International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Review Article)

Check for updates

# Climate applications for food and safety: A review

Chidinma A. Okafor [1,*] and Chidi C. Uhuegbu [2]

[1] *Department of Biological Sciences, Faculty of Natural and Applied Sciences, Godfrey Okoye University, Ugwuomu Nike, Enugu, Nigeria.*

[2] *Department of Physical and Geosciences, Faculty of Natural and Applied Sciences, Godfrey Okoye University, Ugwuomu Nike, Enugu, Nigeria.*

International Journal of Science and Research Archive, 2025, 16(02), 1447-1454

Publication history: Received on 18 July 2025; revised on 25 August 2025; accepted on 28 August 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.16.2.2478

## Abstract

Climate change continues to reshape environmental conditions across the globe as its impact on food safety and food systems has become increasingly urgent. Increasing temperatures, high precipitation, and intensified weather events pose direct and indirect threats to agricultural production, food processing, transportation, and storage. These climate-related disruptions introduce new food safety risks, exacerbate existing hazards, and challenge the integrity of supply chains. This review explores the dynamic intersection of climate science and food safety, highlighting both vulnerabilities and emerging adaptive strategies. It evaluates climate-smart agricultural technologies, predictive modeling tools, cold chain innovations, and interdisciplinary approaches aimed at strengthening the resilience of food systems. Case studies demonstrate practical applications in sectors such as dairy, grain storage, and fresh produce handling, while attention is also given to policy frameworks, international agreements, and certification systems that incorporate climate risk management. Challenges such as technological gaps, regulatory barriers, and inequities in resource access are critically analyzed. The paper concludes by outlining future research priorities, including artificial intelligence-driven forecasting, advanced traceability techniques, and capacity-building in climate-vulnerable regions. Through these integrated climate applications, food systems can transition from reactive to proactive risk management, enhancing food safety and nutritional security in an era of increasing climate variability.

**Keywords:** Food Safety; Climate Application; Risk Management; Environmental Condition; Food Security

* Corresponding author: CHIDINMA A. OKAFOR.

**Graphic abstract**


## 1. Introduction

The interconnection between climate change and food systems has drawn critical interest in recent years, as the escalating impacts of global warming pose unprecedented challenges to food safety and security. Climate change influences every angle of food systems, from crop production and animal husbandry to storage, transportation, and consumption, through rising temperatures, shifting forms of precipitation, sea-level rise, and rising frequency of intense weather events [1, 2]. These climatic stressors not only disrupt food production and supply chains but also heighten food safety risks by promoting the development and spread of foodborne pathogens, toxins, and chemical contaminants [3, 4].

The evolving threat landscape necessitates the integration of climate science into food safety frameworks. Conventional food safety monitoring systems must now accommodate climate-sensitive variables to remain effective. As such, climate application tools that leverage climate data, forecasting models, and risk assessments are emerging as essential mechanisms to predict, manage, and mitigate climate-related food safety risks [5, 6]. This review explores the effects of climate change on food safety and highlights the role of climate-smart technologies, predictive models, and adaptive strategies in ensuring food system resilience.

### *Highlights*

- Climate change intensifies food safety risks by disrupting agricultural production, supply chains, and storage systems.
- Emerging technologies like AI and IoT are revolutionizing climate-responsive food safety.
- Climate-smart agriculture and cold chain innovations enhance resilience.
- Policy frameworks and industry standards integrate climate risk into food safety strategies.
- Capacity building and interdisciplinary research are crucial.

## 2. Climate Impacts on Food Systems

### 2.1. Direct Effects on Agricultural Production

Agricultural production is the frontline of climate vulnerability in food systems. Rising global temperatures have been shown to reduce yields in temperature-sensitive crops such as wheat and maize while potentially increasing productivity in others like sorghum and millet [7]. Altered precipitation regimes and prolonged droughts have destabilized rain-fed agricultural practices, mostly in South Asia and sub-Saharan Africa [1]. These shifts directly affect not just crop quantity but also nutritional quality, with heat stress shown to lower protein and micronutrient content in staples like wheat and rice [8].

Extreme weather situations like floods, hurricanes, and heatwaves, compound these challenges by increasing the risk of microbial contamination and toxin production. For instance, higher temperatures and humidity favour the proliferation of mycotoxin-producing fungi such as *Aspergillus flavus*, which contaminates crops like maize and groundnut [9]. Drought conditions can also cause the accumulation of nitrates and other chemical hazards in edible plants, while floods facilitate the spread of foodborne bacteria like *Salmonella* and *E. coli* through contaminated water sources [10]. Figure 2 presents how food safety is impacted by climate change.

