

Reassessing Global Food Security Challenges Under Climate Change in The Twenty-First Century: A Critical Analytical Review

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ABSTRACT:

Climate change in the 21st century threatens global food security through reduced agricultural productivity, disrupted food supply chains, increased food-borne illness, land degradation, and rising food prices. Extreme weather events like droughts and floods, altered temperature and rainfall patterns, and rising CO₂ levels directly impact crop yields and the nutritional quality of food. Vulnerable populations suffer disproportionately as they have less capacity to adapt to climate shocks and other stressors, highlighting the need for climate-smart and nutrition-sensitive food systems and integrated policies to achieve both climate action and "zero hunger". This review envisages pointing out the factors which all stakeholders and policymakers must consider and act judiciously to combat climate change issues collectively to ensure global food security.

Key words: climate change, global food security, integrated policies, zero hunger

INTRODUCTION:

Global food security is a critical issue in the 21st century, with far-reaching implications for human health, economic development, and environmental sustainability. As the global population continues to rise, projections suggest that the demand for food will increase by approximately 60% by 2050 (Godfray et al., 2010). However, this growing demand is compounded by several challenges, including land degradation, water scarcity, and perhaps most significantly climate change. Climate change, defined as long-term alterations in temperature, precipitation patterns, and other atmospheric conditions, is expected to have a profound effect on food production systems around the world, further straining efforts to meet the nutritional needs of the global population. The impacts of climate change on agriculture are complex and multifaceted. One of the most significant threats is the increased frequency and severity of extreme weather events, such as droughts, floods, and storms, which can disrupt agricultural production and damage food supply chains. Changes in temperature and precipitation patterns can directly affect crop yields, alter growing seasons, and shift the geographic distribution of crop varieties. In many regions, climate-induced reductions in crop productivity are already being observed. For example, wheat and maize yields have been reported to decline due to rising temperatures and changing rainfall patterns in major food-producing regions (Lobell et al., 2011). In addition to the direct impacts on crop yields, climate change is also altering the nutritional quality of food. Elevated atmospheric CO₂ concentrations, for instance, can reduce the protein and micronutrient content of staple crops like wheat, rice, and maize (Myers et al., 2014). This decline in food quality could exacerbate existing nutrition-related challenges, particularly in low-income countries where populations are already at risk of micronutrient deficiencies. Furthermore, climate change disproportionately affects vulnerable populations, particularly those living in developing countries or regions with limited adaptive capacity. These populations, often dependent on agriculture for their livelihoods, are less able to cope with the impacts of climate change, such as crop failures and rising food prices (FAO, 2016). As food production becomes more volatile and supply chains more susceptible to disruption, these populations face increasing food insecurity and hunger. The increasing recognition of the interconnection between climate change and food security (Figure-1) has led to calls for comprehensive and integrated

approaches to tackle these challenges. Climate-smart agriculture (CSA), which focuses on improving agricultural productivity, enhancing resilience to climate impacts, and reducing greenhouse gas emissions, has emerged as a promising strategy for addressing the dual challenges of climate change and food security (FAO, 2013). Additionally, policy frameworks that promote sustainable development and support vulnerable communities are essential for ensuring long-term food security. In this review, we aim to explore the various dimensions of the relationship between climate change and global food security. We will examine the effects of climate change on agricultural productivity, food supply chains, food quality, and the most vulnerable populations. The review will also highlight the importance of integrated policies and climate-smart food systems that can ensure resilience to climate impacts while promoting global food security.

