frontiers | Frontiers in Sustainable Food Systems

TYPE Policy and Practice Reviews
PUBLISHED 17 September 2024
DOI 10.3389/fsufs.2024.1389730

OPEN ACCESS

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RECEIVED 22 February 2024
ACCEPTED 22 August 2024
PUBLISHED 17 September 2024

CITATION
Mehra D, Rael T and Bloem MW (2024) A review of the intersection between climate change, agriculture, health, and nutrition in Africa: costs and programmatic options. *Front. Sustain. Food Syst.* 8:1389730. doi: 10.3389/fsufs.2024.1389730

A review of the intersection between climate change, agriculture, health, and nutrition in Africa: costs and programmatic options

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Background: Climate change adversely affects Africa's agriculture which would worsen the widespread food insecurity and nutritional deficiencies. Vulnerable populations, especially female farmers, women, and children are disproportionately affected.

Methods: The paper synthesizes available peer-reviewed and grey literature on the intersections of climate change, food insecurity, agriculture, gender disparities, health, child nutrition, and micronutrient deficiencies in Africa. It explores the economic ramifications of these factors, particularly their impact on public health and economic stability. The work aggregates insights into the current and future challenges of agricultural sustainability and the expected human capital development and economic costs of climate variations.

Results: The prevalence of hunger and undernourishment in Africa is notably higher compared to other regions. Climate change directly threatens agriculture, with anticipated reductions in crop and livestock yields, compounded by the negative impact of greenhouse emissions on the nutritional quality of staple foods. Female farmers contribute notably to agriculture, but their labor share is less dominant than previously assumed. Exposure to high temperatures, especially for outdoor workers and pregnant women, presents significant health risks, further impacting agricultural and economic output. These interdependencies are presented in a framework along with suggested interventions that could be contextualized to address the climate drivers and interconnectivity across agriculture, health, and livelihoods.

Conclusion: The interdependence between food, agriculture, health, nutrition, and human productivity, all of which are exacerbated by the impacts of climate change in Africa, form a complex challenge with profound health and economic implications. A multifaceted strategy is needed, encompassing climate-resilient farming practices, gender-sensitive interventions, health-focused measures like micronutrient supplementation, and comprehensive economic policies.

KEYWORDS

malnutrition, climate change, agriculture, Africa, food insecurity, gender disparities, child nutrition

1 Introduction

The African Union Commission and the United Nations World Food Program initiated the Cost of Hunger in Africa (COHA) studies in 2010. In the last decade, these studies have proved to be a crucial initiative, assessing the social and economic impacts of child undernutrition in Africa. The study, by 2021, was completed in twenty-one African countries, and showed that the annual economic cost of undernutrition in these nations ranges from 2 to 17% of GDP (WFP, 2022).

Africa's malnutrition crisis is deeply intertwined with the pervasive effects of climate change (IPCC, 2022). Agriculture, which forms a critical component of both this malnutrition challenge and Africa's economy as a whole (African Development Bank, 2019), is heavily influenced by the vagaries of climate change (Wollburg et al., 2024). As the continent contends with the repercussions of an ever-changing climate, its predominantly agricultural economies face the dual threats of food insecurity and nutritional deficiency. The situation is particularly acute among specific vulnerable groups, such as female farmers, women, and children (United Nations Children's Fund (UNICEF), 2023; FAO et al., 2023b).

This paper presents a literature review of the potential impact of climate change on the underlying causes of malnutrition of women and children in Africa by taking a multisectoral lens and considering agriculture, food, health, and human productivity consequences. Climate change threatens crops via natural disaster impacts (Wollburg et al., 2024) as well as greenhouse gas and increased temperature impacts on quantity and quality of production (Zhao et al., 2017; Zhu et al., 2018). Climate change also threatens the livestock aspect of agriculture, with increasing temperatures leading to decreases in animal product production (Cheng et al., 2022) and increased mortality and morbidity of livestock (Rojas-Downing et al., 2017). The paper explores the potential implications of climate change on the nutritional status, micronutrient deficiencies, and health status of women and children. High temperature exposure associated with climate change also has human health impacts, with outdoor workers particularly susceptible to heat-related illnesses and conditions (El Khayat et al., 2022), and pregnant women at higher risk of pregnancy complications associated with heat stress (Samuels et al., 2022; Yuzen et al., 2023a). These complex relationships are illustrated through a simple framework that shows that the impacts of climate change exacerbate the vicious cycle between agriculture, food, health outcomes, and reduced overall productivity.