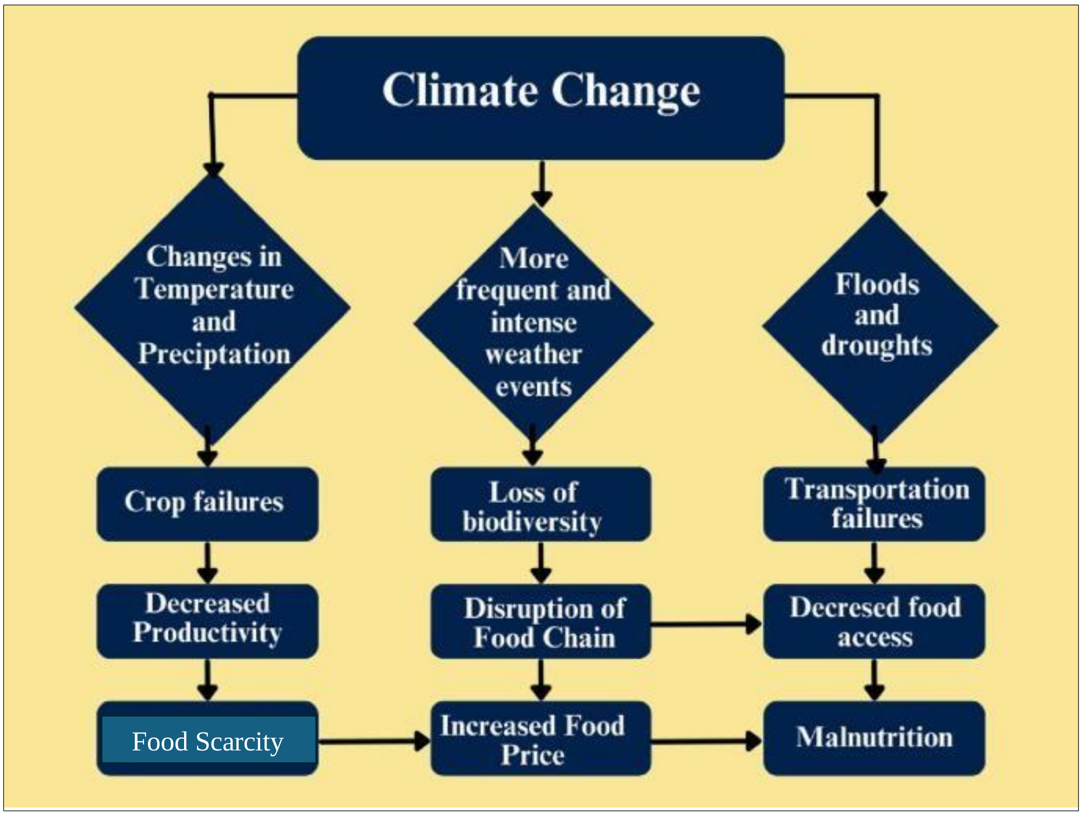


**Figure 1** The impact of climate change on food safety

### 2.2. Indirect Effects Through Supply Chain Disruption

Beyond primary production, climate change also exerts indirect pressure on food systems by affecting logistics and infrastructure. Disruptions in transportation networks due to landslides, flooding, or extreme heat can compromise cold chain logistics, which are critical for preserving perishable items like dairy, seafood, and fresh produce [11]. Even brief interruptions in refrigeration can significantly increase the growth rate of pathogenic microorganisms such as *Listeria monocytogenes*, threatening consumer health. Climate-induced damage to food storage and processing facilities not only increases the risk of contamination but also reduces the capacity of food systems to buffer against shocks. In low- income regions, where post-harvest losses are already high, these disruptions can lead to cascading failures that amplify food insecurity [12]. Therefore, reinforcing infrastructure with climate-resilient materials and technologies is a growing priority in global food safety strategy.

