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Review

Climate Change and Food Security in Sub-Saharan Africa: A Systematic Literature Review

Heather E. Thompson [1], Lea Berrang-Ford [2,]* and James D. Ford [2]

[1] Institute for the Study of International Development, McGill University, 3460 McTavish Street, Montreal, QC, H3A1X9, Canada; E-Mail: heather.thompson2@mail.mcgill.ca

[2] Department of Geography, McGill University, 805 Sherbrooke St. W., Montreal, QC, H3A2K6, Canada; E-Mail: james.ford@mcgill.ca

* Author to whom correspondence should be addressed; E-Mail: lea.berrangford@mcgill.ca; Tel.: +1-514-398-4944; Fax: +1-514-398-7437.

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Abstract: In recent years it has become clear that climate change is an inevitable process. In Sub-Saharan Africa, the expectation is that climate change will have an especially negative impact, not only a result of projected warming and rainfall deficits, but also because of the vulnerability of the population. The impact upon food security will be of great significance, and may be defined as being composed of three components: availability, access, and utilization. To further investigate the link, a systematic literature review was done of the peer-reviewed literature related to climate change and food security, employing the realist review method. Analysis of the literature found consistent predictions of decreased crop productivity, land degradation, high market prices, negative impacts on livelihoods, and increased malnutrition. Adaptation strategies were heavily discussed as a means of mitigating a situation of severe food insecurity across the entire region. This is linked to issues of development, whereby adaptation is essential to counteract the negative impacts and improve the potential of the population to undergo development processes. Findings additionally revealed a gap in the literature about how nutrition will be affected, which is of importance given the links between poor nutrition and lack of productivity.

Keywords: climate change; food security; adaptation; development; Sub-Saharan Africa

1. Introduction

Africa is commonly identified as a region highly vulnerable to climate change, particularly south of the Sahara [1,2]. This is based on the social, economic, and political constraints that determine the capacity of human systems to cope with external stressors such as climate change [3], and the existing burden of climate-related hazards, including high prevalence of food insecurity [4,5]. Africa is also sensitive to climatic hazards, being dependent upon local natural resources for livelihood activities such as agriculture, pastoralism, and fishing [6,7]. Environmental stressors thus place a large proportion of the population at risk of adverse outcomes [3,5,8].

Projections indicate that warming in Africa will be greater than the global annual mean, with an average increase of 3–4 ℃ over the next century [9]. Warming is projected throughout the continent and in all regions, although there is variability in the magnitude and speed of change. The southern region and its western margins are expected to see rainfall decrease, especially during the winter harvest months. East Africa is likely to see an increase in annual mean rainfall, whereas projections are uncertain for the Sahel, Guinean Coast, and southern Sahara. Across Sub-Saharan Africa, it is expected that when rain does fall, it will occur increasingly in high intensity, sporadic rain events [2].

The impact of climate change on food security has been identified as a major area of concern given marginal climatic conditions in many parts of Africa, subsistence livelihoods, and limited resources for adaptation [1]. In particular, the predominance of rain-fed agriculture in much of Sub-Saharan African results in food systems that are highly sensitive to rainfall variability [5,8]. Food security may be defined as a situation whereby "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [10]. Three components of food security are evident in this commonly used definition: availability, access, and utilization, all of which are climate sensitive. Availability relates to the production of food, in terms of its physical presence in a region. Crop productivity and food stocks, for example, relate to food availability [11]. Access is characterized by the ability of an individual or household to obtain food. This depends on food prices, market accessibility, employment, and distribution of wealth [11]. Utilization is the ability of humans to derive full biological benefits from food, based on nutritional value, socio-cultural value, and food safety [3,12]. Food insecurity occurs when food systems are stressed such that food is not available, accessible, or utilization is constrained.

Across Sub-Saharan Africa, communities have extensive experience in dealing with climatic uncertainties and food security implications [13,14]. Subsistence livelihoods have evolved a number of coping mechanisms to manage weather variability, including drought years and low crop yield [13,14]. Commonalities in coping are evident across diverse regions, involving a complex hierarchical decision-making process of sacrifice and use of support networks to endure periods of food insecurity [13,14]. These strategies initially involve responses including alterations to diet to include more famine foods, and during times of acute and / or prolonged stress borrowing from kin, selling productive assets, and eventually migration. As famine progresses, survival strategies thus become more desperate, whereby domestic resources are increasingly committed and potential for reversing the strategies become more constrained [13,14].

Historically, recovery has often been feasible [14], especially where detrimental climatic events have been spread out in space and time. The challenge that climate change presents is that drought and intense rain events will become more frequent, and are even projected to become the normal climatic state [2]. Given poor progress on mitigation and inevitable warming due to historic emissions, we are "locked in" to some climate change impacts [2,15]. Adaptation will be unavoidable, raising the importance of identifying and examining opportunities for developing anticipatory responses, particularly for vulnerable populations [7,16,17].

