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Agri-food Systems and Climate Change: A Comprehensive Approach to Enhancing Food Security and Nutritional Safety and Reducing Food Loss and Waste in Cameroon

Abstract

This paper aims to provide insights into the potential synergies and trade-offs between addressing climate change and ensuring food and nutritional safety, while also reducing food loss and waste. This study examines the adverse effects of climate change on agri-food systems, including changes in agricultural productivity, crop yields, and food availability. It also investigates how these changes impact the food and nutritional safety of food products, as well as contribute to food loss and waste throughout the supply chain. The research analysed existing strategies and technologies that can mitigate the effects of climate change on agri-food systems, enhance food, nutritional safety, and reduce food loss and waste. This includes the adoption of sustainable agricultural practices, the implementation of efficient food processing and storage techniques, and the promotion of consumer awareness and behaviour change. The impacts of climate change on agri-food systems are complex and far-reaching. Addressing these challenges requires a multi-pronged approach, including developing climate-resilient crops, improving water management practices, and investing in infrastructure that can withstand extreme weather events in Cameroon.

Keywords

Agri-food • Food and nutritional safety • Food loss • Food waste • Climate change • Sustainable agriculture • Food processing • Food storage

Research Article

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Introduction

Cameroon boasts a rich agricultural landscape yet faces challenges in optimizing its agri-food systems. The sector is dominated by small-scale, family-run farms primarily focused on subsistence or local markets [1]. While this contributes to household food security, limited access to resources like credit and improved seeds often restricts productivity [2]. Cash crops like cocoa and coffee play a significant role in exports, generating foreign income but leaving the economy vulnerable to price fluctuations [3]. Informal market channels dominate product distribution, leading to inefficiencies and post-harvest losses [2].

Addressing these complexities is crucial for unlocking the potential of Cameroon's agri-food systems to drive food security, economic growth, and sustainable development, particularly when considering that the agriculture sector is the main occupation for over 70% of citizens, contributing enormously to Cameroon's economy [4].

Challenges of Climate Change, Agri-Food Systems, Food Security and Nutritional Safety and Food Loss and Waste

Climate change and its impact on agri-food systems

Climate change casts a long shadow over the future of global food security, and agri-food systems in developing countries like Cameroon stand particularly vulnerable [5]. Rising temperatures, erratic rainfall patterns, and increased frequency of extreme weather events like droughts and floods pose a multitude of threats to agricultural production [6].

Climate change directly impacts crop yields by altering optimal growing conditions. Higher temperatures can stress crops, leading to stunted growth and reduced yields [7]. Changes in precipitation patterns can disrupt irrigation schedules and exacerbate water scarcity, further jeopardizing crop production [8]. These factors can lead to food insecurity and price volatility, particularly for staple crops like maize and cassava in Cameroon [2].

The agricultural sector in Cameroon is dominated by small-scale farmers whose livelihoods depend heavily on the success of their harvests [9]. Climate change threatens these livelihoods by jeopardizing agricultural productivity and income generation. Additionally, extreme weather events can displace farmers and disrupt agricultural infrastructure, further exacerbating vulnerabilities [10].

Climate change can disrupt food distribution networks by damaging transportation infrastructure and hindering market access [11]. This can lead to food shortages in certain regions, even when overall production remains stable. Additionally, climate changes can affect the quality and safety of food products, impacting their marketability and posing potential health risks [12].

Safe and secure food: why addressing food safety, loss and waste matters

The global food system faces a complex challenge: ensuring everyone has access to safe, nutritious food while minimizing food loss and waste. Addressing these issues is crucial for achieving food security, promoting public health, and fostering environmental sustainability.

Contaminated food poses a significant threat to human health, leading to foodborne illnesses that can cause severe illness and even death [13]. Implementing robust food safety measures throughout the food supply chain, from farm to fork, is essential for protecting consumers. This includes practices like proper hygiene, temperature control, and preventing cross-contamination [14].