## 3. Emerging food safety risks under climate change

The intersection of climate change and food safety introduces novel risks and addresses existing hazards. Warming temperatures can expand the geographic zone and seasonal variations of foodborne pathogens, leading to more frequent outbreaks [13]. For example, warmer ocean waters have been linked to the increased prevalence of Vibrio spp., which cause seafood- borne illnesses [14]. Likewise, increased rainfall and flooding events elevate the risk of *E. coli* and *Campylobacter* contamination in surface water applied to irrigation and processing.

Changes in pest and vector populations driven by climate variability may also lead to greater pesticide usage, raising concerns about chemical residues in food products [15]. Concurrently, heat stress during storage may accelerate lipid oxidation and spoilage in animal products, while facilitating the migration of packaging-related chemicals such as bisphenol-A (BPA) into food items [11].

Additionally, the proliferation of naturally occurring toxins like cyanogenic glycosides in cassava and aflatoxins in cereals is expected to increase with climate stress, threatening both public health and food safety [16]. These risks call for adaptive surveillance systems and the development of novel climate-responsive food safety standards and monitoring technologies.

## 4. Policy Frameworks and Implementation Strategies

### 4.1. International Initiatives and Agreements

Climate-resilient food systems are a growing priority in global policy frameworks, particularly under the guidance of the United Nations Sustainable Development Goals (SDGs), which emphasize the integration of climate action with food security [17]. Key agreements, such as the Paris Agreement, recognize the agricultural dual role as both a victim and contributor to climate change and advocate for climate-smart food policies [18]. International funding mechanisms like the Green Climate Fund have increasingly supported food system adaptation projects that enhance resilience and safety, including early warning systems for crop failure and investments in cold chain infrastructure [19].

### 4.2. National and Regional Adaptation Strategies

At the national level, countries have developed climate adaptation plans specific to agriculture and food safety. For instance, the United States Climate-Smart Agriculture and Forestry Strategy promotes sustainable intensification and improved risk management tools for farmers [20]. Similarly, African nations, through the Comprehensive Africa Agriculture Development Programme (CAADP), are developing regional strategies that combine agroecological practices with climate-resilient storage and processing techniques [21]. Regional collaborations like Farm to Fork Strategy of the European Union also integrate climate considerations into food safety legislation, emphasizing traceability and sustainable consumption [22].

### 4.3. Industry Standards and Certification Systems

Food industry standards are increasingly incorporating climate risk assessments. Certification schemes like Global Good Agricultural Practice (G.A.P) and Rainforest Alliance have revised their criteria to include climate- smart practices such as soil carbon management and adaptive irrigation [23]. Traceability systems now integrate climate data to monitor temperature fluctuations and potential exposure to contamination during food transit [24]. These developments ensure that food producers are not only compliant with food safety but also resilient to climate-induced hazards.

## 5. Case Studies and Applications

### 5.1. Dairy Industry Climate Adaptation

In the dairy industry, rising temperatures affect milk yield, microbial stability, and shelf life. In India, for instance, milk spoilage has increased due to insufficient refrigeration and heat stress on livestock [25]. Adaptive strategies such as solar-powered chillers, heat- resistant fodder, and wearable sensors to monitor cow health have been implemented to mitigate climate effects and maintain food safety [26]. In the EU, smart cooling logistics have helped reduce pathogen growth in milk chains during high-heat seasons [27].

### 5.2. Grain Storage and Distribution

Grains are susceptible to mold and mycotoxin contamination due to changing humidity and temperature levels during storage. In Nigeria, hermetic storage bags have proven effective in preserving grain quality under fluctuating climate conditions [28]. In Canada, AI-driven ventilation systems are used to regulate moisture in grain silos based on local weather forecasts [29]. These practices highlight the need for integrating predictive tools with storage systems to ensure safety.

### 5.3. Fresh Produce Safety

Fresh produce, especially leafy greens, is vulnerable to climate-induced water contamination. After flood events, *E. coli* outbreaks have been linked to contaminated irrigation sources [30]. In California, farms use remote sensing to monitor water quality and soil moisture, reducing contamination risks during climate anomalies [31]. Additionally, packaging innovations like biodegradable films with antimicrobial properties are now employed to extend shelf life under variable temperature conditions [32].

## 6. Challenges and Limitations

### 6.1. Technical and Infrastructure Constraints

Many developing nations lack the infrastructure to implement climate-smart food systems. Poor weather monitoring, limited cold chain facilities, and insufficient lab capacity hinder early detection of food safety threats [17]. Moreover, integrating high-tech solutions like AI and IoT requires digital literacy and sustained investment, which are often unavailable in rural food-producing regions [33].