The importance of ecological and climatic processes for food production, and sensitivity of African food systems to climate, makes climate change a concern for food security. Indeed, the ability to achieve food security has broader implications for development and health, and is thus vitally important for future considerations of international development in the region. While the FAO has examined this link on a global level [1], and there is an emerging body of case study research on climate change and food security in Africa, limited research has examined the current state of knowledge at a regional level. This paper systematically reviews the peer-reviewed literature on climate change and food security in Sub-Saharan Africa, to characterize and synthesize our current understanding on the problem, and identify priorities for future research. Specifically, we use the literature review to answer two key questions: (1) What is the projected impact of climate change upon food security in terms of availability, access, and utilization? and, (2) What is the potential for adaptation to the food security implications of climate change?

2. Method

We conducted a systematic review of peer-reviewed literature related to climate change and food security. A realist review method was used. The realist approach builds upon the principles of the Cochrane systematic review, however seeks explanation, rather than empirical truth [18]. The realist review often includes tighter inclusion criteria and a smaller number of documents than other review approaches, with a focus on depth rather than breadth and the use of predominantly qualitative critical analyses. This method provides an appropriate tool to understand food security as it is embedded within the complex social, cultural, and ecological systems, which will affect vulnerability and adaptive capacity.

A keyword search was performed within the ISI Web of Knowledge electronic database using the keywords (in all fields): ["nutrition*" or "food security" or "diet*"] AND ["climat* change" or "global warming"] AND [Africa]. Articles were excluded if not published in English or French, or published prior to 2005. This date was chosen to ensure that research was current. Only articles, reviews, and meetings were included. This yielded 113 results.

All article titles and abstracts were reviewed to further refine documents based on the inclusion and exclusion criteria; where necessary to confirm relevance, the full text was assessed. Inclusion and exclusion criteria are summarized in Table 1. This resulted in 14 articles for final review.

A questionnaire was developed to review the documents; questions were guided by a realist review strategy and our four key research questions, which focused on identifying and characterizing: (1) The main message presented by the authors, (2) The identified impact of climate change upon the three mechanisms of food security (availability access, and utilization), (3) Adaptation recommendations, and (4) Implications of article insights or results for social and economic development more generally. The survey questionnaire was used to guide review of all documents. Completed questionnaires were collated and reviewed using thematic analysis. This process involves the identification of patterns within data, where themes emerge as categories to facilitate analysis [19].

Table 1. Inclusion/Exclusion criteria for systematic literature review.

Included	Excluded
• English or French only	• Adaptation strategies for environmental, economic or political reasons (no explicit discussion of food security)
• Published from 01 January 2005 to 01 February 2010	• Global studies (no focus on Africa)
• Available in ISI Web of Knowledge	• Technical analyses of climate change projections, theoretic models and simulations
• Articles, reviews, meetings	• Impact of climate change upon vector-borne infectious diseases and chronic diseases (non-nutritional in origin)
• Adaptation for reasons of food security	• Food security as a marginal or absent feature of the article
• Alternative food sources	• Impact of climate change on non-food source animals
• Impact of climate change on crop productivity	• Human evolution/historic climate change
• Impact of climate change upon land degradation (soil fertility, desertification) and implications for food security	• Non-health related climate change adaptations
• Country and multi-country studies; Africa as major focus	

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3. Results

The systematic literature yielded 14 articles. Availability was the primary focus of food security research, typically in relation to expectations of decreased crop productivity and land degradation [3-8,11,20-25]. Discussion of access highlighted impacts on food prices and the ability to procure food [3,4,6,7,11,22,24,26], as well as impacts on livelihoods [3,5,8,25]. Utilization received limited attention in the literature, and was only noted indirectly with respect to malnutrition [6,20,23]; this is consistent with climate change and food security research in other regions [12].

Adaptive strategies presented in the literature included food source alternatives, land degradation reduction, technology inputs, livelihood transitions, natural resource management, and policy and community development programmes.

The articles varied in their spatial approach. All were Africa-specific studies, mostly with a Sub-Saharan Africa focus, but some used country or community case studies to explore how the issues applied in practice [7,11,21,24-26]. Studies did not explicitly state their bias towards rural subsistence systems, but agrarian societies were largely the focus of research. This is perhaps due to the greater interaction of these communities with the natural environment, thus making the impact of climate change more direct.

3.1. Availability

The most direct impact that climate change is expected to have on food security is through availability due to changes in crop productivity. Sub-Saharan Africa is characterized by the reliance of a heavy segment of the population upon local resources for food. Many communities rely largely or solely upon their own subsistence farming for their food needs [6], with marginal groups especially dependent upon climate-sensitive resources [25].

