Received: 6 March 2024 | Revised: 18 June 2024 | Accepted: 15 July 2024

DOI: 10.1002/fes3.567

Food and Energy Security Open Access WILEY

REVIEW

The ripple effects of climate change on agricultural sustainability and food security in Africa

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Abstract

Climate change results in lower agricultural outputs, disruption of food supply chains, and widening of the social gap between poor and rich in developing countries, with more vulnerable groups being pushed into untold poverty. This review aims to investigate the consequences of climate change on food insecurity in Africa in the context of environmental degradation. This review emphasizes the complexity of demands on food security systems due to changing climatic conditions under the four pillars (availability, accessibility, utilization, and stability). This review demonstrated the susceptibility of farm production to changes in temperature, precipitation, and weather patterns generated by climate change. In addition, this review investigated the factors shaping food insecurity, such as increasing population growth, poverty, inadequate early warning systems, and weak agricultural infrastructure. Furthermore, the review points out how climate change affects food prices and availability and the widening income gap, potentially leading to social unrest and political instability in Africa. Vulnerable populations, including impoverished, elderly, and physically challenged individuals, are at increased risk due to climate-related health impacts. Women who face gender inequalities and socioeconomic limitations are particularly susceptible. We posit that there is a need for comprehensive strategies that address health disparities and consider vulnerable subgroups within society alongside broader measures to enhance food security in the face of climate change.

KEYWORDS

agricultural sustainability, climate change, climate change adaptation strategies, food security

1 | INTRODUCTION

1.1 | Background on climate change and its impact on food security

Climate change and multifaceted manifestations in food systems, security, and sustainability are among the top environmental issues that societies currently face, and they have recently gained popularity because of the complexity of their effects. It is a singular concern that has resulted in numerous other types of problems, including a rise in sea level, ocean warming, rising ocean temperature and variable rainfall, increasing evaporation, and rising frequency of tropical storms (Raj et al., 2022). These outcomes have also evolved with many implications, including a fall in agricultural activities, drought, floods, migration, health issues, crises among farmers and herdsmen, and many more challenges, while many others have not been realized (Owino et al., 2022). Halvard et al. (2023) states that climate change is the most critical problem among the many social and technical challenges of the 21st century—this means any change in climate or weather is caused by either natural variance or human activities. The effects of climate change are changing the range and patterns of infectious diseases and pests. For instance, *Spodoptera frugiperda* (the armyworm), which first infested Africa in 2016, has since spread throughout much of the continent and poses a severe danger to the continent's ability to feed itself (Ashagidigbi et al., 2022; Timilsena et al., 2022).

Climate change is a major environmental issue threatening human and ecosystem survival. Due to their effects on agricultural production and systems, which depend on weather, they threaten food security. It directly affects the fertility and moisture of the soil, two physical production elements, and this hurts farming output, which in turn severely influences food security (Malhi et al., 2021). Severe drought conditions worsen due to below-average rainfall, and some places are flooded due to delayed heavy rains. According to Kapwata et al. (2022), the Intergovernmental Panel on Climate Change (IPCC) forecasts show that heatwave frequency and intensity will continue to rise throughout the 21st century, affecting most people in Africa and Asia. According to Cheung et al. (2023), climate change negatively affects land and significantly alters water quality by increasing sea levels, acidity, and surface temperatures. High hazards exist for nations whose reliance on the fishing industry for employment and protein consumption is high. According to previous studies, changing climatic circumstances can initiate a vicious cycle in which contagious diseases exacerbate or induce hunger, increasing the affected population's susceptibility to infectious diseases and reducing their ability to effectively consume food. This makes those who are food insecure more prone to experiencing the detrimental consequences of high temperatures (Uwishema et al., 2023).

In Sub-Saharan Africa, South Asia, and Southeast Asia, where agricultural families are disproportionately poor and vulnerable, approximately 80% of the world's population is in danger of crop failures and famine caused by climate change (Suri, 2021). Major droughts caused by climate change or El Niño weather patterns have the potential to impoverish millions of people. Even in countries with relatively high incomes, such as the Philippines and Vietnam, this is true because farmers frequently live on the border of poverty, and food price hikes disproportionately affect poor urban customers (Patterson, 2023). By June 2022, 345 million people were facing food insecurity across 82 nations, up from 135 million in 2019. This was due to supply chain disruptions, the ongoing economic effects of the COVID-19 pandemic, and the conflict in Ukraine, which increased food costs to unprecedented levels. Climatic occurrences have partly caused an increase in global food insecurity. Weather patterns are affected by global warming, resulting in heatwaves, torrential rains, and droughts. A significant contributing factor to nearly 30 million additional individuals experiencing food insecurity in low-income nations in 2021 is the rising prices of food commodities (The World Bank, 2022; Vicente-Serrano et al., 2022).

The Food and Agricultural Organization (FAO, 2014) found that the number of food insecurities and the percentage of undernourished people have been rising since 2009. In a different study, Fawole et al. (2015) discovered that the key food security indicators consulted in their studies, such as the prevalence of inadequate food and the number of undernourished people, increased between 2009 and 2014. They additionally noted that climate change is another significant phenomenon impacting food scarcity in Africa, as it has distorted productivity patterns. Therefore, it is pertinent to say that if the trajectory is not reversed as soon as feasible, it could pose serious security hazards and danger to the nation and the African subregion. Advancements in the battle against food insecurity are at risk owing to climate change. Climate change exacerbates and triggers risks to food security for the most vulnerable countries and communities, including those in arid and semi-arid areas, landlocked countries, and small island developing states, as highlighted by the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report (FAO, 2015). Recently, global food production has been affected by climate change, particularly in Africa and Nigeria, which has led to diminished food security.