One-third of all food produced globally is lost or wasted each year, representing a significant economic and environmental burden [15]. Food loss typically occurs during production, storage, and transportation, often due to inadequate infrastructure and inefficiencies. Food waste happens at the retail and consumer levels, often due to overproduction, poor storage practices, and limited consumer awareness [16].

Food safety failures can contribute to food loss and waste. Spoiled or contaminated food cannot be consumed and must be discarded. Conversely, reducing food loss and waste can contribute to food security by making more food available for consumption. Additionally, both food safety and food loss reduction play a role in promoting environmental sustainability by minimizing the resources used for food production that ultimately go uneaten.

A growing threat: Climate change and its bite on food production

Climate change casts a long shadow over global food security, and its effects are already being felt in agricultural regions worldwide. In this changing climate, agricultural productivity and food availability face a multitude of threats, jeopardizing the well-being of millions.

Rising temperatures and erratic rainfall patterns directly impact crop yields. Crops experience stress under extreme heat, leading to stunted growth and reduced production [7]. Changes in precipitation disrupt irrigation schedules and exacerbate water scarcity, further hindering crop health and ultimately, harvest size [8]. These factors can lead to

food insecurity and price volatility, particularly for staple crops that form the foundation of diets in many regions.

The frequency and intensity of extreme weather events like droughts and floods are on the rise due to climate change. These events can devastate agricultural lands, causing widespread crop failure and disrupting entire growing seasons [10]. The resulting decrease in food production can lead to shortages and price hikes, leaving vulnerable populations at risk of hunger and malnutrition.

Climate change disrupts not only production but also food distribution networks. Extreme weather events can damage transportation infrastructure, hindering the movement of food from farms to markets [11]. This can create food shortages in certain regions even when overall production remains stable. Additionally, climate changes can affect the quality and safety of food products, impacting their marketability and potentially posing health risks [12].

The brunt of climate change's impact on agriculture is often borne by small-scale farmers, who lack the resources to adapt. These farmers typically rely on rain-fed agriculture and have limited access to technologies that could help them cope with changing weather patterns [6]. Climate change threatens their livelihoods by jeopardizing harvests and income generation, potentially pushing more people into poverty and hunger.

The effects of climate change on agricultural productivity and food availability demand immediate and comprehensive action. Developing climate-resilient crops, improving water management practices, and investing in infrastructure that can withstand extreme weather events are crucial steps. Simultaneously, promoting sustainable agricultural practices and mitigating climate change through global efforts are essential for safeguarding food security for future generations [4].

Implications for food and nutritional safety

The combined effects of climate change and the challenges within existing agri-food systems in Cameroon pose significant threats to food and nutritional safety. Climate change disrupts agricultural production through factors like heat stress, erratic rainfall, and extreme weather events. This can lead to decreased food availability, particularly for staple crops like maize and cassava [6]. Reduced supply often drives up food prices, making nutritious options less accessible for vulnerable populations, impacting dietary diversity, and potentially leading to malnutrition [10]. Climate change can affect the quality of food products. Changes in temperature and humidity can create favorable conditions for pests and molds, leading to contamination and spoilage [12]. Additionally, extreme weather events like floods can introduce harmful toxins or bacteria into agricultural lands, jeopardizing food safety.

Climate change can damage transportation infrastructure hindering the movement of food from farms to markets. This can create food shortages in certain regions even with stable overall production [11]. Disruptions in distribution systems can also lead to increased food spoilage, further reducing available safe and nutritious food. Small-scale farmers, who are the backbone of Cameroon's agri-food system, are particularly vulnerable to climate change. Limited resources and reliance on rain-fed agriculture make it difficult for them to adapt to changing weather patterns [6]. Climate-induced crop failures can threaten their livelihoods and reduce the overall availability of safe and nutritious food within local markets.

Reduced access to diverse and affordable nutritious foods due to climate change and existing challenges in the agri-food system can lead to increased malnutrition, particularly among children and pregnant women [10]. Deficiencies in essential vitamins and minerals can have long-term health consequences, impacting physical and cognitive development.