Too often, the challenges of health, nutrition, agriculture, and climate are reviewed separately – there is little existing literature connecting all of these fields. However, in today's age of polycrises, countries are struggling with a landscape of intersecting causes and consequences that demand a multisectoral approach. This paper and its framework aim to make this multisectoral approach more accessible and support governments and other decision-makers in achieving the Sustainable Development Goals in this challenging and evolving environment.

2 Background

2.1 Continental commitments

African countries have committed to international frameworks like the UNFCCC and the Paris Agreement. These agreements aim to strengthen the dependency of productive agriculture on healthy ecosystems and reduce GHG emissions. Priority actions include developing resilient food systems, promoting drought-resistant crops, investing in smallholder irrigation, and transitioning to sustainable agricultural practices to reduce GHG emissions (AGRA, 2022).

These aspirations and objectives are also reflected in continental African Union declarations, strategies, and programs including *Agenda 2063* which sets the continent's development vision and aspirations. Others include the 2014 *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*, with commitments to halving poverty and ending hunger by 2025 and operationalized by the *Comprehensive Africa Agricultural Development Programme* (CAADP); the *Africa Regional Nutrition Strategy* (2015–2025); *Continental Education Strategy* (2016–2025); *Digital Transformation Strategy* (2020–2030), and *African Union Climate Change and Resilience Development Strategy and Action Plan* (2022–2032).

2.2 Food insecurity, malnutrition, and diets in Africa

The prevalence of hunger and food insecurity in Africa remains a pressing issue, reflecting more profound systemic challenges. In 2022, the continent faced a nearly 20% rate of undernourishment, significantly higher than in other regions. Various factors, including economic fluctuations and rising food and energy costs, exacerbate this persistent state of chronic hunger (FAO et al., 2023b). In 2022, African food insecurity was marked by stark regional and urban–rural disparities. Approximately 33.3% of adults in rural areas experienced moderate to severe food insecurity, compared to 28.8% in peri-urban and 26.0% in urban areas (FAO et al., 2023b). These figures highlight the uneven distribution of food resources and access, with rural areas particularly disadvantaged.

Gender disparities are also evident in the realm of food security. In 2022, 27.8% of adult women in Africa were moderately or severely food insecure, a higher proportion than the 25.4% of men experiencing similar levels of food insecurity (United Nations Children's Fund (UNICEF), 2023). This gender gap underscores the impact of societal and economic inequalities on women's access to adequate nutrition.

In Africa, malnutrition affects a substantial number of children under five years of age. The prevalence of stunting is 30 percent, well above the global average of 22.3 percent. Regional disparities are significant, with Central Africa experiencing the highest rates at 37.4 percent, while Northern and Southern Africa are closer to the global average. Stunting has declined since 2000, particularly in Eastern Africa, which saw an 18.1 percentage point reduction (FAO et al., 2023a).

The prevalence of wasting in African children is 5.8 percent, slightly below the global rate of 6.8 percent. Southern Africa reports lower wasting rates, while Western and Northern Africa are slightly above the continental average. In terms of overweight prevalence, it's at 4.9 percent for children under five in Africa, with higher rates observed in Northern and Southern Africa. Northern Africa, in particular, has seen an upward trend since 2015 (FAO et al., 2023a).

Anemia among women aged 15 to 49 is another critical issue, with a prevalence of 38.9 percent across Africa, higher than the global average of 29.9 percent. Western Africa (51.8 percent) and Central

Africa (43.2 percent) have the highest rates. While there has been some progress in reducing anemia since 2000, it still presents a moderate to severe public health problem in nearly all African countries (FAO et al., 2023a).

In Africa, the prevalence of micronutrient deficiencies among preschool-aged children is notably high, with sub-Saharan Africa reporting a deficiency in at least one of three core micronutrients for 62% of children within the region. This is the highest rate when compared to the other areas globally. For non-pregnant women of reproductive age, sub-Saharan Africa again shows the highest prevalence, with an estimated 80% lacking in one or more of these essential micronutrients (GNR, 2022; Stevens et al., 2022).

2.3 Healthy diets

A global increase in the cost of a healthy diet has overshadowed the post-pandemic economic recovery. Between 2019 and 2021, this cost rose by 6.7% globally. Africa witnessed a rise of over 5% between 2020 and 2021. Consequently, in 2021, about 3.2 billion people globally could not afford a healthy diet, an improvement from the previous year but still significantly higher than the pre-pandemic figures. Specifically, regions like Eastern and Western Africa were heavily impacted, indicating the disparity in economic recovery and the effect of rising living costs on food security (FSIN and GNAFC, 2022; GNR, 2022; FAO et al., 2023b).