### 6.2. Institutional and Regulatory Barriers

Fragmented governance across the agriculture, environment, and health sectors creates regulatory bottlenecks. For example, in some low-income countries, food safety authorities lack mandates to address climate risks in food systems [34]. Harmonization of standards and cross-sectoral policy coordination are essential for implementing climate-resilient food safety measures [35].

### 6.3. Economic and Social Considerations

The high cost of adaptive technologies, such as climate-controlled storage or bio-fortified crops, often limits accessibility for smallholder farmers. Without subsidies or financial incentives, adoption rates remain low [36]. Furthermore, consumer awareness of climate-related food safety issues remains minimal, underlining the need for public education campaigns to foster demand for safer, climate-smart food [17].

## 7. Future Directions and Research Priorities

### 7.1. Technological Innovations

Advancements in digital agricultural systems and food safety programs are central to future climate-resilient food systems. Artificial intelligence (AI) and machine learning (ML) tools are increasingly used to analyze large datasets related to weather patterns, crop performance, pathogen outbreaks, and supply chain vulnerabilities [37]. These technologies can identify early warning signals and offer real-time insights to mitigate food safety risks before they escalate. AI- powered predictive models have been used successfully in managing mycotoxin outbreaks and foodborne illness prediction [38].

The use of Internet of Things (IoT) devices and smart sensors enhances traceability and control throughout the supply food chain. These devices collect granular data on temperature, humidity, and contamination risks during production, processing, and distribution [2]. Blockchain technology, when integrated with IoT, offers transparent data storage and verification, reducing fraud and ensuring accountability in climate-sensitive food systems [39].

### 7.2. Interdisciplinary Research Approaches

Future efforts should emphasize interdisciplinary collaboration across climate science, food safety, agricultural economics, public health, and social sciences. For instance, systems thinking can help map out the complex interplay between climate attributes and food system outcomes, creating a comprehensive framework for adaptive planning [40].

Integration of participatory research methods with traditional modeling approaches allows for the co-creation of locally adapted strategies that mitigate environmental and socio-economic issues [41].

Moreover, scenario planning using integrated assessment models enables the exploration of multiple futures under various climate and socio-economic trajectories, offering flexible policy options. These models help stakeholders understand trade-offs amongst addressing, adapting and evaluating food security outcomes [42].

### 7.3. Capacity Building and Knowledge Transfer

Building capacity in low and middle-income countries is essential for evaluating climate applications for food safety. This includes training agricultural extension workers, food safety inspectors, and producers in climate-smart practices and risk-based food safety management systems [43]. Investment in data infrastructure, especially meteorological and food surveillance systems, will empower countries to adopt early warning systems and improve outbreak response times.

South-South cooperation and international knowledge-sharing platforms are crucial for disseminating successful models. Initiatives like the Climate-Smart Agriculture Knowledge Hub and Consultative Group on International Agricultural Research (CGIAR) of FAO research programs have facilitated technology transfer and policy innovation across continents [42].

## 8. Conclusion

The convergence of climate change and food safety concerns demands a paradigm shift in how we approach food system resilience. As demonstrated in this review, climate change disrupts agricultural productivity, alters pathogen behavior, and weakens supply chain infrastructure thereby elevating the concerns of foodborne illnesses, contamination, and nutritional deficiencies. However, the growing field of climate applications provides powerful tools to counter these threats. Predictive models, climate-smart agriculture, smart cold chains, and early warning systems offer promising pathways to adapt and protect food safety under changing environmental conditions. Effective integration of these applications requires not only technological innovation but also robust interdisciplinary collaboration, inclusive policy frameworks, and strategic investment in capacity building, especially in vulnerable and resource-limited regions. As global institutions move toward aligning agriculture and food operations with climate commitments such as the Paris Agreement and the UN Sustainable Development Goals, embedding food safety into climate adaptation policies is more important than ever.

Future research should continue to explore innovative technologies such as AI and IoT, while also addressing socio-economic and governance barriers to implementation. By aligning climate science with food safety objectives, stakeholders can safeguard public health, stabilize food supply chains, and ensure that global food systems remain secure, sustainable, and equitable in the face of a dynamic climate.

## Compliance with ethical standards

*Disclosure of conflict of interest*

The authors declare no conflict of interest.

*Funding*

This review received no funding support.