Food insecurity, characterized by irregular access to sufficient food and nutrient-poor diets, is often associated with low incomes and can lead to illnesses, such

as obesity, heart disease, hypertension, diabetes, and other chronic illnesses (FAO et al., 2021). Global climate change impacts are an increasing concern, and developing African nations, such as Nigeria, will be among those most severely affected (Greg et al., 2011). Nigeria's economy is primarily agricultural and rain fed, making it dependent on unpredictable weather patterns. Farmers in Nigeria often struggle to produce crops at high levels because of poverty and inadequate technological progress, resulting in low crop yields (Ayinla et al., 2020). According to the United Nations (UN) (2024), there will likely be a continued increase in hunger and poverty until 2030. Despite this, many people will still be underfed, even among those who consume enough calories, because diets that meet the body's complex nutritional needs and adequate calorie intake are often expensive. As the population of Nigeria is projected to increase from 206 million in 2020 to 263 million in 2030, these issues will only worsen. Additionally, the growing food demand and wider variety of food options in Nigeria could worsen environmental problems as the country's population and economic levels rise.

These challenges are not unique to Nigeria but reflect broader trends across Africa. The continent's economies are heavily reliant on agriculture, with a significant portion of the population engaged in farming (Patterson, 2023). Like Nigeria, many African countries face issues such as poverty, inadequate technological advancement, and climate vulnerability, which hinder agricultural productivity (Omotoso et al., 2023). Climate change exacerbates these issues by causing more frequent and severe droughts, floods, and unpredictable weather patterns, which disrupt farming activities and threaten food security. The rising population across Africa amplifies these challenges, increasing the demand for food and putting additional stress on already strained agricultural systems.

1.2 | Purpose of the review

This review therefore aims to provide a comprehensive examination of the effects of climate change on agricultural sustainability and food security throughout Africa. It will explore the diverse challenges faced by different regions, including the varied climatic, economic, and social conditions that influence agricultural practices and food systems. The review will also highlight adaptive strategies and resilience-building measures being implemented across the continent. The review will draw on a wide range of examples from various African countries to offer a complete picture of the continent's adaptation to climate change.

2 | CLIMATE CHANGE TRENDS IN AFRICA

2.1 | Overview of climate change trends in Africa

Africa's Sub-Saharan region has continuously evolved and has a wide range of climatic, ecological, and cultural conditions (NASAC, 2015). The number of people in Sub-Saharan Africa is expected to reach 2 billion by 2050 and 4 billion by 2100, gaining more billions and millions of people every year (UN Department of Economic and Social Affairs, 2013). However, according to the World Bank Group (2013), GDP grew from 3.7% in 2012 to 4.7% in 2013, despite the recent conflicts in the Central African Republic and South Sudan, which have disrupted economic activities. Of all the world's regions, Sub-Saharan Africa has the highest percentage of the world population living in poverty (World Bank, 2015b). Chronic hunger causes poor growth rates in children under the age of 5, which is a drop from the high prevalence of 39.6% in 2011 (United Nations Children's Fund, World Health Organization, & The World Bank, 2012). A quarter of the world's undernourished people live in Sub-Saharan Africa, with 795 million people suffering from malnutrition (FAO, IFAD, & WFP, 2014).

Climate change is expected to significantly impact food security in coming decades, particularly in underdeveloped and developing nations. This is due to poverty, vulnerability, and lack of resources for adaptation in these regions. Additionally, agriculture is highly susceptible to the effects of climate change, which disproportionately affects rural populations in developing countries that rely on agricultural output for employment and income (Rahut et al., 2022). By 2020, food insecurity, poverty, and displacement in Africa had increased because of climate change. The year 2020 saw several climate indicators in Africa, including persistently rising temperatures, acceleration of sea level rise, harsh weather, and climate catastrophes such as droughts, landslides, and floods, which are disrupted by increased weather and climate variability (Baptista et al., 2022). Up to 118 million of the continent's most impoverished people are predicted to experience drought, flooding, and intense heat by 2030, impeding efforts to reduce poverty and promote prosperity. By 2050, climate change may significantly reduce Sub-Saharan Africa's GDP by 3%. The number of impacted individuals and worsening physical circumstances are significant challenges for climate adaptation and resilience initiatives. Over the next 10 years, it was projected that Sub-Saharan Africa would need to invest $30–50 billion per year in climate adaptation, or around 2%–3% of GDP (United Nations, 2021).

The world's climate is changing, and strong evidence supports this, as indicated by the increasing frequency of

storms, altered rainfall patterns, extreme weather, and elevated temperatures. Global mean annual temperatures have risen by 0.85°C since 1880, by 2050, an increase of 0.3 to 2.5°C is expected (Davis et al., 2017). Southern Africa has experienced significant warming over the last century, with regional temperature trends indicating a rise of 0.4°C per decade between 1961 and 2014, consistent with global climate changes (Weathering Risk, 2023). The increase in temperature and alteration of rainfall patterns are anticipated to continue, resulting in higher risks and uncertainty in regions with limited adaptation capacity. Changes in weather patterns caused by these factors are already visible in Southern Africa, with insect infestations now common, increasing numbers of armyworms and locust invasions, and more droughts and floods (Phophi et al., 2020). Trends in weather observations indicate that only two of the last nine crop seasons have favorable average rain levels (WFP, 2021). Weather pattern changes affect crop growth, adversely affecting both low-income and high-income earners. The cereal market has gone down by a great margin in the last decade, with the number of shortfalls occurring varying from 0.1 to 8.9 million metric tons in this region (SADC, 2022). The 2015–2016 El Niño event caused a 24% decline in cereal production, resulting in a shortfall of 7.9 million metric tons (SADC, 2022).

