private sector; and commercial bank loans, green bonds and loans, and sustainability-linked bonds and loans are also potential financing channels.

At the 29th United Nations Climate Change Conference (COP29) in Azerbaijan in 2024, developed countries agreed, for the first time in 15 years, to increase their support for climate change mitigation and adaptation funds in developing countries. The new target set for developed countries to provide \$300 billion annually by 2035 was an improvement over the previous target of \$100 billion annually by 2020. It was also agreed that all financial actors would contribute at least \$1.3 trillion annually by 2035.³⁶ However, this figure still falls far short of what is actually needed. Therefore, leaders from various countries reached a consensus and called on all stakeholders to work together to raise \$1.3 trillion annually for the countries most vulnerable to climate change by 2035.

These figures thus indicate a significant funding gap. To redefine funding flows and actively expand new financing channels, vertical funds such as the Green Climate Fund (GCF), the Global Environment Facility (GEF), the Adaptation Fund (AF), and funds from multilateral development banks, as well as other bilateral and multilateral funds, should play a positive role.

3.3-Promoting Trade and Reducing Trade Protectionism and Restrictions on Food Exports

International trade plays a crucial role in offsetting changes in regional productivity caused by climate change, and an effective international trading system can support adaptation to climate change challenges. With sufficiently free and flexible trade, food and agricultural exports can better maintain domestic food prices and the well-being of producers in regions where climate change will increase crop yields. Conversely, increased imports can mitigate rising food prices in adversely affected areas. Reforming policies affecting trade and markets can enhance climate adaptation by improving food security and nutrition, and strengthening the resilience of producers, consumers, and traders to unforeseen crises.

In this context, the World Trade Organization (WTO), in its 2023 report, "Trade Policy Tools to Enhance Climate Action," calls for the development of domestic climate action plans to reduce market distortions, remove trade barriers, improve competition, and raise food safety standards. Furthermore, agricultural sector reforms and the reallocation of subsidy funds can enhance the sustainability and resilience of food systems.³⁷ In June 2022, at the 12th WTO Ministerial Conference, trade ministers agreed on a package of measures, including a declaration report affirming the vital role of trade in improving global food security, a decision to exempt the World Food Programme from humanitarian export restrictions on food purchases, and an agreement on fisheries subsidies, with members committing to eliminate subsidies for the most harmful fisheries.³⁸

In the short term, releasing grain stocks as appropriate, within the framework of WTO rules, and facilitating a diplomatic solution that would allow the export of currently banned grain and fertilizers from Ukraine would contribute to increased food supplies and lower prices. As stated in

the WTO Ministerial Declaration on an Urgent Response to Food Security, promoting trade and improving the functioning and resilience of global food and agricultural markets, including for grains, fertilizers, and other agricultural inputs, is crucial. The 2008 crisis demonstrated that restricting global trade directly leads to higher food prices. Therefore, removing export restrictions and adopting more flexible inspection and licensing procedures would help reduce supply disruptions while lowering prices.

3.4-Strengthening Infrastructure and Supply Chain Resilience to Reduce Food Loss and Waste

Investment in public infrastructure is essential to creating an ideal environment for a thriving capital market, particularly in rural areas. The stability, cost, and accessibility of food supplies are significantly affected by transportation, which in turn affects food security. Therefore, with well-developed transportation networks, food can be transported from surplus areas to areas of need in a timely and cost-effective manner. Furthermore, the development and maintenance of secondary rural roads, cold chain logistics systems for perishable goods, and affordable urban transport options to food retail areas should be among the top priorities for targeted investments. Governments should also facilitate public-private partnerships (which ensure sustainability and efficiency through risk sharing and innovation) to provide the substantial capital required for large-scale infrastructure projects.³⁹

Infrastructure development also includes strengthening the construction and maintenance of agricultural land infrastructure, establishing irrigation facilities and mechanized agricultural roads, implementing measures such as field leveling and soil fertilization, and maintaining and constructing roads, ports, and transport hubs to ensure the smooth transport of agricultural products and reduce transit time. Encouraging the construction and use of renewable energy projects, such as solar irrigation, wind power, and household photovoltaic panels, is crucial to providing rural areas in low- and middle-income countries with the electricity needed for agricultural production, processing, transportation, storage, and consumption. For perishable micronutrient-rich foods, the availability of cold storage facilities and the cold chain must be increased to maintain freshness or even improve accessibility by reducing spoilage.

Simultaneously, to ensure the smooth functioning of the cold chain, cold storage facilities should be established on or near farms after harvest, and agricultural products should be transported to these facilities or to retail outlets by refrigerated trucks. Food handlers should also be trained in proper handling procedures. In the short term, reducing food loss and waste can help maintain supply chains, but in the medium and long term, increased investment in climate-smart infrastructure, including the construction and electrification of new roads to support the development of the cold chain, is crucial for ensuring food security. Furthermore, the development and use of e-commerce platforms can reduce the logistical links for agricultural products and expand their distribution, thereby minimizing storage and waste.

3.5-Improving Social Security Systems and Enhancing Climate Change Resilience in Vulnerable Countries and Groups

National social security systems should be adjusted to include climate-related protection programs, taking into account the resilience of groups affected by climate change, and providing timely financial and material assistance to strengthen the resilience of vulnerable and marginalized groups to the food-related impacts of climate change.