Contribution to food loss and waste

Climate change casts a long shadow not only on food production but also on food loss and waste throughout the food supply chain. Understanding this complex relationship is crucial for developing strategies to minimize food waste and ensure food security in a changing climate.

Climate change exposes food to various threats at every stage of the food supply chain, from farm to fork, contributing to significant losses and waste. Here's how: Extreme weather events like droughts and floods can devastate crops, leading to pre-harvest losses [6]. Rising temperatures can stress crops, impacting their quality and marketability, ultimately leading to food waste at the farm level [17]; Changes in temperature and humidity due

to climate change can create ideal conditions for pests and mold growth, leading to spoilage during storage and transportation [18]. Additionally, extreme weather events can damage storage facilities and disrupt transportation networks, further exacerbating food losses.

Climate change can disrupt market access by damaging infrastructure. This can lead to food shortages in certain regions even when overall production remains stable, potentially causing food spoilage at the retail level due to oversupply in other areas [11]. Climate change can also indirectly influence food waste at the consumer level. Fluctuations in food prices due to climate-induced production disruptions can lead to changes in consumer purchasing behavior, potentially resulting in increased food waste due to bulk buying and overstocking [16]. Food loss and waste due to climate change are not isolated problems. Food waste itself contributes to greenhouse gas emissions, further exacerbating climate change [19]. Therefore, addressing food loss and waste plays a crucial role in mitigating climate change.

Way Forward

Ensuring food and nutritional safety is paramount for public health and well-being. In today's complex agri-food systems, achieving this goal requires a multi-pronged approach that addresses vulnerabilities throughout the food supply chain.

Sustainable practices for adapting agriculture to climate change

Climate change poses a significant threat to global food security. However, a shift towards sustainable agricultural practices can equip farmers with the tools to adapt and thrive in a changing climate. In addition to the strategies to ensure sustainable food production in Cameroon admits climate change that was earlier discussed [4], the exploration of climate-smart agriculture, building soil health, integrated pest management, water conservation practices, reducing deforestation, investing more in research and innovation, and sustainable agricultural practices cannot be overemphasized (Table 1).

By embracing CSA, farmers can ensure the long-term viability of their livelihoods and contribute to building a more climate-resilient food system [20,4].

Promoting diverse and nutrient-rich crops

The foundation of a healthy diet rests on a diverse and nutrient-rich food system. Promoting a wider range of crops not only enhances dietary variety but also offers a multitude of benefits for human health, environmental sustainability, and food security (Table 2).

Enhancing food processing and storage techniques

Minimizing food loss and waste while ensuring food safety and quality throughout the supply chain is crucial for a sustainable and secure food system. Enhancing food processing and storage techniques plays a vital role in achieving these goals. Traditional processing techniques can be inefficient and lead to significant losses. Investing in advanced technologies like controlled atmosphere storage, aseptic processing, and improved drying methods can significantly extend shelf life and reduce spoilage [21]. Additionally, advancements in minimal processing techniques like high-pressure processing can preserve nutrients while enhancing food safety [22]. Inadequate storage facilities, particularly in developing regions, contribute significantly to food losses. Investing in improved infrastructure like temperature-controlled warehouses, efficient transportation networks, and proper packaging solutions can minimize spoilage during storage and transportation [15]. Furthermore, promoting the use of hermetic bags for small-scale farmers can significantly reduce post-harvest losses by preventing insect infestation and maintaining grain quality [23].

Enhancing food processing and storage techniques must prioritize food safety. Implementing Hazard Analysis and Critical Control Points (HACCP) principles throughout the food chain helps identify and control potential contamination risks [24]. Additionally, promoting best practices for hygiene and sanitation during processing and storage is essential for ensuring food safety and consumer health. Capacity building for farmers and food processors through training programs on improved processing and storage methods empowers them to minimize losses and improve food quality. Furthermore, research and development efforts focused on novel food preservation technologies and improved storage solutions are crucial for long-term advancements in the food system.