Climate change threatens the existence of plants and animals that are commonly used as food sources for human consumption. The most common victims of climate change are residents of developing countries who mainly depend on agriculture for their livelihoods and survival (Acquaye, 2021). These effects may be negative and may reduce the pace of development. In addition, the effect of climate change on food security at the national level is also an issue. Climate change adds complexity to the problem of feeding a growing population, in addition to changes in rainfall patterns and weather events that affect agriculture (Malhi et al., 2021). For example, in Ghana, the agricultural economy depends heavily on rainfall and lacks irrigation infrastructure. Changes in rainfall patterns can significantly impact annual food yield, leading to food scarcity and unequal access to food by different socioeconomic groups (Sarku, 2023).

Climate change is forecasted to render food insecurity more severe owing to rising food prices and reduced production (Acquaye, 2021). Ghana, a country affected by climate change, has also suffered from the effects of climate change. Climate change causes an increase in food prices due to energy costs that surge due to mitigation efforts, drought, low water supply for crops because of rising water use for agricultural purposes, and competition for land, as some areas become unsuitable for farming due to climate change. The harsh climate changes caused by climate change can result in sharp drops in agricultural productivity, which will swiftly increase prices. Acquaye (2021) suggested allocating sufficient resources and formulating intentional policies as strategies for handling the impacts of climate change on food security. Efficient irrigation systems, a more scientifically based forecasting mechanism that helps farmers plant crops in the right seasons, planting climate-resistant crops, and environmental protection through conscious and continuous policy can also help reduce the possibility of climate change's impact on food security in Ghana.

Alemu and Mengistu (2019) researched the impact of climate change on food security in Ethiopia, focusing on Adaptation and Mitigation Options, and stated that Africa's food security is already being impacted by climate change. They determined that Ethiopia is vulnerable to climate change because its economies rely mostly on climate-sensitive agricultural output. Concerns regarding food security have grown in response to environmental changes, including variations in rainfall patterns, droughts, higher or colder temperatures (which alter the growing seasons), and changes in land cover. According to the Growth and Transformation Plan (GTP), Ethiopia saw climate change as both an opportunity and threat. Given the challenges of mitigating and adapting to climate change, the GTP outlines a nation's goal of creating a climate-resilient green economy by 2030. The effects of climate change on agriculture and cattle are contingent on variations in temperature, precipitation, and climate variability, which include irregular rainfall, floods, and droughts. This would hurt agricultural production, resulting in the soil being less moist, faster loss of soil organic matter, premature drying of grains, high temperatures, and less food production and consumption, leading to worsening food security.

The research presented by Bankole (2020) documented the impact of climate change on food security; however, it has uncovered how difficult it is to find a model-based study that investigates and analyzes the influence of climate change on food access and security, focusing on India. In the past, when there was no technology to perform such a study, Bankole (2020) researched the impact of climate change on food access and security in a town in India and found it difficult to locate a model-based study that investigated and assessed the impact of climate change on food access and security in India. Bankole, in his statements, infers that climate change causes food scarcity in India to be more predominant following the increase in the number of years when economic calamities occur as a consequence of changes in the length of the growing season, increase in the frequency of climate-related disasters, and decline in production, thus reducing farmers' income. This signifies India's strong vulnerability because many poor farmers depend on rain-fed agriculture and monocropping. They also enjoy a short period of food security experience of a year. The same idea is put forward in Ramachandran & Ramachandran's (2014) study that climate change seriously

threatens a country's progress toward food security. He asserts that due to food subsidy reduction, the availability of food, especially after 3–4 months of harvest, falls, farming becomes unviable, and in the subsequent planting cycle, starvation becomes a reality.

Climate change significantly affects communities by eliminating access to food and jobs for those who mainly rely on fishing and forest resources, especially landless farm workers whose livelihood is based only on farm wages. Keeping in mind the trends of climate change effects on food security in India, Vedeld et al. (2014) surveyed nine villages located in the Jalna District of Maharashtra (a state in India). It was observed that drought in the area between 2012 and 2013 had a negative impact of about 60% on local crop production and farmers' income. Poor families that spend most of their income on food could face long periods of unpleasant effects on their children's well-being if they are affected by a decrease in their income. Similarly, the most worrying trend is that this is not limited to villages; India's urban food insecurity index also points to a problematic situation. In India, roughly one-third of children under 5 in urban Bihar, Madhya Pradesh, and Karnataka are underweight. Despite affluent states, such as Karnataka and Maharashtra, stunting and undernourishment are noticeable in urban areas (Bankole, 2020).

2.2 | Temperature and precipitation changes in Africa

Since the 21st session of the Conference of Parties in Paris, the debate on climate change has focused on the temperature limit threshold rather than on carbon emissions or concentrations. The African climate is highly diversified and varies from humid equatorial to seasonally dry tropical to subtropical Mediterranean-type climates, which are all known to exhibit varying levels of temporal fluctuations, particularly rainfall (Couvreur et al., 2021). Shepard (2019) stated that warming in Sub-Saharan Africa is expected to be higher than the global average. This means that the production areas for some crops and products will become less rainy. This is based on scientific research made by the Intergovernmental Panel on Climate Change (IPCC) and other climate research, which employs advanced general circulation models (GCMs). Nevertheless, using such highly evolved GCMs poses a challenge for regional impact assessments because they convey various local variations. Model differences result from the fact that diverse regions react in different ways to anthropogenic climate change and multidecadal variability attributed to chaotic behaviors and climate variability, such as multidecadal variability, which is a challenge for the models. Although GCMs for Sub-Saharan Africa generally agree on temperature increases across the region, they disagree on precipitation trends, with some areas experiencing a decline in rainfall, while others show an increase. Recent findings by Palmer et al. (2023) suggest that local circulation influences may reduce precipitation in East Africa, and it is uncertain whether Sahel will increase or decrease rainfall in the future.