## References

[1] Food and Agriculture Organization of the United Nations. The State of Food and Agriculture 2021: Making agri-food systems more resilient to shocks and stresses. Rome: FAO; 2021.

[2] Kamilaris A, Kartakoullis A, Prenafeta-Boldú FX. A review on the practice of big data analysis in agriculture. Comput Electron Agric. 2017;143:37–49. https://doi.org/10.1016/j.compag.2017.09.037

[3] MacDougall C, Chambers HF. Aminoglycosides. In: Brunton LL, Chabner BA, Knollman BJ, editors. Goodman and Gilman's The Pharmacological Basis of Therapeutics. 12th ed. New York: McGraw-Hill; 2011. p.1505–20.

[4] Miraglia M, Marvin HJP, Kleter GA, Battilani P, Brera C, Cocconcelli E, Cornaglia G, Ramos F, Vass M, Vespermann A. Climate change and food safety: An emerging issue with special focus on Europe. Food Chem Toxicol. 2009;47(5):1009–22. https://doi.org/10.1016/j.fct.2009.02.005

[5] Luber G, Prudent N. Climate change and human health. Trans Am Clin Climatol Assoc. 2009;120:113–27.

[6] Havelaar AH, Kirk MD, Torgerson PR, Gibb HJ, Hald T, Lake RJ, Praet N, Bellinger DC, de Silva NR, Gargouri N, Speybroeck N, Cawthorne A, Mathers C, Stein C, Angulo FJ, Devleesschauwer B. World Health Organization estimates of the global and regional disease burden of 31 foodborne hazards. PLoS Med. 2021;12(12):e1001923. https://doi.org/10.1371/journal.pmed.1001923

[7] Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. Science. 2011;333(6042):616–20. https://doi.org/10.1126/science.1204531

[8] Myers SS, Zanobetti A, Kloog I, Huybers P, Leakey AD, Bloom AJ, Carlisle E, Dietterich LH, Fitzgerald G, Hasegawa T, Holbrook NM, Nelson RL, Ottman MJ, Raboy V, Sakai H, Sartor KA, Schwartz J, Seneweera S, Tausz M, Usui Y. Increasing $CO_2$ threatens human nutrition. Nature. 2014;510(7503):139–42. https://doi.org/10.1038/nature13179

[9] Medina A, Rodríguez A, Magan N. Effect of climate change on Aspergillus flavus and aflatoxin B1 production. Front Microbiol. 2014;5:348. https://doi.org/10.3389/fmicb.2014.00348

[10] World Health Organization. Food safety in the context of climate change. Geneva: WHO; 2022.

[11] Olabi A, Barbano DM. Temperature-induced moisture migration in reduced-fat Cheddar cheese. Journal of dairy science. 2002 Sep 1;85(9):2114-21.

[12] High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Food security and nutrition: Building a global narrative towards 2030. Rome: HLPE; 2020.

[13] Miraglia M, Marvin HJ, Kleter GA, Battilani P, Brera C, Coni E, Cubadda F, Croci L, De Santis B, Dekkers S, Filippi L. Climate change and food safety: an emerging issue with special focus on Europe. Food and chemical toxicology. 2009 May 1;47(5):1009-21.

[14] Baker-Austin C, Trinanes JA, Taylor NG, Hartnell R, Siitonen A, Martinez-Urtaza J. Emerging Vibrio risk at high latitudes in response to ocean warming. Nat Clim Change. 2013;3(1):73–7.

[15] Yamanoshita M. IPCC special report on climate change and land. Institute for Global Environmental Strategies.; 2022.

[16] Van der Fels-Klerx HJ, Vermeulen LC, Gavai AK, Liu C. Climate change impacts on aflatoxin B1 in maize and aflatoxin M1 in milk: A case study of maize grown in Eastern Europe and imported to the Netherlands. PLoS One. 2019 Jun 27;14(6):e0218956.

[17] Food and Agriculture Organization of the United Nations. The State of Food Security and Nutrition in the World 2022. Rome: FAO; 2022.

[18] United Nations Framework Convention on Climate Change. Paris Agreement. Bonn: UNFCCC; 2015. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement

[19] Green Climate Fund. Green Climate Fund projects on climate-smart agriculture. Songdo: GCF; 2021. Available from: https://www.greenclimate.fund/projects

[20] United States Department of Agriculture. Climate-Smart Agriculture and Forestry Strategy. Washington DC: USDA; 2022.