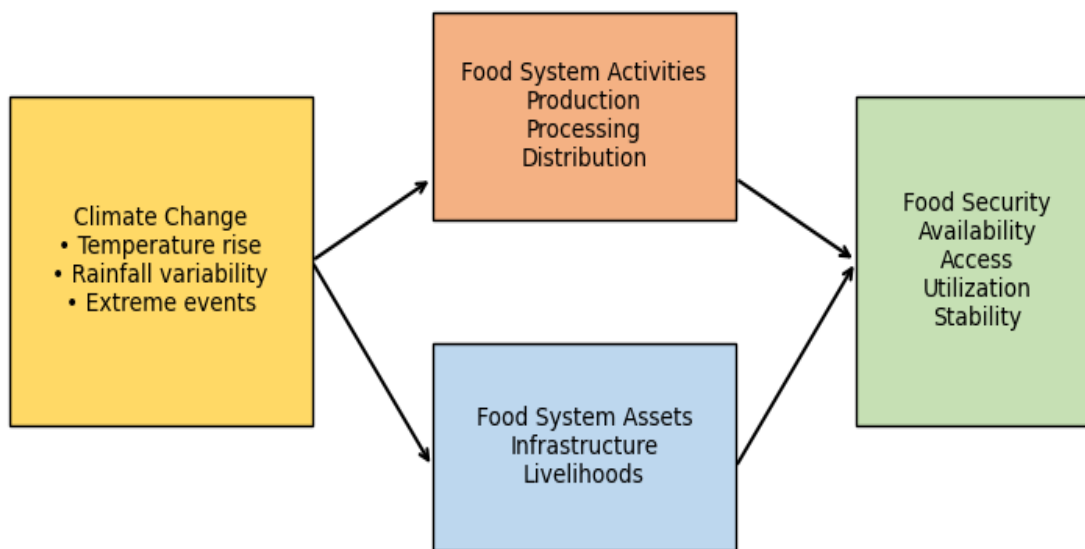


Figure-1: Diagram clearly shows the link between climate change and food security. Climate change (yellow) influences both food system activities (orange) such as production, processing, and distribution, and food system assets (blue) like infrastructure and livelihoods. Together, these determine food security outcomes (green), including availability, access, utilization, and stability. The colour coding helps distinguish each component and emphasizes how climate impacts flow through the food system to affect overall food security.

REVIEW OF LITERATURE:

Climate Change and Agricultural Productivity: Agriculture is one of the sectors most vulnerable to climate change due to its direct dependence on climatic variables such as temperature (Figure-2) precipitation, and atmospheric CO₂ concentration. Numerous studies indicate that rising global temperatures have already begun to negatively affect crop yields in many regions. Lobell et al. (2011) reported that climate change has reduced global wheat and maize production by 5.5% and 3.8%, respectively, since 1980. Projections suggest that without adaptation, crop yields in tropical and subtropical regions may decline significantly by mid-century due to heat stress and water scarcity (IPCC, 2022). Extreme weather events such as droughts, floods, and heat waves have increased in frequency and intensity, posing severe threats to both rain-fed and irrigated agriculture. Drought stress affects physiological processes in plants, reducing photosynthesis, nutrient uptake, and grain filling, while floods damage root systems and promote pest and disease outbreaks (Porter et al., 2014). Smallholder farmers in developing countries are particularly vulnerable due to limited access to irrigation, technology, and climate

information. Rising atmospheric CO₂ levels may enhance photosynthesis and biomass production in some crops (the CO₂ fertilization effect), particularly C₃ plants such as rice and wheat. However, the benefits are often offset by heat stress, water limitations, and nutrient constraints, leading to uncertain yield outcomes (Ainsworth & Long, 2021). Moreover, elevated CO₂ has been shown to reduce concentrations of essential nutrients such as zinc, iron, and protein in staple crops, posing a hidden threat to global nutrition (Myers et al., 2014).