As reported by Sultan and Gaetani (2016), West and Central Africa, where agriculture is rainfall dependent, possesses a low capacity to economically and institutionally adapt to climate change, and high climate variability is among the regions at risk of climate change. Therefore, the question is whether non-linear relationships exist between climate parameters and global temperature and whether climate change will occur gradually or abruptly (James & Washington, 2013). A study by James et al. (2014) analyzed temperature and precipitation variability related to global warming of 1, 2, 3, and 4°C in Africa. It was concluded that rainfall changes gained greater importance with an increase in global temperature. Chadwick et al. (2016) argued that parts of Africa that typically reside in the tropics will likely experience profound rainfall changes, with some models predicting a rainy pattern in eastern Africa and a drying pattern in southern Africa, the Guinea Coast, and western Sahel.

Diedhiou et al. (2018) analyzed temperature and precipitation extremes in the subregions of West and Central Africa and found that the paradigm of "dry becomes drier, wet gets wetter" is invalid for these regions. Furthermore, the study revealed that, at lower scales, forecast temperature increases in these regions are larger than the projected increases in global temperature, and the Sahel region is experiencing the most significant warming. Serdeczny et al. (2017) found that monthly summer temperatures in Africa will rise to 5°C above the 1951–1980 baseline by 2100 under high-emission scenarios, which will cause Africa to transition to a new climatic regime. Schellnhuber et al. (2013) reported that heat extremes will increase in both emission scenarios, and the multi-model mean of RCP8.5 predicts that 75% of summer months will be hotter than 5 sigma by 2100. Finally, Zomer et al. (2008) developed the aridity index (AI), which can identify "arid" regions with a structural deficit in precipitation. AI is calculated by dividing the total yearly precipitation by the potential evapotranspiration, which typically increases under global warming (Serdeczny et al., 2017). The multi-model mean indicated a modest decline in potential evapotranspiration across East Africa and the Sahel region.

According to a study by Gebrechorkos et al. (2019a), there is a rising trend in monthly maximum and minimum temperatures, as well as daily maximum and minimum temperatures throughout much of East Africa, especially in Ethiopia, Kenya, and Tanzania. Significant upward increases in warm nights (TN90p), warm days (TX90p),

warm spell duration index (WSDI), and summer days index (SU) were also present. In addition, there was a noticeable decline in the number of cold days (TX10p) and nights (TN10p). Overall, the findings indicate that temperature extremes are trending upward, which is consistent with rising global mean temperatures. Furthermore, most temperature extremes recorded after 2000 were warmer than the long-term averages (1979–2010). Conversely, there was no overall pattern in the precipitation indices, with Ethiopia, Kenya, and Tanzania exhibiting both rising and falling patterns. The results make it possible to design adaptation and mitigation strategies at a much finer spatial scale than previously feasible and detect hotspot areas.

3 | IMPACT OF CLIMATE CHANGE ON AGRICULTURE IN AFRICA

Climate change poses a severe threat to agricultural systems worldwide, with Africa being particularly susceptible to its adverse effects. As a continent heavily reliant on agriculture for sustenance, economic growth, and employment, any disruption to agricultural productivity due to shifting climatic patterns could have devastating consequences (Ramachandran & Ramachandran, 2014). In recent years, the impact of climate change on African agriculture has become increasingly pronounced, manifesting in erratic rainfall patterns, rising temperatures, prolonged droughts, and more frequent extreme weather events (Gebrechorkos et al., 2019b).

Table 1 below shows the various effects of climate change on agriculture in Africa.

4 | IMPACT OF CLIMATE CHANGE ON FOOD SECURITY IN AFRICA

4.1 | Overview of the impact of climate change on food security in Africa

Climate change in Africa is an increasingly serious threat because Africa is among the most vulnerable to the effects

TABLE 1 Effects of climate change on food security.

Impact	Description	References
Reduced Crop Yields	Changes in temperature and rainfall patterns may reduce staple foods like millet, maize, and rice yields	Pereira (2017)
Increase in Pest and Disease	Warmer temperatures can favor the proliferation of pests and diseases that can harm crops	Kaushik et al. (2023)
Soil Degradation	Increased droughts and flooding can lead to soil erosion, affecting crop growth	Lal (2018)
Loss of Livestock	Increased temperatures and altered rainfall patterns can lead to inadequate pasture and water, resulting in livestock deaths	Habte et al. (2022)
Shift in Agricultural Zones	Traditional agricultural zones may shift due to altered temperature and rainfall patterns, affecting local farming practices	Malhi et al. (2021)
Decline in Fish Catch	Changes in sea temperature and acidity might impact the marine ecosystem, affecting fish populations vital to Nigeria's food supply	Oluowo (2017)
Food Price Volatility	Challenges in livestock farming due to heat and reduced water and pasture availability	Udeaja and Isah (2024), Onyeneke et al. (2023)
Socioeconomic Impacts	Reduced agricultural productivity can increase poverty rates, decreasing the ability to purchase food	Masipa (2017)
Water Scarcity	Increased evaporation rates and changing rainfall patterns lead to water shortages, affecting irrigation and drinking water supplies across Africa	Leal Filho et al. (2022)
Infrastructure Damage	Extreme weather events damage infrastructure critical for food storage and distribution, leading to increased food waste in Africa	Yiadom et al. (2023)
Land use Changes	Expansion of agricultural land due to population growth and displacement from climate events leads to deforestation and loss of biodiversity in Africa	Okeleye et al. (2023)
Heat Stress	Rising temperatures result in heat stress for both crops and livestock, reducing productivity and quality across the continent	Parkes et al. (2022)
Conflicts and Displacements	Climate-induced resource scarcity exacerbates conflicts, leading to displacement and further strain on food resources in Africa	Adesete et al. (2022)
Economic instability	Fluctuations in agricultural productivity due to climate change affect income stability for farmers and food prices for consumers in Africa	Adesete et al. (2022)