The quality of one's diet is a crucial factor connecting food security and nutrition. Inadequate diet quality can lead to various forms of undernutrition, including micronutrient deficiencies, and contribute to the prevalence of overweight and obesity. In 2021, the cost of maintaining a healthy diet in Africa rose to an average of 3.57 purchasing power parity (PPP) dollars per person per day, marking a 5.6 percent increase from the previous year. This cost significantly exceeds the extreme poverty threshold set at 2.15 PPP dollars per person daily (FAO et al., 2023a).

Consequently, not only those living in poverty but a substantial segment of the population above the poverty line found it challenging to afford a healthy diet. The issue has intensified since the COVID-19 pandemic, with over three-quarters of the African population, around one billion people, unable to afford a healthy diet in 2021. This increase, particularly notable in Western and Eastern Africa, highlights a concerning trend where the rising cost of a healthy diet compromises the food security and nutritional status of many people across the continent (FAO et al., 2023a).

2.4 Agriculture in Africa: economic markers and female participation

Agriculture is undeniably central to Africa's economy, accounting for 60% of jobs on the continent and 16.5% of Africa's GDP (African Development Bank, 2019). Livestock agriculture accounts for about 40% of agricultural GDP in Africa, ranging widely from 10 to 80% in different countries (Balehegn et al., 2021). While African agricultural productivity has shown promising growth, increasing 13% annually on average between 2013 and 2020, the disparity between jobs and GDP from agriculture is due to low overall productivity and underdeveloped private sector infrastructure. For example, Africa's cereal yield reaches only 41% of the international average, and while Africa produces nearly 70% of the world's cocoa beans by weight, it receives only 2% of the revenue from global chocolate sales (African Development Bank, 2019). Agriculture in most African countries is characterized by small-scale, low-technology farming, leaving farmers and food systems particularly vulnerable to climate, economic, and conflict-related shocks, and contributing to decreased productivity (African Development Bank, 2019).

With agriculture a key employment sector in Africa, it is important to clearly understand the role of women in agriculture. Estimates for women's contribution to agriculture in Africa have been updated in the last few decades, from previous findings that women constituted 60 to 80 percent of the agricultural labor force in Africa (UNECA, 1972), to more recent findings in 2022. This new study, titled "Assessing the Female Labor Share in African Crop Production: Evidence from Six Countries," suggests that women contribute around 40% of the labor in crop production (Palacios-Lopez et al., 2017). A 2011 Food and Agriculture Organization (FAO) study estimated women's time allocation to agriculture at between 30–80%, with significant disparities both across countries and within them, as well as across distinct crops, agricultural tasks, and technological approaches (FAO, 2011). While data on women's contribution to agricultural labor is evolving, women remain a key component of the agricultural labor force and will be central in the changing agricultural landscape.

3 Methods

To conduct this review, a search was performed using electronic databases, including PubMed, Web of Science, Scopus, and Google Scholar. The search strategy utilized a combination of keywords related to each of the fields described in the paper: "agriculture," "climate change," "food and nutrition," and "health," specifically within the context of Africa. Articles were initially screened based on their titles and abstracts to assess relevance to the study's focus on examining intersections between agriculture, food, nutrition, health, climate change, and pregnancy outcomes. The review included both peer-reviewed and grey literature. In total, 26 peer-reviewed articles and 15 grey-literature publications were selected for detailed review and synthesis of findings.

4 Results

4.1 Framework outlining the vicious cycle between agriculture, food and nutrition insecurity, and health, exacerbated by the impacts of climate change

This schematic (Figure 1) shows the complex relationship between climate change, agriculture, health, and livelihoods, with each of these linkages elucidated by the evidence presented below. Climate change increases floods, droughts, and other extreme weather events, which negatively impact agricultural production. Greenhouse emissions and