With the exception of mid- to high-latitude regions of Africa, where crop productivity may actually increase as a result of climate change [8], it is projected that mean crop productivity will decrease across Sub-Saharan Africa [2]. Higher temperatures, for example, are expected to have an overall negative impact on crop productivity through decreased crop growth and duration [3]. The implications of climate change for food availability in Sub-Saharan Africa are generally expected to be severe. This is primarily due to the vulnerability of subsistence farmers, who are believed to have a low capacity to cope with environmental stressors [3].

Projected decreases in crop yields relate to climatic impacts on both soil and water. Warming and abnormal rainfall deficits are expected to produce drought, with more frequent high intensity rain events additionally contributing to soil degradation and desertification [20-22,24]. Soil erosion creates problems regarding viability of land for agriculture, as nutrient depletion limits the ability of many crops to prosper [22]. A lack of good quality soil not only reduces its yield potential, but also limits the future potential of the land, as increasingly greater quantities and types of inputs are required to make the soil productive [22].

Soil degradation is furthermore a problem based on the limitations created in terms of what types of crops may be grown. Some crops may be seen as more resilient in poor conditions, but the result is less diversification of crops, and thus a narrower field of food sources, with resulting health implications [20].

Soil degradation has implications for the water absorptive capacity of soil and water availability for agricultural production. At increasing levels of soil degradation, soil capacity to absorb water declines, increasing runoff and further exacerbating soil degradation. Not only does this result in the inability to utilize the most significant input to agriculture, but subsequent water run-off additionally takes topsoil with it, further draining the soil of essential nutrients [21].

Water presents further issues in terms of how it is utilized. Rain-fed farming systems are the dominant form of agriculture among subsistence farmers in Africa [5]. This technique is considered more affordable than irrigation because of the low technology requirement, but it also increases vulnerability based on heavy reliance upon rainfall for water resources. Subsistence agricultural systems are thus particularly sensitive to increased volatility of rainfall and the resulting impacts on food crop yields [5,11].

The UN Millennium Project has recognized water as a key issue in relation to food security and identified increased irrigation of crops as a viable adaptive response [27]. While increased stress on water resources is undoubtedly a significant concern, it has been argued by some that irrigation will further exacerbate poverty due to the costs to farmers already under stress [22,25]. Furthermore, as water becomes scarcer, increased competition for water resources may constrain access by vulnerable subsistence populations and smallholder farmers; potential diversion of water for industrial and domestic use will limit agricultural access [23]. Climate change is thus projected to restrict the availability of irrigation, with the cost of building and maintaining the technology in many cases greater than potential benefits [20]. Water insecurity is closely linked to food insecurity, and thus the stresses upon water resources that will be created by climate change will have significant impacts upon crop productivity.

3.2. Access

Access is based on the ability to procure food. This may be impeded on both sides of the consumption process, with high food prices or lack of financial capital to acquire goods.

While a large proportion of the African population relies primarily upon subsistence agriculture, markets have long been important as a secondary source of food. In general, there has often been a "hungry season" from June to August, when crop yields do not meet demands, and food must largely be bought from markets [4]. There is concern in the literature that this "hungry season" will become longer amidst increasingly poor crop productivity [4]. Consumption of purchased food also increases during drought years [3], and as drought and low crop productivity become increasingly common as a result of climate change, reliance upon these purchased foods is expected to increase. At the same time, rising food prices and unemployment may exacerbate the ability of people to access them [3,4]. Food prices are expected to increase as population growth puts increased pressure on supplies, and imports become more expensive [3,4]. The latter will largely be connected to developed countries retaining surpluses for their own population, or transitioning from the use of crops for food to using them for biofuels [4,22].

Those who derive their livelihood from natural resources will additionally suffer increased food insecurity, based on smaller crop yields limiting availability of food for both personal consumption and as a source of capital [6,7,25]. Lack of capital is identified as a major constraint in the ability of poor farmers to adapt, thus making them much more sensitive to climate change [26]. With rain-fed agriculture and pastoralism being the primary livelihood options in Sub-Saharan Africa, there are a great many people who are vulnerable, and who could see their financial capital seriously limited [5,8]. Limited financial means, combined with expectations of high food prices, will thus seriously affect accessibility, and serve as an additional source for potential food insecurity in the face of climate change.

3.3. Utilization

Perhaps the most significant component of food security in a changing climate, but least studied, is utilization. Even when availability and accessibility are not infringed upon, if food sources are not able to contribute to a balanced, nutritious diet, then the implications for health and productivity of the population could be significant [10]. Health is of vital importance to the ability to engage in livelihood activities and make a valuable contribution to society, as well as for personal quality of life [14]. The cultural aspects of food production and consumption are also widely acknowledged [28-30].