of climate change. The representation of convection in climate models has slowed Africa's capability to correctly simulate African weather extremes and this limits climate change predictions (Kendon et al., 2019). The effects of climate change on the natural environment have led to changes in agricultural practices, including human food production and consumption. According to the World Food Summit 1996 report, food security is defined as "the condition when every single person, at any given time, has both physical and economic access to safe and nutritious food that is sufficient to meet the dietary needs and food preferences to lead an active and healthy life" (FAO, 2016a). Food security depends on four factors: (1) accessibility, (2) utilization, (3) functionality, and (4) credibility. Availability measures the amount of food in physical terms, whether it comes from a field, forest, or another source. Access involves different categories of economy and society that can constrain people from accessing available food. Utilization involves the use of available and accessible, nutritious, safe, and high-quality food. Food stability implies that availability, access, and utilization should not be present only at a particular point in time, but should shift over time to continue and become sustainable. Agriculture and climate change are very strong; therefore, negative changes in climate conditions will be a worldwide problem for food security. In terms of climate change impact, the FAO found that about 80% of the disasters reported globally are climate related, referring to the damaging effects that climate change can have on a country's food security (FAO, 2016b; Sweileh, 2020).

To date, and for the most part, agricultural production has been most negatively impacted by climate change, making agriculture very susceptible to climate change (Molotoks et al., 2021). The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer" (Field et al., 2014).

Climate change directly affects climatic and weather conditions such as temperature, heat waves, precipitation, and wind speed, which have a knock-on effect on the quantity and quality of agricultural output and food security as shown in Figure 1 (Eitzinger et al., 2019; Molotoks et al., 2021). According to FAO statistics provided since 2016, there will inevitably be an enormous decrease in food production and an increase in food costs that will result in difficulties in meeting the food demands of a fast-growing global population if climate change issues are not decisively addressed (Arora, 2019). The world's population is expected to reach 8 billion by 2024–2030 (UN, 2024), indicating an increased rate of the global population that potentially worsens the food security challenge, especially for rural dwellers (Sweileh, 2020). The effects of climate change on agricultural productivity have been investigated in several studies. Despite the application of production adaptation technology in many agricultural parts of the world, one study indicated that by 2050, the main crop yields will decrease by 17%, and food costs will increase by 25% (Schilling et al., 2020).

In a study conducted in southern Ethiopia, Mekonnen et al. (2021) discovered that the last three decades of

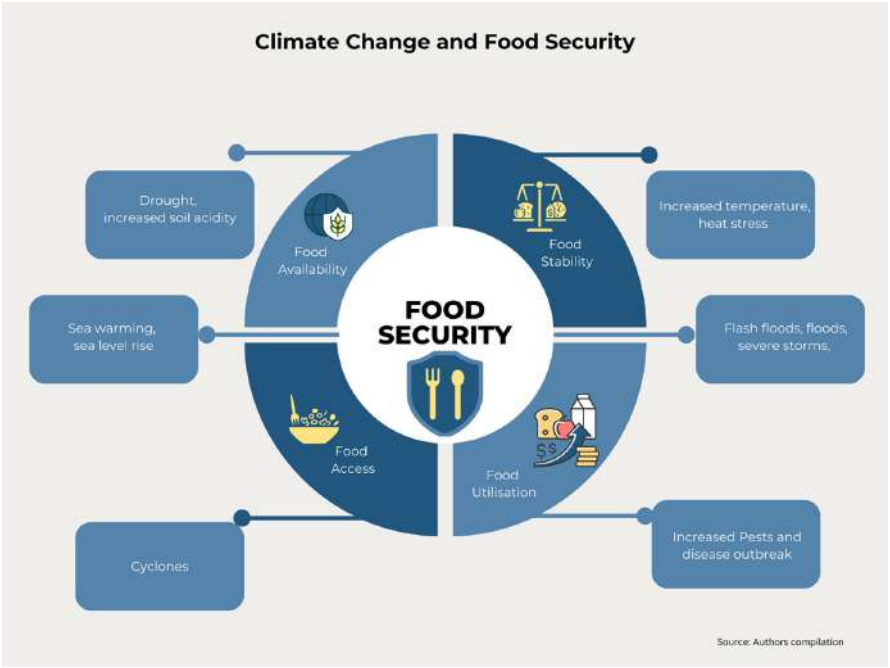

FIGURE 1 The impacts of climate change on food security in Africa.

climate change have had a detrimental effect on households' food security. Insufficient rainfall, significant erosion, and rising temperatures limit crop yield. Other contributory variables include pests, illnesses, and the unpredictable nature of rainfall. It was discovered that 60.5% of the selected respondents experienced food insecurity when using the calorie intake technique. The logistic regression model analysis results indicated that the amount of cultivated land, rainfall, age, and family size were significant ($p < 0.05$) factors influencing the status of food security in the household. In addition to revenue diversification, a sizable majority of the farmers (69.8%) implemented adaptive measures in farm management, such as better utilization of crop varieties and livestock output. When considered collectively, the results of Mekonnen et al. (2021) demonstrate that raising knowledge of climate change, assisting households headed by women in creating income, and fortifying current adaptation strategies all benefit from food security.

A sizable section of the Ethiopian population suffers from both temporary and chronic food insecurity, which is closely related to severe, repeated food shortages and famines linked to droughts that occur frequently due to climate change. Most food-insecure households are found in the core regions of southern Ethiopia, typically referred to as famine- and drought-prone areas (Mota et al., 2019). Millions of people suffer from predominantly agrarian economies such as Africa, where agriculture is the primary means of subsistence.