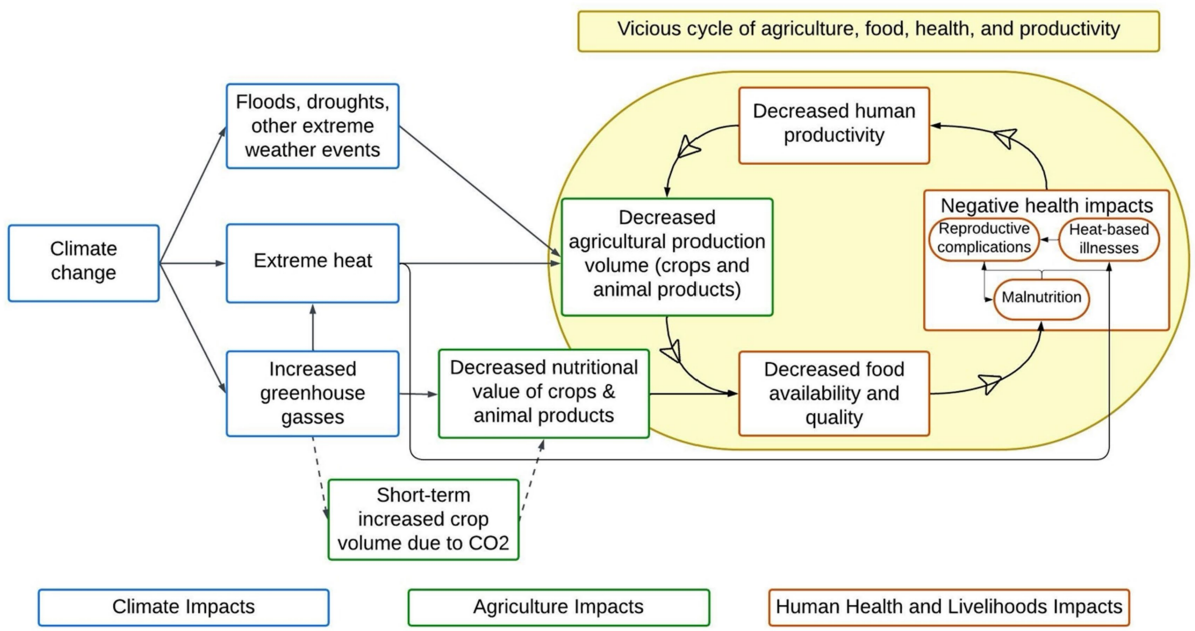

FIGURE 1
A vicious cycle between Agriculture, Food, Health and Productivity.

the resulting temperature increases have a dual impact on the world's food supply — while they may initially appear to boost crop productivity by increasing carbon dioxide levels, they also reduce the nutritional quality of staple foods like rice and wheat, as well as animal products such as meat, milk, and eggs. Overall, the impact of climate change decreases agricultural production, food availability, and quality.

Reduced food availability and quality cause malnutrition, but extreme increases in temperature, independent of the food pathway, directly lead to other health implications, which in turn impact overall human and economic productivity. Micro-economically, climate change deepens extreme poverty, potentially driving agricultural expansion into natural forests, thus causing habitat loss and reducing ecosystem services. The dependence of subsistence households on food stock rather than technological investments perpetuates a cycle of shocks, risks, and poverty.

4.1.1 Climate change, extreme weather events, and impact on agriculture

Disproportionately affected by climate change, Africa faces escalating temperature-related health burdens amid global temperatures already 1.2°C above preindustrial levels. The continent, responsible for a minimal fraction of global greenhouse gas emissions, struggles to secure climate finance and reparations. Temperatures in many African regions exceed the global average, with the Sahel's urban areas predicted to experience heatwave conditions for over half of the warm season by 2,100 if emissions continue unabated. Such extreme temperatures threaten "livability" and the capacity for labor. Research across Burkina Faso, Ghana, Kenya, South Africa, and Tanzania indicates significant rises in mortality and healthcare strain during hotter days (Ebi et al., 2021; IPCC, 2022; Bogolo et al., 2023; Chersich et al., 2023).

Currently, East African countries, including Ethiopia, Kenya, and Somalia, are grappling with severe multi-season droughts, some of the worst in recent history, posing a significant threat of starvation to millions (Funk et al., 2023). This situation exacerbates the slow pace of agricultural innovation and productivity growth in Sub-Saharan Africa, where agriculture largely depends on expansion and extensification.

Climate change hotspots in West and Southern Africa, including the Sahel region, are particularly affected. Climate-induced conflicts over scarce resources like land, water, and pasture are intensifying here. The macroeconomic and poverty implications are significant, with potential reductions in economic growth, poverty alleviation capacity, and increased vulnerability to global food supply chain shocks (Mbaye, 2020).

A recent paper, as part of the World Bank Policy Research Working Paper Series, describes a study of the impact of disasters on crop agriculture in six African countries. This study employs an analysis of survey micro-data to evaluate the extent of disaster damages, contrasting with the conventional approach based on macro statistics derived from disaster inventories. One of the central findings of the research is the profound impact of disasters on agriculture. The study reveals that 36 percent of agricultural plots within the sample experienced crop losses directly attributed to adverse climatic events. The study highlights that a substantial portion of losses resulting from disasters is underreported or goes undetected in conventional macro statistics. This disparity raises critical questions about the accuracy and comprehensiveness of existing disaster inventories and their

ability to capture the extent of agricultural losses (Wollburg et al., 2024).