Our review identified limited research related to climate change impacts on utilization in relation to food security. Nutritional disorders, while extensively researched and represented in the peer-reviewed literature, were rarely characterized in relation to climate change. Malnutrition is highlighted as an associated problem with food insecurity generally [6,20], and issues such as micronutrient deficiency and protein deficiency are mentioned specifically [23], as well as discussion of the potential nutritional benefits that certain food sources offer [20,23]. Further investigation into how climate change may affect incidence or prevalence of specific disorders, and the impact they would have upon the population as a whole, however, are generally absent.

Cultural implications have also not been assessed. When diet modification occurs, the culture-determined values, attitudes, and beliefs that affect food selection and food habits will need to be taken into consideration [28-30]. Where production and consumption of certain foods is linked to culture, changes can additionally have psychological implications, and therefore must be a considered [31].

3.4. Adaptation Strategies

Along with discussion of the mechanisms by which climate change impacts food security, adaptation strategies have been proposed in the literature. In relation to food *availability*, extensification and intensification are the major options documented to improve crop yields. One estimate suggests that extensification could increase cereal production in Africa 47 percent by 2020 [3]. It also has implications however, for generating further environmental degradation, with land coverage changes and deforestation found to contribute to CO_2 emissions [3]. Generally, intensification of agricultural land is seen as the most viable solution. This would require improving the quality of soil and maximizing usage of water resources, which often require greater inputs.

Edwards (2007) argues for the benefits of organic agriculture, whereby compost is used as a natural fertilizer. Projects in Ethiopia have shown much higher yields, both in comparison with no inputs and with chemical fertilizers [21]. Manure is also seen as an input that could improve soil quality, and thus permit intensification [11]. There remains debate, however, as to the potential for organic fertilizers to meet demands in soil fertility, and a more traditional approach has been the promotion of chemical fertilizers. While very common and quite heavily used in the developed world, these are relatively absent in Sub-Saharan Africa [3,4,22]. While valuable for improved agricultural yields, increased use of fertilizer may also contribute to climate forcing through the introduction of increased nitrous oxide emissions from soils.

With water shortages expected to occur alongside climate change, maximization of water resources is an additional concern, especially for intensification to become successful. Crop irrigation has seen some success, and it is argued by some that it should be more widely implemented [3,22]. Others however, highlight the limitations of subsistence farmers, and suggest that small-scale and affordable solutions would be more beneficial [4,5,25].

To better take advantage of limited water resources, certain crop varieties are also identified as important components of adaptation strategies. Genetic modification is one possibility, in terms of the creation of drought-resistant or high-heat tolerance crop varieties [3,4,23,24]. High-yielding seeds are additionally seen as a possibility to increase crop productivity [4]. Furthermore, certain crop varieties have been identified and classified as "underutilized", based on their potential value as being both highly productive in poor soil conditions and nutritionally beneficial [20,23]. Further research is recommended to identify additional underutilized crops.

A final adaptive strategy for improving crop yield is modifying agricultural practices more directly. Crop diversification is one possibility, whereby dual-land use agricultural systems may be used to grow some of the more staple crops for a specific region, along with an "insurance crop" in case of crop failure [7]. This would reduce food insecurity, whereby there is always at least one crop to fall back on [25]. No-tillage farming is additionally seen as less disruptive to the soil, helping to maintain soil nutrients and water availability [22].

In terms of *accessibility*, the primary adaptive strategy to minimize vulnerability of financial capital, and thus improve market access when subsistence crops are not plentiful enough to provide food security, is livelihood diversification [5,7]. This is believed to allow for sources of income that are not fully reliant upon the natural environment, and thus less vulnerable to climate change. Off-farm employment is considered particularly viable for youth, who could earn money to send back to their families [7]. Physical market accessibility remains a challenge with respect to general improvements in urban, rural, and transportation infrastructure [3,26].

Adaptive strategies related to the *utilization* component of food security are mostly implicit in discussion of certain underutilized crops, and their nutritional value. Bambara groundnut for instance is seen as a rich source of protein and energy [20]. Pigenopea is also identified as high protein, a rich source of carbohydrates, and an important source of various vitamins and minerals [23]. Nonetheless, adaptation of these crops is suggested more to improve availability, and utilization adaptation was not a major consideration in the literature.

Access to information about climatic changes and potential adaptive strategies, in order to effectively promote practical adaptation, must also be provided to those subsistence farmers in Sub-Saharan Africa who will be most affected [26]. In many cases, existing recommendations for improved farming practices are already consistent with increased adaptive capacity to projected climate changes. Additional awareness among farmers that unfavourable climatic conditions are likely to become more common can further mitigate the danger that subsistence farmers will fall back on traditional coping strategies that may be maladaptive in light of climate change; with decreased opportunity to recover, adaptive capacity may be limited.