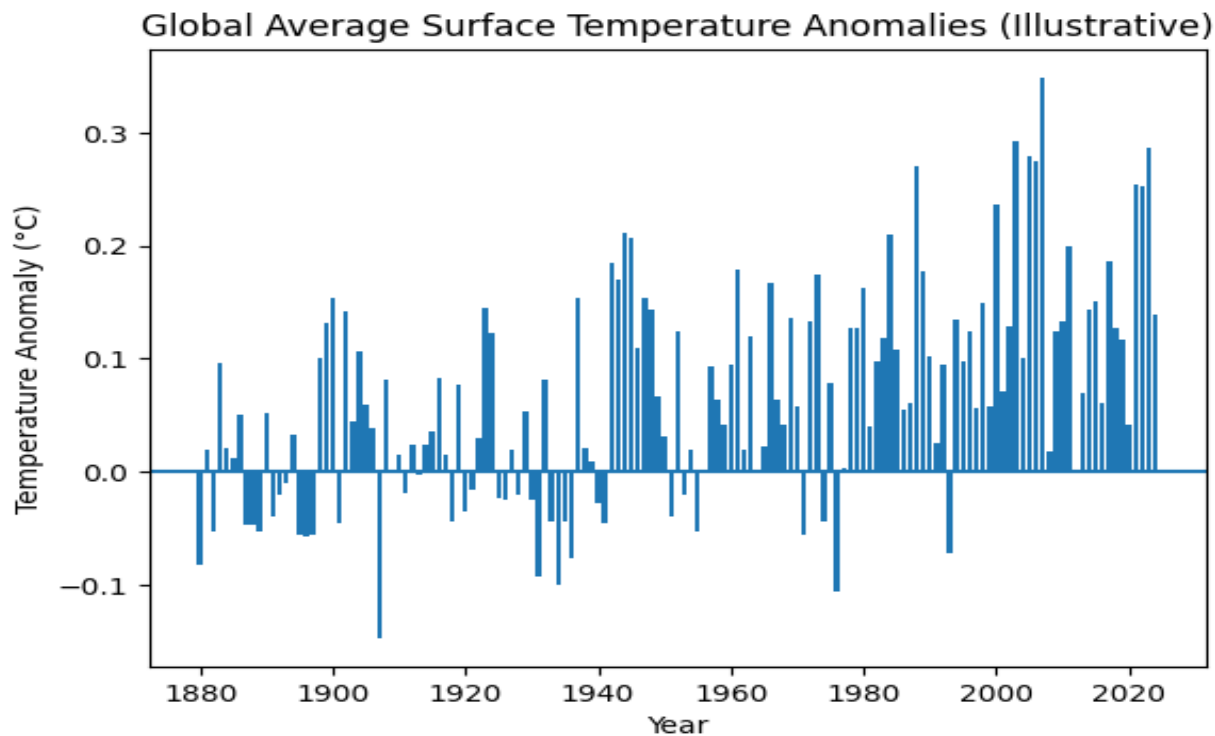


Figure-2: Figure shows a clear long-term rise in global average surface temperature anomalies over time. Early years are mostly cooler than the baseline, while recent decades are dominated by positive anomalies, indicating sustained global warming. This pattern highlights the increasing influence of anthropogenic climate change on the Earth's temperature system (IPCC, 2022).

Climate Change, Soil Health, and Land Degradation: Soil health plays a critical role in food production, yet it is increasingly threatened by climate change. Rising temperatures accelerate soil organic matter decomposition, reducing soil fertility and carbon storage capacity (Lal, 2020). Changes in rainfall patterns exacerbate soil erosion, salinization, and desertification, particularly in arid and semi-arid regions. According to FAO (2017), nearly 33% of global soils are moderately to highly degraded, directly impacting agricultural productivity and food security. Climate-induced land degradation reduces water retention and nutrient availability, making soils less resilient to climatic shocks. Sustainable land management practices such as conservation tillage, organic amendments, crop rotation, and agroforestry have been recommended to enhance soil resilience and mitigate climate impacts (Smith et al., 2020). These practices also contribute to climate change mitigation by increasing soil carbon sequestration.

Food Supply Chains and Climate Variability: Beyond agricultural production, climate change affects food security through disruptions in food supply chains, including storage, transportation, processing, and distribution. Extreme weather events damage infrastructure such as roads, ports, and warehouses, leading to post-harvest losses and food shortages (Vermeulen et al., 2012). Climate-related disruptions can increase food price volatility, making food less affordable for low-income populations. Globalized food systems are particularly vulnerable to climate shocks occurring in major food-producing regions. For example, climate-induced crop failures in exporting countries can affect global food availability and prices, as observed during the 2007–2008 global food crisis (Headey & Fan, 2008). Strengthening local food systems, improving storage facilities, and enhancing early warning systems are considered essential strategies for reducing climate-related risks in food supply chains.

Climate Change and Food Safety: Climate change also poses emerging risks to food safety and public health. Rising temperatures and humidity create favourable conditions for the proliferation of food-borne pathogens such as *Salmonella* and *E. coli* (Tirado et al., 2010). Increased incidence of floods can contaminate agricultural fields with pathogens and chemical pollutants, compromising food quality. Additionally, climate change influences the distribution and toxicity of mycotoxin-producing fungi, particularly in cereals and legumes. Studies indicate that warmer and wetter conditions may increase aflatoxin contamination, posing serious health risks, especially in developing countries with limited food safety regulations (Paterson & Lima, 2010).