4.2 | Changes in food prices and availability

Increased demand for food necessitated by an increasing population often means that intensive agricultural practices, such as increased use of agrochemicals, livestock production for meat production, and unsustainable water resource exploitation, are employed to address food demand. These intense practices contribute to greenhouse gas (GHG) emissions, further polluting natural resources (Molotoks et al., 2021, Seneviratne et al., 2016).

Food and Agriculture Organization (FAO) (2016c) suggest that if the current rate of greenhouse gas (GHG) emissions and climate change persists, there will be a decline in major cereal crop production by 2100, with maize, wheat, and rice yields falling by 20–45%, 5–50%, and 20–30%, respectively (FAO, 2016c). Such a decrease in food production can contribute to spiked food prices and insecurity. Changes in food prices and availability can result in reduced risks to agricultural income and loss of livelihood for people living in rural areas, as the capacity for increased sales is reduced (FAO, 2016c). In Africa, climate change tends to negatively impact agricultural production in such a way that the resulting food insecurity can lead to social unrest and protests, causing political instability (Scheffran et al., 2019; Waha et al., 2017).

Climate change makes food supplies and prices more unstable in Sub-Saharan Africa because of low adaptation to weather changes, high food import needs, and excessive government control. Many people live in rural areas where they farm or fish but lack the facilities to cope with harsh weather, as they rely on rainfall for their crops, and irrigation is very rare on their land. Domestic food production is thereby affected by weather in cases of climate change, so it depends heavily on imports, mostly from other regions. Food imports can help with local problems, but they can also inflate weather shocks in the places from which they come. Likewise, the weather can make transportation more expensive. High food import costs can reduce foreign money and affect exchange rates, leading to faster price increases over time, as shown in Figure 2 (Kemoe et al., 2022). According to Hoskins (2024), dry weather in West Africa has damaged cocoa crops and caused global cocoa prices to reach an all-time high in February 2024. This resulted from Ghana and the Ivory Coast, the world's largest producers of cocoa beans, suffering from the effects of El Niño, a weather pattern that brings less rainfall. This has resulted in a twofold increase in the price of chocolate's main component since the start of 2023 (Charlotte & Rebecca, 2024).

4.3 | Impact on vulnerable populations

Populations considered vulnerable face challenges and may experience prejudice, stigma, and discrimination

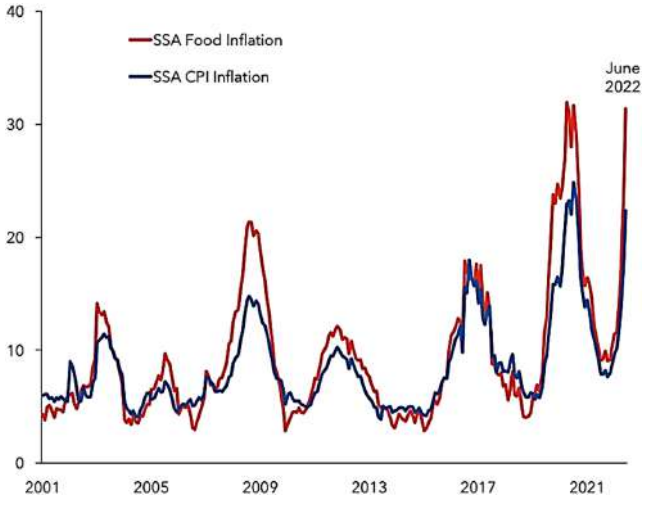

FIGURE 2 Food inflation and Consumer Purchase Index (CPI) in Africa (in percent) (IMF, 2022).

because of their socioeconomic situation, color or ethnicity, sex, age, or physical or cognitive abilities, among other factors. The effects of climate change have serious consequences for people's health, which can exacerbate the problems mentioned above, particularly for the most vulnerable (Pérez-Peña et al., 2021). Natural disasters caused by climate change can pose dire challenges for vulnerable individuals such as impoverished, aged, or crippled children, inmates, and substance abusers (Benevolenza & DeRigne, 2019).

Climate change risks have a growing impact on population health and healthcare systems. Individuals with low incomes and few resources, those living in remote areas, and those with fragile health conditions are more susceptible to climate-related risks at the individual level. Africa is by far the continent that is most affected by severe food insecurity, with most of its region containing large population of Individuals facing hunger as seen in Figure 3 (FAO, 2023). Generally, at the population level, people living in low- and middle-income countries (LMIC) are more at risk than those in high-income countries because of improved financial and healthcare systems (Tong & Ebi, 2019).

Addressing health and financial disparities is crucial for mitigating the effects of climate-related threats on vulnerable populations. This involves first identifying and concentrating efforts on the most vulnerable subgroups within a population, and ensuring that living conditions are safe for all. At certain times, the government should know when to implement public health intervention programs aimed at vulnerable populations, whereas at other times, a population-wide scheme has better health benefits for all. Primarily, the key to tackling health issues related to climate change is to provide health for everyone, with consideration for the vulnerable within society (Tong & Ebi, 2019).

Women are among the groups that are most susceptible to climate-related risks. In Africa, women's low cultural, educational, and socioeconomic position in society puts them in a disadvantaged position in their ability to cope with climate change-induced problems, such as flooding and drought. In addition, the unequal poverty levels of vulnerable women predispose them to low food intake, malnutrition, diseases such as malaria and cholera, and poor housing conditions (Pérez-Peña et al., 2021).