At the same time, the international community should provide timely international and humanitarian assistance to countries affected by climate change and armed conflict to reduce the resulting poverty and hunger. In this regard, the World Food Programme's 2023 report prioritizes climate action in vulnerable and conflict-affected areas, providing climate relief in Somalia, Yemen, Mali, Burkina Faso, and The Gambia. This includes revitalizing areas through food and cash assistance, insurance policies, safety nets, and sustainable energy⁴⁰.

Furthermore, establishing local early warning and monitoring systems for climate change will provide more accurate information on the impact of climate change for risk management and offer low-cost, comprehensive, and accessible climate risk management measures. Promoting the adoption and use of risk management tools will also reduce the economic risks posed by climate change. These tools include agricultural insurance, weather index insurance technology, image-based crop insurance, and other risk mitigation instruments.

3.6- Strengthening International Cooperation on Food Security

Ensuring food security has become a key strategy for addressing the challenges of climate change within a framework of global cooperation. International organizations, such as the Food and Agriculture Organization (FAO) and the World Food Programme (WFP), play a vital role in promoting global food security. For example, FAO's Climate Change Adaptive Agriculture Programme aims to support developing countries in improving the resilience of their agricultural systems and mitigating the negative impacts of climate change on food production through international cooperation.⁴¹ Furthermore, FAO, through its Global Information and Early Warning System (GIEWS), provides countries with real-time information on food security, helping policymakers develop response strategies.

In addition, the Global Climate Action Plan (GCF) offers financial support to developing countries to implement climate-smart agricultural technologies, such as precision agriculture and water-efficient irrigation systems, which have proven effective in increasing crop yields and reducing resource waste. Another important aspect of international cooperation in food security strategies is improving global agricultural productivity through the exchange of knowledge and technology. For example, the International Alliance for Agricultural Research in the Dry Areas (ICARDA) promotes the dissemination of agricultural innovations through its research network, helping farmers adapt to climate change.⁴² The results of the Alliance's research, such as the development of drought-resistant crop varieties, have been applied in arid regions of Africa and Asia, significantly improving food security in these areas.

Furthermore, global cooperation can lead to the discovery of new ways of thinking about addressing food security challenges posed by climate change threats. Food security strategies within the framework of global cooperation also include the establishment of transnational systems for managing agricultural disaster risks. For example, through the World Meteorological Organization's (WMO) Global Climate Observing System, countries can share climate data and forecast information to prepare in advance and mitigate the impact of extreme weather events on food production. Thus, this transnational cooperation model, such as the Global Food Security Initiative (GFSI), provides a common platform for countries to address climate change by pooling resources and expertise, thereby ensuring the stability and sustainability of food supplies.

Conclusion

This study has provided a comprehensive and in-depth understanding of the impact of climate change on global food security, focusing on international and national responses to the repercussions of climate change and ways to support food security. It also identifies various adaptation strategies as essential tools for mitigating its severe effects and ensuring global food security.

The study demonstrated a clear correlation between climate disruption and reduced agricultural productivity in the most vulnerable regions. However, adaptation strategies, including the introduction of climate-resilient crops, the application of agroecology, and the diversification of agricultural systems, have shown a positive impact by increasing community resilience and improving food security. This finding underscores that implementing sustainable practices can partially mitigate the harmful effects of climate change, aligning with current research highlighting the potential of nature-based solutions and innovative resource management technologies.

Study Findings: Based on the research topic, this study reached the following conclusions:

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-The food supply system is inherently complex, and foodborne risks, influenced by climate factors, are diverse.

-Climate change poses a range of risks to ecosystems, agroecology, agricultural production, food chains, related incomes, and trade. It also affects farmers' livelihoods, food security, and nutrition through economic and social impacts.

-The most vulnerable populations, whose livelihoods depend on the agricultural sector in climate-sensitive regions of the world, are expected to be the most directly and significantly affected by climate change.

-A comprehensive understanding of the hierarchical structure of risks and the weak links in addressing them is crucial for developing global strategies for environmental adaptation to climate risks.

Recommendations: To enhance the resilience of food security to climate change, the following recommendations are needed:

-To ensure food security and nutrition, climate change adaptation measures in agricultural and food systems require a foundation of tangible transformation and support from investment, policies, and institutions across multiple relevant sectors.

-For interventions and measures to maximize their effectiveness, they must be integrated into comprehensive and coherent strategies and plans.

-Climate change adaptation strategies should be gender-sensitive and multidimensional, multisectoral, and multistakeholder.

-Transparency in the measures adopted is essential, taking into account the various factors (social, economic, and environmental) and timelines required to achieve the appropriate transformation.

-The development of adaptation strategies should be based on risk and vulnerability assessments, lessons learned from implementation practices, and be subject to regular monitoring, evaluation, and adjustment. In this regard, regular assessments are becoming increasingly effective in middle- and high-income countries, but countries lacking this capacity require significant support. National adaptation plans developed under the United Nations Framework Convention on Climate Change (UNFCCC) offer countries a valuable opportunity to integrate food security and nutrition needs as key policy objectives. These national strategies and plans also require the continued strengthening of national and regional cooperation.

-Various stakeholders must take short-term adaptation actions to ensure the effectiveness of response measures in the short, medium, and long term. To achieve some medium- and long-term impacts, immediate planning and action are essential, including the prompt implementation of investments. This is particularly true for investments requiring longer-term design and implementation, such as forestry, livestock farming, seed dissemination, research and development, innovation, and knowledge transfer for climate change adaptation.

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