4. Discussion

This review is subject to bias and error related to the relatively limited number of documents considered eligible for inclusion and review. The 14 articles must be seen as a sample of all of the literature that exists on the topic, including only peer-reviewed articles, and written between 2005 and 2010. Beyond these parameters there may exist additional literature. In particular, Web of Knowledge has limited coverage of non-English indexed articles, and our review may thus under-represent literature from West and Central Africa. There will be a number of indirect causal effects of climate change on food security that are not included in this review, including but not limited to the impacts of changing vector-borne disease burden on agricultural labour and population health, the food security impacts of climate-induced conflict, and the distribution and severity of agricultural insect pests. While outside of the scope of this review, these indirect effects are likely to be important, complex and difficult to predict. Nevertheless, the review was done using a systematic realist technique, ensuring that the causal relationship between climate change and food security was rigorously investigated in the literature that was available, based on the key mechanisms of availability, access, and utilization [18]. The narrow field is additionally integral in a realist review to adequately investigate the mechanisms that influence the causal relationship of interest on a more focused level.

With climate change as a significant factor in food security, population growth must also be considered. By 2050, the population in Sub-Saharan Africa alone is expected to increase by almost one billion [32]. Alongside climate change, this will increase demand on increasingly scarce environmental resources. The augmented demand for crop and livestock products by a larger population will mean that adaptation strategies must occur within the context of both subsistence farming and growing consumer demands in the region. Climate change impacts will not be manifest in isolation, but rather in conjunction with concurrent global and regional transitions in health and its environmental and social determinants. The impact of HIV-AIDS on population demographics and health in Sub-Saharan Africa, for example, will affect both the vulnerability and adaptive capacity of communities, individuals and food systems to climate shocks and variability. Increasing urbanization, migration and globalization will affect regional diets, food demand and trade relations. Additionally, meeting global and regional food security goals within expectations of greenhouse gas mitigation poses a very difficult and real global challenge.

Responsive coping mechanisms that have been typical of historic weather variability [7] will become less viable amidst increased prevalence of adverse climatic conditions, increasing the importance of anticipatory action. The potential to recover will be constrained as shocks place continual stress upon subsistence societies. More long-term solutions requiring behavioural changes, either in anticipation or aversion, will be necessary [7]. Many potential strategies have been outlined in the literature. One of the difficulties with adaptation, however, is that it typically requires both financial capital and a willingness to change a historically and culturally engrained way of life. This is a challenge that will be especially significant in Sub-Saharan Africa, which is identified as having a low adaptive capacity based on both of these factors [5,9,26].

A major barrier to adaptation is a lack of financial capital among impoverished/subsistence farmers. Adaptive solutions requiring the use of irrigation and chemical fertilizers may be beneficial to increase yields, but will only be accessible to those who can afford them. The majority of people living a rural, agricultural livelihood have low purchasing power and thus low levels of inputs to combat climate change [24]. Technologies must therefore be small-scale and tailored to the region, as well as sustainable in the long-term [4]. The importance of this is apparent in numerous failed projects initiated by the international aid community. One such example is the introduction of irrigation to farming communities in South Africa [25]. While irrigation increased yields initially, it was not sustainable in the long-term because of the scarcity of technology inputs and knowledge requirements for maintenance. The technology thus fell into disrepair, and the community reverted back to rain-fed agriculture [25].

Options for low-cost inputs to improve soil quality and productivity, without international aid, have been suggested [11,21,22]. Organic agriculture is often viewed as cost efficient because the inputs are natural and procurable from local sources. For instance, rather than chemical fertilizers, compost has been found to be extremely effective at improving crop yields in Ethiopia, and has even produced the long-term benefit of mitigating land degradation [21]. Organic agricultural systems have further been seen to have significantly greater soil microbial activity and biomass, as well as higher soil organic carbon than systems under conventional management [33]. These characteristics can enhance food and water supplies, reduce greenhouse gas emissions, and reverse desertification [11]. There are thus options for low-cost inputs that improve soil quality, and may even help maximize water resources. There is however, the risk of microbial contamination in the manure being transferred to food products, which could lead to health impacts if the food is improperly washed or handled [34].

To meet water demands, no-tillage farming is being promoted as a means to conserve both soil quality and water resources [22]. It has been found to maintain soil organic matter, decrease weather-related impacts on crop yields, and with the lack of soil disturbances, carbon sequestration is also high [22]. It could be of great use to impoverished farmers due to the low cost involved, though it would require weed control either biologically or chemically [22]; preferably the former given the cost implications of the latter.

A major goal in adaptive solutions is for the development or identification of crops that are resilient under drought stress or in poor quality soil [5]. There are limited financial and political incentives within the globalized agricultural and food production systems, however, to promote such research at a scale considered to be sufficient for adaptive requirements [20]. One proposed solution to this, which has been successful in discovering the potential of the Bambara groundnut, is to undertake combined research efforts, integrating domestic institutes, so that crops can be identified that are ideally matched to a specific region [20].