5 | RECOMMENDATIONS AND CONCLUSION

5.1 | Recommendations

- Increased investment in research: More research on the impact of climate change on food security can help better understand the complex relationships among climate change, agriculture, and food security. This research can inform policies and programs that can help mitigate the negative impacts of climate change on food security, particularly in developing countries, where data availability and capacity for research may be limited.
- Developing early warning systems: Developing early warning systems for climate-related disasters such as droughts, floods, and heat waves can help farmers and other food producers better prepare for and adapt to the negative impacts of climate change. This can include

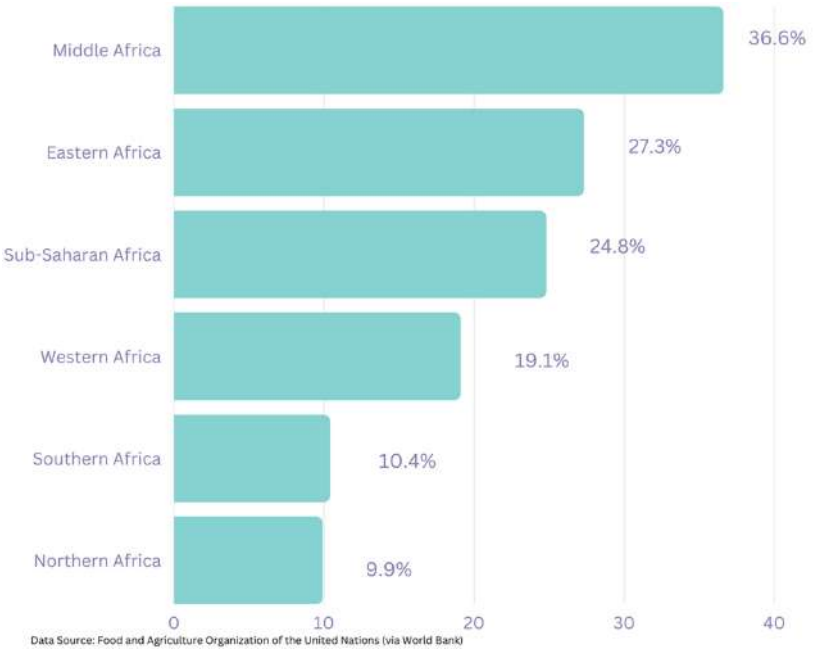

FIGURE 3 Percentage of the population experiencing severe food insecurity in different regions of Africa in 2020. *Source*: FAO (2023).

forecasts of weather patterns and crop yields, and the development of early warning systems that can inform farmers about when to plant, harvest, and take other measures to protect their crops.

- Promoting sustainable agriculture: Encouraging sustainable agricultural practices, such as conservation agriculture, agroforestry, and water-saving irrigation systems, can help increase food production and reduce the negative impact of climate change on food security. Sustainable agricultural practices can also help farmers reduce their greenhouse gas emissions and adapt to the changing climate.
- Support small-scale farmers: Small-scale farmers are often most vulnerable to the negative impacts of climate change on food security. Policies and programs that support small-scale farmers, such as access to credit, training, and markets, can help improve their resilience to climate change and increase their ability to adapt to it.
- Infrastructure, such as irrigation systems, water storage, and transportation, can help mitigate the negative impacts of climate change on food security. For example, irrigation systems can help farmers access water in times of drought, while improved transportation infrastructure can help farmers access their crops to the market.
- Develop climate-resilient crops: Investing in developing climate-resilient crops that are better suited to changing weather patterns can help increase food production and reduce the negative impacts of climate change on food security. This can include the development of more drought-resistant crops, heat-tolerant crops, or crops that can withstand other forms of extreme weather.
- Encourage conservation and sustainable land use: Encouraging conservation and sustainable land use practices can help preserve soil and water resources and reduce the negative impacts of climate change on food security. This includes practices such as reforestation, soil conservation, and sustainable land management.
- Foster International Cooperation Climate change is a global problem that requires international cooperation. Encouraging international cooperation in research, policy making, and funding can help tackle the negative impacts of climate change on food security. This could include international agreements on climate change, joint research programs, and coordinated efforts to assist farmers and other food producers in developing countries.

As part of the post-pandemic recovery period, the quick adoption of African adaptation measures will spur economic growth and the creation of additional jobs. Following the recommendations of the African Union's green recovery plan would enable both successful climate action and sustainable recovery (United Nations, 2021). Even though policymakers have a comparatively high level of knowledge on the effects of climate change and Ethiopia is actively participating in international climate change negotiations, several factors, including El Niño, are causing the local climate to deteriorate and increasing the population's susceptibility to both regional and global climate change. To effect change at the required scale and speed, policies and implementation strategies must prioritize a holistic, data-driven, and climate-resilient approach to food security across all levels: national, local, private, public, and civil society. This strategy should encompass research, policy formulation, and investment (Alemu & Mengistu, 2019).

Climate change poses a serious risk to people's lives and livelihoods in many nations worldwide. As there is no way to eliminate these risks, governments must move decisively to assist businesses and individuals in managing them. Planning and implementing proactive actions that lower the risk of climate change, accelerate growth, and alleviate poverty are necessary to achieve this. Development cannot occur before adaptation. Rather, governments may reduce their susceptibility to climate change and stimulate strong economic development by incorporating it early in their policies (The World Bank, 2020).

It can be difficult to take effective action on resilience and climate change adaptation; it requires coordinated efforts from the highest levels of government to individual homes and businesses. The adaptation principles provide practical advice for developing, implementing, and overseeing national adaptation plans. They serve as roadmaps for successful climate change adaptation. It outlines six guiding concepts that align with typical policy areas: (1) providing swift and equitable development to ensure robust foundations; (2) encouraging businesses and individuals to adapt; (3) modifying land use to safeguard vital public assets and services; (4) increasing people's ability to absorb shocks and bounce back; (5) forecasting and controlling macroeconomic and fiscal risks; and (6) ensuring efficient implementation through prioritization and ongoing oversight (Hallegatte et al., 2020).