Vulnerability, Inequality, and Nutrition Security: The impacts of climate change on food security are unevenly distributed across regions and populations. Low-income countries, smallholder farmers, women, and children are disproportionately affected due to limited adaptive capacity and reliance on climate-sensitive livelihoods (FAO et al., 2021). Climate change exacerbates existing inequalities by reducing food availability, increasing prices, and limiting access to nutritious food. Nutritional security is increasingly recognized as a key dimension of food security. Climate change affects not only food quantity but also dietary diversity and nutrient content. Reduced availability of fruits, vegetables, and animal-source foods can lead to micronutrient deficiencies, particularly among children and pregnant women (Springmann et al., 2016). Addressing climate change impacts on nutrition requires integrating agricultural, health, and social protection policies.

Climate-Smart Agriculture and Integrated Policy Approaches: Climate-smart agriculture (CSA) has emerged as a holistic approach to address the challenges of climate change and food security. CSA aims to sustainably increase agricultural productivity, enhance resilience to climate variability, and reduce greenhouse gas emissions where possible (FAO, 2013). Practices such as drought-tolerant crop varieties, precision agriculture, integrated nutrient management, and efficient water use have shown promising results across different agro-ecological zones. However, successful implementation of CSA requires supportive policies, institutional frameworks, and investment in research and capacity building. Integrated policies that align climate adaptation, mitigation, food security, and nutrition goals are essential to achieving the United Nations Sustainable Development Goals, particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action) (United Nations, 2015).

MATERIALS AND METHODS:

This study is based on a systematic narrative review of peer-reviewed scientific literature, reports from international organizations, and authoritative policy documents addressing climate change and global food security in the 21st century. The review methodology was designed to synthesize existing knowledge on the impacts of climate change on agricultural productivity, soil health, food supply chains, food safety, nutrition security, and policy responses. Relevant literature was identified through comprehensive searches of major academic databases including Web of Science, Scopus, Google Scholar, and PubMed, along with institutional repositories of organizations such as the Food and Agriculture Organization (FAO), Intergovernmental Panel on Climate Change (IPCC), and the United Nations. Keywords and search strings used included combinations of “climate change,” “global food security,” “agricultural productivity,” “soil degradation,” “food supply chains,” “nutrition security,” and “climate-smart agriculture.”

Publications from 2000 to 2023 were prioritized to ensure relevance to contemporary climate trends and food system challenges, while seminal earlier studies were included where necessary for conceptual grounding. Only English-language sources were considered. Studies were selected based on their scientific credibility, relevance to the review objectives, and contribution to understanding climate–food system interactions at global and regional scales. The collected literature was critically analysed and categorized into thematic areas: (i) climate change impacts on crop productivity, (ii) soil health and land degradation, (iii) food supply chains and price volatility, (iv) food safety and public health risks, (v) vulnerability and nutrition security, and (vi) climate-smart agriculture and integrated policy approaches. A qualitative synthesis approach was employed to identify trends, consensus, knowledge gaps, and policy implications. This integrative review approach enables a holistic understanding of the multifaceted relationship between climate change and global food security, providing a foundation for evidence-based recommendations for researchers, policymakers, and stakeholders.

RESULT & DISCUSSION:

The review reveals that climate change has already exerted measurable and increasingly severe impacts on global food security, with implications across agricultural productivity, food quality, supply chains, and socio-economic equity. Evidence from multiple studies confirms that rising temperatures, altered precipitation patterns, and increased climate variability are negatively affecting crop yields, particularly in tropical and subtropical regions. Global analyses indicate that climate change has reduced wheat and maize yields by 5.5% and 3.8%, respectively, since 1980, highlighting the vulnerability of major staple crops to warming trends (Lobell et al., 2011). Projections from the IPCC (2022) further suggest that yield losses will intensify without effective adaptation measures, posing serious risks to future food availability (Figure-3). Beyond yield quantity, the review underscores a significant decline in food quality linked to elevated atmospheric CO₂ concentrations. Experimental evidence demonstrates reductions in protein, iron, and zinc content in staple crops such as rice and wheat under higher CO₂ conditions (Myers et al., 2014). These findings suggest that climate change threatens not only caloric sufficiency but also nutritional security, potentially exacerbating “hidden hunger,” particularly among vulnerable populations in low-income countries (Springmann et al., 2016).