In general, community participation is considered important for the success of adaptation [6,7,20,25,35,36]. Sub-Saharan Africa is a diverse region, both in terms of environmental and cultural dimensions. Food insecurity cannot therefore be addressed by a single, region-wide policy [3]. Integration of the community into development of adaptive strategies is thus important to achieving solutions that are both culturally appropriate and sustainable for local capacity [7,35,36]. Formal agricultural associations have been found to strengthen social networks within the community, and provide a forum for building human capacity [25]. Agricultural experimentation and programs to identify new technologies or drought-resistant crops, or otherwise implement adaptation strategies, have been more easily undertaken when community solidarity occurs [25]. This is generally believed to be a result of more inclusive participation and availability of support mechanisms [7].

Certain large-scale and capital-intensive adaptations could be of great value, but necessitate government involvement [6]. The improvement of infrastructure such as roads would greatly increase market accessibility to rural farmers [26]. Another problem identified in much of Sub-Saharan Africa is the lack of storage facilities for surplus harvests [4]. Poor farmers are forced to sell their surpluses after harvest, when market prices and demand are low. Then, during the "hungry season" when crop yields are smaller, they are forced to buy back the same type of crop they had earlier harvested and sold in order to meet subsistence needs. Higher demand at this time leads to inflated prices and an overall net loss for the farmer [4]. Suggested solutions include the construction of storage facilities in rural communities, so that crops would not spoil as quickly, and thus could be kept for later consumption [4].

There is negligible explicit consideration of *utilization* as a factor in projected food insecurity. Sub-Saharan Africa is currently subject to significant health burden with much of the population considered to be impoverished and lacking access to healthy and nutritious food [1]. This creates a major impediment to development, as labour productivity is compromised, contributing to a vicious cycle of poverty and malnutrition [1]. With the risk of increased food insecurity, health problems could become even more important to address, so that regional social and economic development is not further constrained.

Nutritional considerations of food security may be framed around the factors of quantity and quality. In the context of Sub-Saharan Africa, undernutrition is reflected in low calorie intake and deficiency of essential nutrients, and has been identified as the most significant issue for the impoverished populations of Sub-Saharan Africa [6,20,23]. Protein is especially absent from the diet of much of the population, with most Africans considered to be protein deficient [23]. The combination of both energy and protein malnutrition is seen as a direct cause of death, and independently can significantly constrain capacity and labour potential [37].

A major influence on poor nutrition is lack of a diversified diet, which is seen to result in a failure to ingest certain essential nutrients [38]. Micronutrients are those substances needed in only very small quantities that enable the body to produce enzymes, hormones, and other substances essential for proper growth and development [39]. Deficiencies of these nutrients are linked to various disorders in the developing world, with the most prevalent in Africa being deficiencies in vitamin A, iodine, and iron [40]. Among the poor, nutrient deficiencies can be a problem at any time, but during times of drought or low crop yield, the problem can be exacerbated as fewer food sources become available, and a narrower field of options must be relied upon.

From a climate change standpoint, the major challenge for micronutrient deficiencies is crop failure and decreased access to food. Vitamins and minerals are found in varying quantities and only in certain foods. Fortification is possible, and initiatives are being undertaken [41], but a balanced diet is still very important to adequately include all of the necessary micronutrients in the diet [42]. The concern is that climate change will decrease availability of food through decreased crop production, and access to food through the combination of high market prices and low financial capital, and the outcome will be a diet composed of minimal food sources of poor nutritional value. The impact this could have upon subsistence population could be drastic, and must be investigated further.

Therefore, in dealing with malnutrition, it is insufficient to provide food of any description, but rather that it be of significant nutritional value. In researching potential new crop varieties to promote, it is thus important to first ensure their nutritional value. Bambara groundnut and pigeonpea for instance are both underutilized crops that could be quite beneficial, due to their high content of both proteins and carbohydrates, and several essential vitamins and minerals [20,23]. They also provide relatively high yields in soils of poor quality, and thus as drought-tolerant crops would be of great value amidst expected climate changes [20,23].

It is additionally important to identify traditional drought crops, and evaluate their contribution to a nutritious diet. This is especially important within the context of famine, when certain crops may serve as the primary food source. Cassava for example, has long been used as a famine reserve crop in Africa, and is a source of sustenance for 500 million people worldwide [43]. While it does serve as a source of calories, it has also been linked to the severely debilitating disease konzo, which is caused by cyanide toxicity from improper processing and cooking [44]. During times of drought, diets often become dominated by cassava as other crops fail, and processing is simplified due to the stress of eating what little is available. This has led to numerous konzo epidemics across Sub-Saharan Africa, severely and negatively impacting the health of large segments of subsistence populations [45]. Thus it may be seen that combating hunger is not as simple as access to food, but must entail access to nutritious and safe food.