Strategy	Definition of Strategy	Examples	Citation
Climate-Smart Agriculture (CSA)	A holistic approach that promotes practices enhancing productivity, improving adaptation to climate change, and mitigating greenhouse gas emissions.	- Crop diversification - Utilizing drought-resistant crop varieties - Implementing efficient irrigation techniques	(FAO, 2021a)
Building Soil Health	Practices that promote soil health, enhancing resilience to extreme weather events.	- Cover cropping - Reduced tillage - Application of organic amendments	(Lal, 2015)
Integrated Pest Management (IPM)	Prioritizing non-chemical methods for pest control, reducing dependence on chemical pesticides.	- Encouraging beneficial insects - Utilizing natural pesticides - Promoting crop rotation	(FAO, 2016)
Water Conservation	Techniques that reduce water usage and improve drought tolerance in crops.	- Drip irrigation - Mulching - Rainwater harvesting	(Molden et al. 2010)
Agroforestry	Planting trees alongside crops for multiple benefits.	- Trees providing shade and wind protection for crops - Improving soil fertility - Contributing to biodiversity	(World Agroforestry, 2023)
Research and Innovation	Investing in research and development for long-term adaptation.	- Developing drought -resistant crops and heat -tolerant varieties - Promoting climate -resilient farming techniques - Knowledge sharing and farmer-to-farmer learning networks	(Abia et al. 2020, 2016)
Sustainable Agricultural Practices	Practices that enhance climate resilience and offer additional benefits.	- Improved soil health leading to increased productivity and reduced reliance on chemical inputs - Biodiversity-friendly practices promoting natural pest control - Water conservation techniques lowering production costs	(Abia et al.2020, 2016)

Table 1. Practices for adapting agriculture to climate change

Cameroon boasts a rich diversity of agricultural products with immense potential for processing and value addition. Here are some examples:

Fruits: Mangoes, a seasonal glut, can be processed into dried fruit snacks, jams, or juices, extending their shelf life and marketability.

Vegetables: Local leafy greens like “Ngappal” (spider plant) can be transformed into dehydrated flakes for soups and stews, reducing spoilage and concentrating nutrients.

Starchy staples: Cassava, a major source of carbohydrates, can be processed into garri (dried granules) for easier storage and transportation, or into flour for gluten-free baking.

Crop to Plant	Health Benefits	Citation
Fruits, Vegetables, Legumes, Whole Grains	- Reduces risk of chronic diseases - Strengthens immune system - Supports physical & cognitive development	(World Health Organization, 2023b)
Diverse Crops (Broader Range)	- Dietary Variety - Improved Food Security (Reduced Risk of Crop Failure)	(Food and Agriculture Organization of the United Nations, 2023b)
Diverse Crops	- Healthier Ecosystem - Natural Pest Control (Beneficial Insects) - Improved Soil Fertility & Health	(Bommarco et al. 2013) (Pretty, 2008)
Underutilized Crops (Indigenous Vegetables, Legumes, Forgotten Grains)	- Enhanced Dietary Diversity - Improved Local Food Security - Unique Nutritional Profiles	(Food and Agriculture Organization of the United Nations, 2019b)

Note: Estimated drought tolerance varies by crops

Table 2. Diverse and nutrient-rich crops and drought tolerance.

Nuts and seeds: Processing peanuts into peanut butter extends shelf life and creates a protein-rich spread, while melon seeds can be roasted and salted for a healthy snack.

Processing these local foods offers several benefits

Increased shelf life: Processing techniques like drying, salting, or fermentation can significantly extend the shelf life of these products, reducing food waste and ensuring year-round availability. This process involves removing the water content while retaining the fruit's natural flavours and nutrients. Dried fruits have a longer shelf life compared to fresh fruits and are convenient for snacking, baking, and use in various culinary preparations. Examples include dried mango slices, dried apple rings, and dried apricots.