A notable portion of the underestimation of disaster impact arises from more minor, less severe, yet frequent adverse events that often go unrecorded in disaster inventories—these smaller-scale disasters, although individually less devastating, collectively contribute significantly to the overall losses in agriculture (Wollburg et al., 2024). Recognizing the significance and cumulative impact of these smaller events is essential for a more accurate disaster risk assessment.

4.1.2 Greenhouse emissions and increased temperatures on agricultural production

Increasing greenhouse gas concentrations and rising temperatures contribute to complex but overall detrimental impacts on agricultural production. While higher CO2 emissions increase photosynthesis and thus can increase crop yields, recent studies have shown that higher CO2 is linked to declines in essential nutrients in crops, particularly protein, iron, zinc, and specific vitamins, which are critical for human health (African Development Bank, 2019). One comprehensive study on rice, a primary food source for over two billion people, used extensive *in situ* free-air CO_2 enrichment (FACE) experiments. This research confirmed protein, iron, and zinc reductions with losses up to 10, 5, and 8%, respectively. Additionally, it revealed declines in vitamins B1, B2, B5, and B9 while vitamin E levels increased (Zhu et al., 2018).

Another study on zinc deficiency estimated that anthropogenic CO_2 emissions could place between 132 million and 180 million people at a new risk of zinc deficiency by around 2050. The most affected populations are expected to be in Africa and South Asia, with India facing an exceptionally high risk (Myers et al., 2014). Further reports from the Intergovernmental Panel on Climate Change (IPCC) reinforce these findings, stating that wheat and rice grown under increased CO_2 levels could have considerably less protein, zinc, and iron. The decrease in these vital nutrients places hundreds of millions of people, especially in low-income countries, at an increased risk of nutritional deficits (IPCC, 2022).

In addition to CO_2 concentrations, rising temperatures will also have a detrimental long-term impact on agricultural production. One study found that each degree-Celsius increase in global mean temperature would reduce global yields of wheat by 6.0%, rice by 3.2%, maize by 7.4%, and soybean by 3.1% (Zhao et al., 2017). Further, UNEP's Africa Adaptation Gap Report found that at global mean temperature increases exceeding 3 degrees Celsius, nearly all existing maize, millet, and sorghum growing areas across Africa would become unviable (UNEP, 2013).

The impacts of extreme high temperatures are not limited to crop-based agriculture, but also have impacts on livestock-based agriculture, a crucial component of food systems. While the literature on climate impact on livestock is less robust than the literature on crop impact, heat stress has been shown to decrease the production volume and quality of meat, as well as animal byproducts such as milk and eggs (Cheng et al., 2022). In addition, heat stress has been shown to increase livestock mortality and decrease reproduction, a dual threat to healthy stocks (Rojas-Downing et al., 2017). It is also important to consider that livestock production often relies on grain-based feeds, and the negative impacts of climate on staple crop production described previously may thus have an indirect on livestock production via scarce or lower-quality feeds.

4.1.3 Human health implications of increased temperature exposure

Ambient heat exposure poses significant health risks, especially to outdoor workers such as women farmers. The primary concern is the increasing incidence of heat-related illnesses due to elevated temperatures. These conditions can lead to a variety of health problems, including kidney issues, cardiovascular and respiratory complications, and heat stroke (El Khayat et al., 2022).

Outdoor workers are at a heightened risk of heat stroke, cramps, heat exhaustion, heat rash, and other heat-related problems. These conditions can be exacerbated by heavy physical activity and lack of acclimatization to hot environmental conditions. Additionally, the risk of occupational exposure to increased temperatures can lead to more severe conditions like urolithiasis (kidney stones), which has been noted in various studies involving outdoor workers (El Khayat et al., 2022).

Female farmers, often pregnant or caregivers, face unique challenges due to climate change. As temperatures rise, their exposure to dehydration and heat-related illnesses increases as well, reducing their ability to work (Flocks et al., 2013; Vanos et al., 2023).

4.1.4 Impact on pregnant women and children

Thermoregulation during pregnancy is complex, as the body must maintain core temperature within narrow limits despite various physiological changes. Pregnancy brings about cardiovascular adaptations, such as a 50% increase in plasma volume and cardiac output by the third trimester, directly affecting placental blood flow, which is crucial for fetal temperature regulation (Soma-Pillay et al., 2016).