[21] New Partnership for Africa's Development. Africa Agriculture Transformation Scorecard. African Union Development Agency; 2021.

[22] European Commission. Farm to Fork Strategy. Brussels: EC; 2020. Available from: https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

[23] Rainforest Alliance. Certification Standard: Sustainable Agriculture. New York: Rainforest Alliance; 2021. Available from: https://www.rainforest-alliance.org

[24] Codex Alimentarius. Guidelines for food traceability and import inspection. FAO/WHO; 2022.

[25] Subhankar B, Ajay V, R. Sendhil, AK Dixit, Ajmer S. Ponnusamy K. Impact of Climate Change on Milk Production and Perceptions of Farmers in West Bengal. 2021;39(11):533–540

[26] Thornton PK, van de Steeg J, Notenbaert A, Herrero M. Climate change adaptation in livestock systems. Agricultural system. 2009;101(3):113-127.

[27] Garbero A, Jäckering L. The potential of agricultural programs for improving food security: A multi-country perspective. Global Food Security. 2021 1;29:100529.

[28] Abbas AM, Abbas II, Agada IG. Reducing postharvest losses in Nigeria's agricultural sector: pathway to sustainable agriculture. Innoriginal: International Journal of Sciences. 2018 Jan 21;5(2):16-21.

[29] Jayas DS. Grain storage for food security and safety: research at the University of Manitoba, Canada. Journal of Agricultural Engineering. 2012;49(1):1.

[30] Centers for Disease Control and Prevention. Outbreaks of E. coli linked to leafy greens. Atlanta: CDC; 2023. Available from: https://www.cdc.gov

[31] Galal YG, Soliman SM. Soil and Water Management by Climate Smart and Precision Agriculture Systems under Arid Climate. Managing Soil Drought; CRC Press: Boca Raton, FL, USA. 2024 Jun 10:310-61.

[32] An L, Hu X, Perkins P, Ren T. A sustainable and antimicrobial food packaging film for potential application in fresh produce packaging. Frontiers in Nutrition. 2022 Jul 7;9:924304.

[33] World Bank. Building resilient food systems: A policy roadmap. Washington DC: World Bank; 2021. Available from: https://www.worldbank.org

[34] World Health Organization. Climate change and food safety: Emerging risks. Geneva: WHO; 2020.

[35] Swensson LF, Tartanac F. Public food procurement for sustainable diets and food systems: the role of the regulatory framework. Global Food Security. 2020 Jun 1;25:100366.

[36] Altieri MA, Nicholls CI, Henao A, Lana MA. Agroecology and the design of climate change-resilient farming systems. Agron Sustain Dev. 2015;35(3):869–90.

[37] Benke K, Tomkins B. Future food-production systems: Vertical farming and controlled-environment agriculture. Sustain Sci Pract Policy. 2017;13(1):13–26. https://doi.org/10.1080/15487733.2017.1394054

[38] Gachoki S, Muthoni F, Mahuku G, Atehnkeng J, Njeru N, Kamau J, Tripathi L. Predicting aflatoxin risk in maize using machine learning and satellite data in East and Southern Africa. World Mycotoxin Journal. 2025 Apr 8;18(2-3):101-20.

[39] Behnke K, Janssen MFWH. Boundary conditions for traceability in food supply chains using blockchain technology. Int J Inf Manag. 2020;52:101969. https://doi.org/10.1016/j.ijinfomgt.2019.05.025

[40] Ingram J. Agricultural adaptation to climate change: New approaches to knowledge production. Geogr J. 2017;183(4):313–24. https://doi.org/10.1111/geoj.12182

[41] Eakin H, Connors JP, Wharton C, Bertmann F, Xiong A, Stoltzfus J. Identifying attributes of food system sustainability: Emerging themes and consensus. Agric Human Values. 2017;34:757–73. https://doi.org/10.1007/s10460-017-9764-8

[42] Food and Agriculture Organization of the United Nations. Climate-smart agriculture sourcebook: Second edition. Rome: FAO; 2023. Available from: https://www.fao.org/3/i3325e/i3325e.pdf

[43] Tirado MC, Hunnes D, Cohen MJ, Lartey A. Climate change and nutrition in Africa. Journal of Hunger & Environmental Nutrition. 2015 Jan 2;10(1):22-46.