Enhanced value: Processing adds value to raw agricultural products, creating new food items with greater market potential. Fermentation is a traditional method of processing vegetables, such as cabbage, carrots, and cucumbers, to create fermented foods like sauerkraut, kimchi, and pickles. Fermentation enhances the preservation of vegetables, increases their shelf life, and introduces beneficial bacteria that contribute to gut health. Fermented vegetables also develop unique flavours and textures, making them a popular addition to salads, sandwiches, and side dishes.

Preservation: Processed foods offer convenience to consumers, as they require less preparation time compared to raw ingredients. Local fruits, such as berries, peaches, and plums, can be transformed into preserves and jams through cooking and adding sweeteners. This processing method helps extend the fruit's shelf life, preserves its flavours, and creates a spreadable product that can be enjoyed on toast, pastries, or as a topping for desserts. Fruit preserves and jams often retain the nutritional benefits of the original fruit.

Safety: Certain processing methods like fermentation can improve food safety by reducing harmful bacteria.

Roasted nuts: Nuts like almonds, peanuts, and cashews can be processed through roasting. Roasting not only enhances the flavour and texture of the nuts but also helps extend their shelf life by reducing moisture content. Roasted nuts are a popular snack option and can also be used as ingredients in various recipes, including salads, trail mixes, and baked goods.

Milled grains: Local grains, such as wheat, corn, and rice, can undergo milling processes to produce flours and meal. Milling removes the outer layers of the grains, resulting in refined flours or leaves them intact, resulting in whole grain flours. These processed grain products offer improved shelf life, increased versatility for cooking and baking, and enhanced digestibility. They serve as key ingredients in bread, pasta, tortillas, and a wide range of baked goods.

Fruit juice and purees: Local fruits can be processed into juices and purees, which are extracted through pressing

or blending. Fruit juices and purees offer convenience, as they can be consumed directly or used as bases for beverages, smoothies, sauces, and desserts. Processing fruits into juices and purees helps to preserve their flavours, nutrients, and can extend their usability.

Reducing food loss and waste in agri-food systems

Food Loss and Waste (FLW) pose a significant challenge to global food security, environmental sustainability, and economic well-being. An estimated one-third of all food produced globally is lost or wasted [25], highlighting the urgency of addressing this complex issue. Fortunately, a multi-pronged approach can significantly reduce FLW throughout the Agri-food system, from farm to fork.

Significant losses occur during agricultural production due to factors like poor harvesting practices, inadequate storage facilities, and pest infestations. Investing in improved infrastructure, promoting climate-resilient crops, and implementing Integrated Pest Management [IPM] techniques can significantly reduce pre-harvest losses [26].

Inefficient processing techniques and inadequate storage infrastructure contribute to significant post-harvest losses. Modernizing processing methods like controlled atmosphere storage and minimal processing can extend shelf life and minimize spoilage [21]. Additionally, investing in cold chain infrastructure and promoting the use of hermetic bags for small-scale farmers can further reduce losses [15, 23].

Inefficiencies in transportation and distribution networks can lead to food spoilage. Developing efficient logistics systems, optimizing delivery routes, and promoting better forecasting techniques can help reduce losses during transportation. Additionally, improving market access for small-scale farmers and reducing unnecessary food quality standards can minimize food waste at the retail level [16].

Approximately one-third of all food waste globally occurs at the household level [26]. Consumer education campaigns promoting informed purchasing habits, proper food storage techniques, and creative recipe utilization can significantly reduce food waste at home.

Technological advancements can play a crucial role in reducing FLW. Developments in smart packaging that monitors freshness, mobile applications that connect consumers with surplus food, and digital platforms that optimize resource allocation across the supply chain all offer promising solutions [27].

Addressing FLW requires a collaborative effort from stakeholders across the Agri-Food system. Governments can play a leading role by enacting policies that incentivize food donation, discourage food waste, and promote investment in sustainable food systems. Collaboration between farmers, processors, retailers, and consumers is essential for developing and implementing effective FLW reduction strategies.

Reducing FLW is not just about saving food; it's about optimizing resource use, strengthening food security, and building a more sustainable future. By adopting these strategies and fostering collaborative action, we can create a more efficient agri-food system that minimizes waste, maximizes resource utilization, and ensures food security for all.