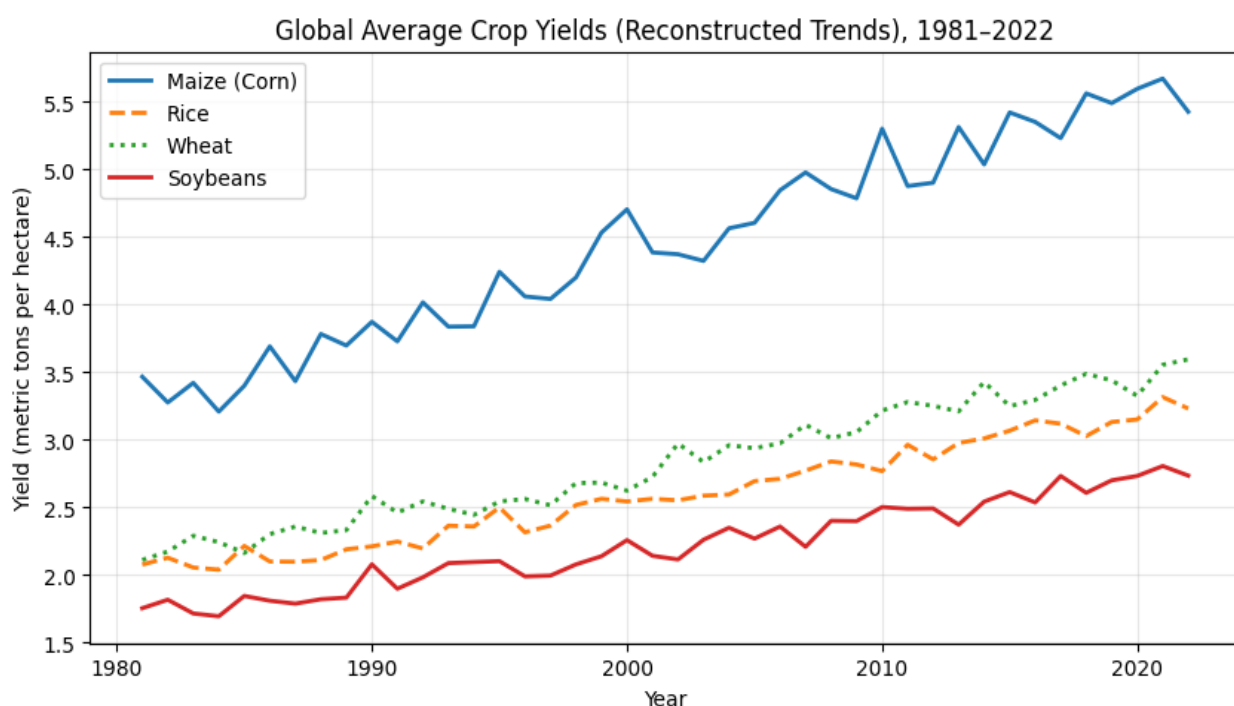


Figure-3: The figure illustrates long-term global trends in average crop yields for major staple crops between 1981 and 2022. All four crops show a sustained upward trajectory, reflecting the combined effects of technological improvements, intensification, improved crop varieties, and expanded use of fertilizers and irrigation. Maize exhibits the strongest yield growth, while wheat and rice display more moderate but consistent increases. Soybean yields improve at a slower rate, reflecting crop-specific physiological and management constraints. Despite overall gains, the figure does not capture growing spatial variability and climate-related yield risks, which increasingly threaten yield stability in many regions.

Soil degradation emerges as a critical mediating factor between climate change and food insecurity. Approximately one-third of the world’s soils are moderately to highly degraded, limiting their capacity to support resilient agricultural systems (FAO, 2017). Rising temperatures accelerate soil organic matter decomposition, while erratic rainfall intensifies erosion and salinization, reducing long-term productivity (Lal, 2020). The reviewed literature consistently highlights sustainable soil management practices such as conservation tillage, organic amendments, and agroforestry as effective strategies to enhance soil resilience and contribute to climate mitigation through carbon sequestration (Smith et al., 2020).