It is challenging to generate precise projections of the amounts and timing of future precipitation because of the complex mechanisms of climate systems and non-linear responses to global warming. Nonetheless, the present data make it clear that certain forecasts of exceptionally high flooding and droughts are coming true, endangering Sub-Saharan Africa's (SSA) food security. Despite contributing the least to global climate change, it severely affects SSA. Numerous growing obstacles cause crops to encounter lower productivity in drought and flood situations. To guarantee a sustained supply of food, SSA must prepare agricultural soils for the predicted variations in

climate. Using technologies from several scientific fields, concerted effort is needed to adapt soils to climate change. To maintain a healthy soil–water balance, stakeholders must use water-smart practices. They must concentrate on controllable natural soil characteristics that regulate how susceptible or adaptable farming systems are to climate change (Brempong et al., 2023). Soils require conservation agricultural techniques that improve soil organic matter, preserve soil life, shield the soil from compaction and erosion, reduce soil disturbance, and increase soil infiltration and groundwater recharge capability. Many of these methods provide soils with the tools they need to absorb surplus water in flood-prone areas better and hold more water in drought-prone areas. To conserve water for later use, governments, farmers, and other stakeholders must invest in basic and sophisticated water collection and rerouting infrastructures. Farmers need to use water-efficient irrigation techniques when there is water shortage. Above all, it is critical to close knowledge gaps among academia, businesses, governments, and farmers to facilitate the rapid adoption of mitigation methods for climate change and the simple flow of new technology (Brempong et al., 2023).

5.2 | Conclusion

Climate change poses a serious challenge to Africa's food security landscape, with far-reaching consequences spanning the various dimensions of availability, accessibility, utilization, and stability of food resources. Its adverse effects co-exist with other pre-existing socioeconomic challenges in Sub-Saharan African countries, exacerbating the developmental challenges of low-middle income countries as competing priorities exist for small financial budgets. In this context, this review conducted a literature review to delve deeper into the intricate relationship between food security and climate change in order to draw policy recommendations for nutrition practitioners, food security policy development, and strategies aimed at cushioning the effects on the most vulnerable segments of the population.

The need to investigate the interplay among climate change, the environment, and human activities has been underscored by recent climate trends ranging from floods to droughts, heavy storms, and wildfires. The cascading effects of such events reverberate across all sectors of the economy. In Africa, they are mostly felt in the agricultural sector because the continent houses almost 60% of the world's arable land. This also implies that the continent experiences disproportionate impacts of climate shocks, especially since the continent has been pushed to the periphery of global climate finance.

Changes in temperature, precipitation patterns, and extreme weather events directly affect caloric production and cropping frequency in Sub-Saharan African countries. Projections of crop yield reduction and rising input costs lead to food scarcity and negative nutritional outcomes. Moreover, with the projected population increase in Sub-Saharan Africa, the pressure on resources, food, energy, water, and infrastructure will increase. This underscores the need for targeted policies, interventions, and strategies to adapt to climate change and to safeguard food security. With persistent poverty, countries have created a complex backdrop against the implications of climate change. Saharan Africa must consider cash transfers targeted to policies linked to nutritional outcomes. Furthermore, the nexus between food price volatility and agricultural production should be tracked to reduce the vulnerability of specific socioeconomic groups, particularly women and impoverished populations.

Notwithstanding, the challenges presented by climate change on food security point to opportunities for innovation in agri-food systems, such as the development of new varieties, mixed crop–animal farming systems, agroforestry development, and restoration of devastated croplands. The emergence and rise of artificial intelligence also presents unique solutions, such as early warning systems based on either predictive machine learning methods or remote sensing of arable lands against disease and pest outbreaks. Moreover, the government must conduct educational campaigns and strategically link social security insurance and cash transfers to nutritional policies. In addition, the promotion and adoption of smart agriculture by both large- and small-scale farmers could forge a path toward resilient and food-secure Africa.

Future research must attempt to explore green financing options for agri-food systems that are context specific. African countries have low sovereign credit ratings, making it difficult for climate finance to flow toward Africa, especially in agriculture. Multilateral development banks must consider de-risking African agri-food systems to make funds available for innovation and expansion. In addition, future studies need to explore the role of regional trade cooperation in improving food supply chain resilience and measures to reduce the devastating effects of food supply chain disruptions. Finally, we argue that innovation needs to incorporate local knowledge and traditional practices in combating climate change, and future research needs to explore integrating indigenous strategies with modern technology for sustainable agriculture and food security.

AUTHOR CONTRIBUTIONS

Helen Onyeaka contributed to the conception and design of the paper, analysis and interpretation of the data, drafting of

the paper, and revising it critically for intellectual content. Uju M. Nwauzoma contributed to the analysis and interpretation of the data, drafting of the paper, and revising it critically for intellectual content. Adenike A. Akinsemolu contributed to the drafting of the paper and revising it critically for intellectual content. Phemelo Tamasiga contributed to the drafting of the paper and revising it critically for intellectual content. Keru Duan contributed to the drafting of the paper and revising it critically for intellectual content. Zainab T. Al-Sharify contributed to the drafting of the paper and revising it critically for intellectual content. Kehinde Favour Siyanbola contributed to the drafting of the paper and revising it critically for intellectual content. All authors approved the final version of the manuscript to be published and agree to be accountable for all aspects of the work.

ACKNOWLEDGEMENTS

We would like to extend our deepest gratitude to all the authors who have significantly contributed to this article.

FUNDING INFORMATION

This research received no external funding.

CONFLICT OF INTEREST STATEMENT

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created in this study.

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How to cite this article: Onyeaka, H., Nwauzoma, U. M., Akinsemolu, A. A., Tamasiga, P., Duan, K., Al-Sharify, Z. T., & Siyanbola, K. F. (2024). The ripple effects of climate change on agricultural sustainability and food security in Africa. *Food and Energy Security*, *13*, e567. https://doi.org/10.1002/fes3.567