Adaptations also occur in a pregnant woman's thermoregulatory system, including a lower core temperature and sweating threshold, alongside increased plasma volume, skin blood flow, and thermal heat capacity due to higher body mass. These adaptations are vital in managing the additional heat produced by the metabolic activities of the fetus and placenta. Exposure to extreme temperatures, especially in environments with high humidity, could overwhelm these protective mechanisms and lead to pathological changes (Samuels et al., 2022; Yuzen et al., 2023a). Exposure to high ambient temperatures during pregnancy has been shown in many studies across different geographical settings linked to a range of severe maternal and fetal health outcomes: increased risk of congenital anomalies, preterm birth, low birth weight, intrauterine growth restriction (IUGR), and stillbirth (Asamoah et al., 2018; Zhang et al., 2023; Zhao et al., 2023; Yuzen et al., 2023b).

To the best of our knowledge, there is only one study from Africa, a Ghanaian investigation of the association between long-term exposure to heat stress, measured by the Universal Thermal Climate Index (UTCI), and stillbirth rates. Analyzing over 90,000 stillbirths from nearly 6 million births across 260 districts (2012–2020), the study found moderate heat stress prevalent, with the mean UTCI around 28.5°C. Risks of stillbirth were higher under higher-moderate heat stress conditions, particularly at the 90th percentile of UTCI. These risks were shown to increase with longer exposure durations. Rural districts, characterized by lower population density and GDP, faced higher risks (Nyadanu et al., 2023).

4.1.5 Economic costs

The extent of economic implications of climate-related extreme weather events are grossly underreported. According to a micro-data analysis from 6 African countries, economic losses in crop agriculture

attributed to droughts and floods are estimated to be $5.1 billion higher than macro statistics suggest. This stark contrast in economic figures signifies the magnitude of the underestimation and underscores the far-reaching consequences of extreme weather events on agricultural economics (Wollburg et al., 2024).

Furthermore, the analysis found that the impact of these underreported losses extends to a substantial population. In the six countries analyzed, the data indicated that extreme weather events affected 145 to 170 million people, a figure more than four times higher than the number stated by macro statistics (Wollburg et al., 2024). This revelation calls for reevaluating disaster management strategies, as it becomes evident that a much more significant portion of the population is vulnerable to the repercussions of adverse climatic events.

Adaptation to these increasingly severe climate conditions is underfunded, and Africa will require substantial international climate adaptation financing to cope with the effects of climate change. If the Earth warms by just over 2 degrees Celsius above preindustrial levels, Africa will need $50 billion per year in adaptation funding by 2050 to manage and mitigate the impacts of climate change effectively (IMF, 2023).

The economic ramifications of hunger and malnutrition in Africa are profound and far-reaching. These issues manifest in various ways, impacting individual health and macro-economically. The human capital development-related costs range from health-related expenditures, impact on education outcomes, and longer-term reductions in human productivity. Treating malnutrition and its myriad of complications, such as stunted growth and underweight issues in children, demands resources from already strained healthcare systems and contributions need to be assessed from other sectors such as agriculture and social protection.

Lost productivity is another critical concern. Malnutrition and increased temperature exposure can lead to health complications that prevent adults from working and contributing economically. This not only impacts individual earning potential but also national economic productivity. Furthermore, undernutrition during childhood is responsible for a significant percentage of child mortality, with estimates ranging from 8 to 44% (Akseer et al., 2022). Educational setbacks associated with undernutrition can be particularly damaging. Stunting, linked to malnutrition, correlates with school repetitions and a reduction in years of education. This educational impairment restricts future earning potential and productivity, contributing to a cycle of poverty and undernutrition. According to studies, stunted children achieve 0.2 to 3.6 fewer years of schooling, which can significantly affect their lifetime earnings and economic contributions (Akseer et al., 2022).

The economic cost of undernutrition, expressed as a percentage of GDP, is substantial. It varies widely among African countries, from 2% of GDP in Egypt to as much as 17% in Ethiopia (WFP, 2022). These data illustrate malnutrition's profound impact on national economies, highlighting the urgency of addressing this issue from a humanitarian perspective and an economic standpoint.