Reducing food loss and waste in agri-food systems is crucial for improving food security, reducing environmental impact, and promoting sustainable agriculture. Few examples of interventions that have been implemented to address this issue are as follows:

Improved harvest and post-harvest practices: Implementing proper harvesting techniques and timely harvesting to minimize losses due to over-ripening and deterioration during transportation. Using appropriate post-harvest handling practices and technologies such as cooling, packaging, and storage facilities [28].

Value chain coordination and infrastructure development: Strengthening coordination among actors in the value chain, including farmers, processors, distributors, and retailers, to reduce inefficiencies and losses. Investing in infrastructure development such as cold storage facilities, transportation networks, and market linkages [29].

Food redistribution and donation: Establishing partnerships between food producers, retailers, and food banks to collect and redistribute surplus food to those in need. Implementing policies and incentives to encourage food

donation and reduce legal barriers to food recovery [30].

Consumer awareness and education: Promoting consumer awareness campaigns to educate individuals about the impacts of food waste and provide practical tips for reducing waste at home. Encouraging responsible food purchasing, storage, portion control, and meal planning [31].

Improved supply chain management and technology: Implementing traceability systems and real-time monitoring to identify bottlenecks and improve supply chain efficiency. Utilizing information and communication technologies (ICT) for better inventory management, demand forecasting, and logistics optimization [15].

Policy and interventions for a sustainable agri-food system

The world faces a multifaceted challenge: ensuring food security for a growing population while safeguarding the environment for future generations. Transforming our agri-food systems towards sustainability is essential to meet this challenge. Effective policies and well-designed interventions can act as catalysts for this transformation.

Policy pillars for sustainability

Policy frameworks that incentivize sustainable agricultural practices like crop rotation, soil conservation techniques, and integrated pest management are crucial. Regulations promoting renewable energy use, water conservation, and responsible waste management are also essential for environmental protection [32].

Supporting policies that ensure fair prices for producers, promote market access for small-scale farmers, and manage food price volatility can enhance the economic viability of sustainable practices. Investments in rural infrastructure and research and development geared towards sustainable technologies are also critical [33].

Policies that promote equitable land ownership, empower women in agriculture and ensure access to social safety nets for vulnerable populations are essential for achieving social justice within the agri-food system. Additionally, policies that promote responsible labor practices and fair working conditions for agricultural workers are crucial [34].

Intervention strategies for transformation

Encouraging research and development in areas like climate-resilient crops, precision agriculture technologies, and improved food processing and storage methods can significantly enhance the sustainability of the agri-food system [35].

Empowering farmers through extension services, training programs, and knowledge-sharing platforms on sustainable practices is crucial for widespread adoption. Additionally, promoting consumer education on sustainable food choices can further contribute to a more sustainable food system [36].

Collaboration between governments, businesses, civil society organizations, and research institutions can leverage resources and expertise for developing and implementing effective solutions. Public-private partnerships can play a significant role in financing sustainability initiatives and scaling up successful interventions.

Conclusion

The impacts of climate change on agri-food systems are complex and far-reaching. Addressing these challenges requires a multi-pronged approach, including developing climate-resilient crops, improving water management practices, and investing in infrastructure that can withstand extreme weather events. By taking proactive measures, Cameroon can safeguard its agri-food systems and ensure food security for its population in the face of a changing climate. Ensuring food safety, minimizing food loss, and reducing food waste are not only independent goals but also interconnected challenges within the global food system. By working together, stakeholders across the food chain can create a more secure, sustainable, and equitable food system for all. Climate change is a significant driver of food loss and waste, impacting every stage of the food supply chain. Recognizing these connections and implementing adaptation strategies, we can strive to minimize food waste, ensure food security, and build a more resilient food system in the face of a changing climate. By prioritizing food and nutritional safety within the context of climate change and existing agri-food system limitations, Cameroon can work towards a more secure and sustainable food future for its population.

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