The analysis also demonstrates that climate change disrupts food supply chains, increasing post-harvest losses and price volatility. Extreme weather events damage infrastructure and restrict market access, with cascading effects on food availability and affordability (Vermeulen et al., 2012). The 2007–2008 global food crisis illustrates how climate-related shocks in major exporting regions can rapidly escalate into global food price spikes, disproportionately affecting poor consumers (Headey & Fan, 2008). Food safety risks associated with climate change represent an emerging but critical concern. Warmer and more humid conditions favour the proliferation of food-borne pathogens and mycotoxin-producing fungi, increasing health risks, especially in regions with limited regulatory capacity (Paterson & Lima, 2010; Tirado et al., 2010). These risks further compound the burden of malnutrition and disease in climate-vulnerable populations (figure-4).

Conceptual Diagram: Vulnerability to Food Insecurity under Climate Change

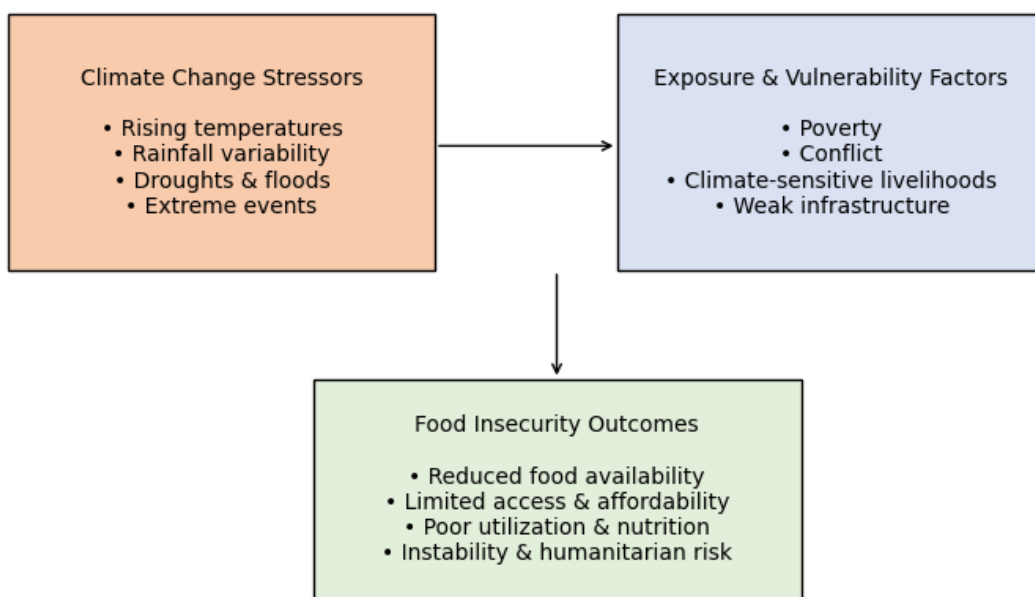


Figure-4: This conceptual diagram illustrates how climate change stressors interact with socio-economic vulnerability factors to increase the risk of food insecurity. Climate extremes affect food systems directly, while poverty, conflict, and limited adaptive capacity determine the severity of impacts on populations. As a result, vulnerable regions experience reduced food availability, access, utilization, and stability, increasing the likelihood of humanitarian crises.

Overall, the findings emphasize that climate change amplifies existing inequalities in food systems. Smallholder farmers, women, and children face heightened exposure due to limited adaptive capacity and dependence on climate-sensitive livelihoods (FAO et al., 2021). The literature strongly supports climate-smart agriculture (CSA) as a viable pathway to address these interconnected challenges by enhancing productivity, resilience, and sustainability (FAO, 2013). However, the effectiveness of CSA depends on integrated policy frameworks, institutional support, and alignment with broader development goals, particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action) (United Nations, 2015).

CONCLUSION:

In conclusion, the reviewed evidence confirms that climate change poses a multidimensional threat to global food security. Addressing these challenges requires coordinated, science-based, and equity-focused strategies that integrate agricultural innovation, nutrition sensitivity, and climate policy to ensure sustainable and resilient food systems in the 21st century.

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