5 Discussions and policy recommendations/implications

The food insecurity and malnutrition crisis in Africa involves a complex interplay between climate-induced agricultural disruption (both for crops and livestock), gender-specific health impacts, and socioeconomic factors, reinforcing a vicious cycle of health, nutritional, and economic deficits. Altered weather patterns and rising temperatures,

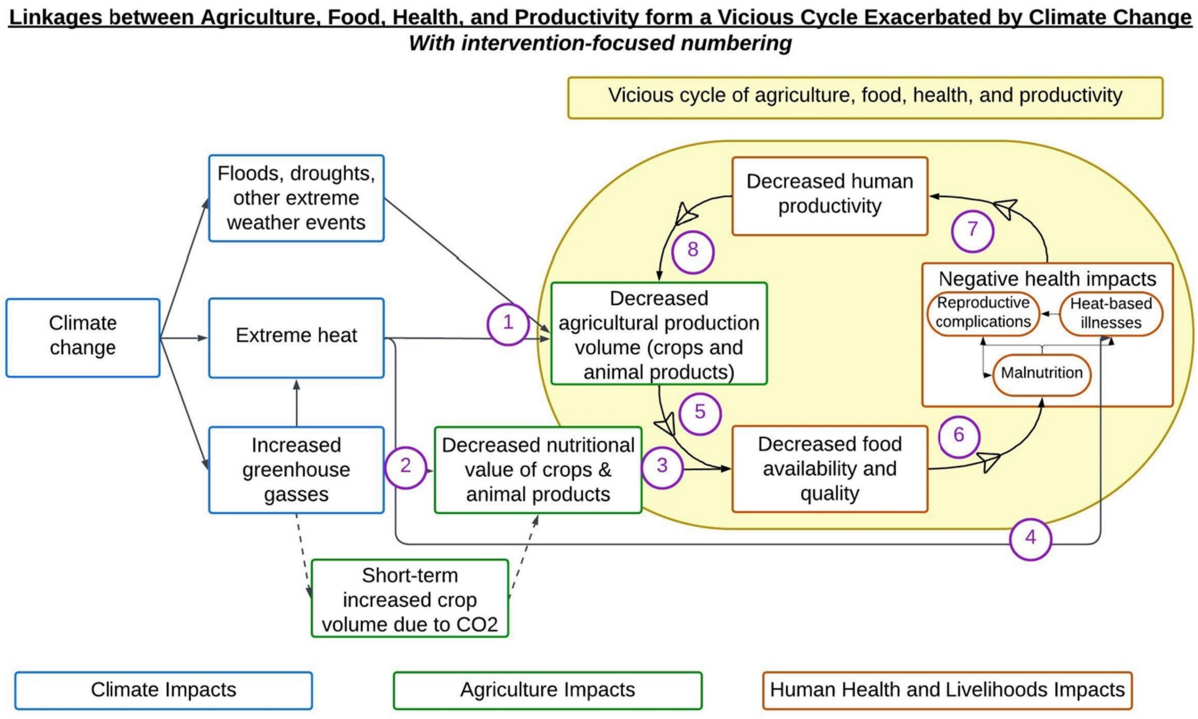

FIGURE 2
Summary of potential interventions.

TABLE 1 Interventions across agriculture, health, and livelihoods can disrupt the vicious cycle and its climate-based drivers.

Target sector	Proposed intervention	Stages of Intervention*
Agriculture	Teach and encourage **climate-aware agricultural practices**, such as crop diversification, water management, and soil health.	1, 2
	Encourage the use of **climate-focused agri-tech interventions**, including drought-resistant seed and crop varieties and biofortification.	1, 2
	Develop and offer **agricultural insurance schemes** with specific climate provisions to protect farmers and food systems.	1
	Explore alternative crop options which are higher-value and more climate-resilient in areas with rapidly changing climate.	1, 2
	Increase availability of **climate forecasting and monitoring data** (e.g., early warning systems) for smallholder farmers	1
	Educate smallholder farmers on climate impacts on agriculture to increase awareness and uptake of climate-aware practices, technologies, resources, and data.	1, 2
	Ensure access to **climate-sensitive post-harvest processing resources & education,** including reduction of post-harvest losses associated with climate impacts.	5
	Utilize **climate-smart agriculture** concepts as guiding frameworks in the development of climate-smart agricultural policies.	1, 2
	Push for **the recognition and valuation of carbon emissions as a global externality** to increase the valuation and uptake of sustainable farming practices.	1, 2
	Incentivize smallholder investment in climate-smart tools and practices by increasing access to financing and leveraging regulatory measures to encourage strong market for climate-smart crops.	1,2
Agriculture/Human health & livelihoods	Increase access to **sustainable agricultural mechanization**, reducing the manual labor of certain agricultural tasks to increase efficiency and reduce extreme weather exposure.	4, 8
	Implement **temperature-sensitive agricultural policies**, including work environment standards for both outdoor and indoor facilities.	4, 8
	Realign financial flows to support a climate-sensitive sustainable agrifood system, pulling from multisectoral sources.	5,6, 8
	Promote **indigenous climate-resistant crops** which are climate and nutrition sensitive.	1, 2, 5
	Increase **academic study/data collection focused on the intersection between climate, health** (particularly reproductive health), and productivity to support urgency of national policy interventions.	4, 7, 8
Human health & livelihoods	Increase **post-harvest staple fortification** to compensate for nutrients lost due to extreme temperature exposure.	3, 5
	Champion **gender-sensitive nutrition interventions**, including multiple micronutrient supplements (MMS) for pregnant and lactating women, and stunting/wasting prevention.	4, 6
	Support pregnant women through **balanced energy and protein supplementation** to improve pregnancy outcomes, following WHO guidelines (World Health Organization, 2023).	4, 5
	Encourage **private sector development of specialty nutrition supplementation products** for women at risk of extreme temperature exposure.	4, 6
	Increase focus on **climate-and nutrition-sensitive health care** for women of reproductive age.	4, 6, 7
	Develop **climate and gender-sensitive health education**, focusing on impacts of extreme temperature exposure on both reproductive and general health.	4, 6, 7
	Integrate **climate and gender-sensitive measures into social protection policies**, accounting for the detrimental health and productivity impacts of extreme temperatures.	7, 8
	Conduct **additional research** on the impacts of high ambient temperatures on pregnancy and reproduction within the context of female agricultural workers in Africa.	4, 7