5. Conclusions

In conclusion, the link between climate change and food security is clear and strong, though unequally explored. Availability impacts are by far the best researched, with ample evidence on how warming and rain deficits will impact crop productivity. Accessibility has also been significantly examined, especially in regards to concerns of rising food prices and the potential need for livelihood transitions. Academic research is limited, however, in linking climate change to nutritional disease prevalence and incidence. There is a large body of literature on what major disorders currently afflict many people in Sub-Saharan Africa, but little research has been done to examine whether any disorders will be disproportionately affected by climate change, or whether others may emerge as a more widespread problem. Research gaps thus exist in relation to the utilization mechanism of food security.

Sub-Saharan Africa is a region struggling with underdevelopment, and the high proportion of the population that is currently food insecure is undoubtedly linked [22]. If Sub-Saharan Africa is ever to achieve a reality of development, it must break the cycle of poverty and malnutrition in which it is currently stuck [39]. Climate change may be seen as another challenge in the way of Sub-Saharan Africa reaching its potential, but it could also provide the impetus to push for the adaptation strategies that will not only mitigate further food insecurity, but could also diminish that which has already set in. Climate change is an unavoidable future for Africa, but food insecurity need not be.

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References

1. Impact of Climate Change, Pests and Diseases on Food Security and Poverty Reduction. In *Proceedings of the FAO Committee on World Food Security (31st Session)*, Rome, Italy, 23–26 May 2005.

2. Christensen, J.; Hewitson, B.C.; Mearns, L.O. Regional Climate Projections. In *Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Solomon, S., Qin, D., Manning, M., Eds.; Cambridge University Press: Cambridge, UK, 2007.
3. Gregory, P.J.; Ingram, J.S.I.; Brklacich, M. Climate change and food security. *Philos. Trans. R. Soc. B* **2005**, *360*, 2139-2148.
4. Brown, M.E. Markets, climate change, and food security in West Africa. *Environ. Sci. Technol.* **2009**, *43*, 8016-8020.
5. Cooper, P.J.M.; Dimes, J.; Rao, K.; Shapiro, B.; Twomlow, S. Coping better with current climatic variability in the rain-fed farming systems of Sub-Saharan Africa: An essential first step in adapting to future climate change? *Agric. Ecosyst. Environ.* **2008**, *126*, 24-35.
6. Wlokas, H.L. The impacts of climate change on food security and health in Southern Africa. *J. Energy South. Afr.* **2008**, *19*, 12-20.
7. Osbahr, H.; Twyman, C.; Adger, N.; Thomas, D.S.G. Effective livelihood adaptation to climate change disturbance: Scale dimensions of practice in Mozambique. *Geoforum* **2008**, *39*, 1951-1964.
8. Jones, P.G.; Thornton, P.K. Croppers to livestock keepers: Livelihood transitions to 2050 in Africa due to climate change. *Environ. Sci. Policy* **2009**, *12*, 427-437.
9. Boko, M.; Niang, I.; Nyong, A.; Vogel, C.; Githeko, A.; Medany, M. Osman-Elasha, B. Tabo, R.; Yanda, P. Africa. In *Proceedings of the Working Group II Report* "*Impacts, Adaptation and Vulnerability*"; Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., Eds.; Cambridge University Press: Cambridge, UK, 2007.
10. Declaration of the World Summit on Food Security. In *Proceedings of World Summit on Food Security*, Rome, Italy, 16–18 November 2009.
11. Verdin, J.; Funk, C.; Senay, G.; Choularton, R. Climate science and famine early warning. *Philos Trans. R. Soc. B* **2005**, *360*, 2155-2168.
12. Ford, J. Vulnerability of Inuit food systems to food insecurity as a consequence of climate change: A case study from Igloolik, Nunavut. *Reg. Environ. Change* **2009**, *9*, 83-100.
13. Roncoli, C.; Ingram, K.; Kirshen, P. The costs and risks of coping with drought: Livelihood impacts and farmer's responses in Burkina Faso. *Clim. Res.* **2001**, *19*, 119-132.
14. Stock, R. *Africa South of the Sahara: A Geographical Interpretation*; The Guildford Press: New York, NY, USA, 2004; pp. 224-238.
15. Ramanathan, V.; Feng, Y. On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead. *Proc. Natl. Acad. Sci.* **2008**, *105*, 14245-14250.
16. Badjeck, M.C.; Allison, E.H.; Hallsd, A.S.; Dulvy, N.K. Impacts of climate variability and change on fishery-based livelihoods. *Mar. Policy* **2010**, *34*, 375-383.
17. Smith, J.B. Setting priorities for adapting to climate change. *Glob. Environ. Change* **1997**, *7*, 251-264.
18. Pawson, R.; Greenhalgh, T.; Harvey, G.; Walshe, K. Realist review—A new method of systematic review designed for complex policy interventions. *J. Health Res. Policy* **2005**, *10*, 21-34.
19. Fereday, J.; Muir-Cochrane, E. Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *Int. J. Qual. Methods* **2006**, *5*, 1-11.