*Numbers in stages of intervention refer to the diagrammatic numbers in Figure 2.

10.3389/fsufs.2024.1389730

symptomatic of climate change, directly undercut food production, compromising the availability of critical staples essential for the continent's diet.

The consequences are more pronounced for women and children. Within the agricultural sector, women, critical contributors to food production, bear the brunt of these challenges. Malnutrition diminishes their capacity for physical labor, decreasing their ability to contribute to agricultural production and perpetuating malnutrition. The situation deteriorates further for pregnant agricultural workers, susceptible to the compounded risks of increased temperature exposure. Such conditions jeopardize both maternal and child health and may lead to increased morbidity and mortality rates, as well as complicated pregnancies. Additionally, the heavy involvement of women in agriculture means that these health risks can inadvertently influence agricultural output, closing the loop where reduced production feeds back into the cycle of malnutrition.

A recent paper by Shankar et al. in Pakistan showed that supplementing pregnant women with micronutrients can mitigate some effects of high temperature exposure (Shankar et al., 2023). While additional studies are required to confirm these outcomes, nutritional supplements have already proven to be successful in the livestock sector to counter the effects of increased temperatures (Abdel-Moneim et al., 2021).

This paper considers the impacts of climate on the intersections of both human productivity and agriculture outputs as a means of bridging two fields which are often considered in isolation. However, the authors note that each of human productivity and agricultural productivity could be analyzed at length with greater depth in subsequent, highly specific papers.

Addressing this multisectoral crisis necessitates a multifaceted approach that supports women's health and nutrition, fortifies agricultural resilience, and incorporates climate adaptation strategies to break the cycle of malnutrition and secure food systems across Africa. The intertwining of malnutrition, agriculture, and climate change has profound economic implications. The cost of hunger, manifesting as healthcare expenses, lost productivity, and educational setbacks, further aggravate the cycle of poverty, food insecurity, and undernutrition. This economic burden underscores the urgency of addressing these interconnected challenges holistically (see Table 1).

6 Conclusion

Food and nutrition security in Africa is deeply embedded in the interdependencies between climate change, agricultural output, women's nutritional and health status, and its subsequent impact on human productivity. Tackling these complex issues demands a multi-pronged approach that addresses the root causes and their interconnections. Strategies must include climate-resilient agricultural practices, gender-sensitive interventions, health-focused measures, and economic policies aiming to break the poverty and malnutrition cycle. Intervention strategies should draw from the latest thinking and recommendations across climate, agriculture, and health, including the World Health Organization's guidelines on maternal nutrition, among others. This integrated approach is essential for sustainable development and improving health and well-being across the continent. The approach presented here addresses the climate drivers and interconnectivity across agriculture, health, and livelihoods. Depending on the context and local analyses, the most impactful cycle-disrupting interventions with a continued focus on climate impacts and women have the potential to achieve far-reaching and positive impacts.

Author contributions

DM: Conceptualization, Writing – original draft, Writing – review & editing, Visualization. TR: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. MB: Conceptualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

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