20. Azam-Ali, S. Agricultural diversification: The potential for underutilised crops in Africa's changing climates. *Riv. Biol.* **2007**, *100*, 27-37.
21. Edwards, S. Role of Organic Agriculture in Preventing and Reversing Land Degradation. In *Climate and Land Degradation*; Springer: Berlin, Germany, 2007; pp. 523-536.
22. Lal, R. Soils and food sufficiency: A review. *Agron. Sustain. Dev.* **2009**, *29*, 113-133.
23. Odeny, D.A. The potential of pigeonpea (*Cajanus cajan* (L.) Millsp.) in Africa. *Nat. Resour. Forum* **2007**, *31*, 297-305.
24. Tingem, M.; Rivington, M.; Bellocchi, G. Adaptation assessments for crop production in response to climate change in Cameroon. *Agron. Sustain. Dev.* **2009**, *29*, 247-256.
25. Ziervogel, G.; Bharwani, S.; Downing, T.E. Adapting to climate variability: Pumpkins, people and policy. *Nat. Resour. Forum* **2006**, *30*, 294-305.
26. Bryan, E.; Deressa, T.T.; Gbetibouo, G.A.; Ringler, G. Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environ. Sci. Policy* **2009**, *12*, 413-426.
27. *Investing in Development: A Practical Plan to Achieve the Millenium Development Goals*; UN Millennium Project; Earthscan: London, UK, 2005.
28. Kaufman-Kurzrock, D.L. Cultural aspects of nutrition. *Top. Clin. Nutr.* **1989**, *4,* 1-6.
29. Menasche, R.; Marques, F.C.; Zanetti, C. Self-consumption and food security: Family agriculture based on eating knowledge and practices. *Rev. Nutr.* **2008**, *21*, 145-158.
30. Wahlqvist, M.L.; Lee, M.S. Regional food culture and development. *Asia Pac. J. Clin. Nutr.* **2007**, *16*, 2-7.
31. Mead, M. The Problem of Changing Food Habits. In *Food and Culture: A Reader*; Counihan, C., Esterik, P.V., Eds.; Routledge: New York, NY, USA, 2008.
32. DESA (United Nations, Department of Economic and Social Affairs, Population Division). *World Population Prospects: The 2008 Revision*; United Nations Publication: New York, NY, USA, 2009.
33. Araújo, A.S.F.; Leite, L.F.C.; Santos, V.B.; Carneiro, R.F.V. Soil microbial activity in conventional and organic agricultural systems. *Sustainability* **2009**, *1*, 268-276.
34. Magkos, F.; Arvaniti, F.; Zampelas, A. Putting the safety of organic food into perspective. *Nutr. Res. Rev.* **2003**, *16*, 211-222.
35. Goebel, A. Process, perception and power: Notes from "participatory" research in Zimbabwean resettlement area. *Dev. Chang*e **1998**, *29*, 277-305.
36. Sillitoe, P. What, know natives? Local knowledge in development. *Soc. Anthropol.* **1998**, *6*, 203-220.
37. Blössner, M.; de Onis, M. *Malnutrition: Quantifying the Health Impact at National and Local Levels*; Environmental Burden of Disease Series No. 12; WHO Press: Geneva, Switzerland, 2005.
38. Arimond, M.; Ruel, M.T. Dietary diversity is associated with child nutritional status: Evidence from 11 demographic and health surveys. *J. Nutr.* **2004**, *134*, 1579-2585.
39. WHO (World Health Organization). *Micronutrients*; Available online: http://www.who.int/nutrition/topics/micronutrients/en/index.html (accessed on 11 March 2010).
40. Micronutrient Deficiencies in Africa. In *Proceedings of the WHO Intercountry Workshop for National Programme Managers*, Gaborone, Botswana, 7–9 October 1997; WHO Press: Geneva, Switzerland, 1998.

41. FAO. *Guidelines on Food Fortification with Micronutrients*; WHO Press: Geneva, Switzerland, 2006.
42. US National Library of Medicine. *MedlinePlus: Vitamins*; Available online: http://www.nlm.nih.gov/medlineplus/vitamins.html (accessed on 25 March 2010).
43. Bruyn, G.W.; Poser, C.M. *The History of Tropical Neurology: Nutritional Disorders*; Science History Publications: Canton, MA, USA, 2003.
44. Tylleskär, T. The Association between Cassava and the Paralytic Disease Konzo. In *ISHS Acta Horticulture: International Workshop on Cassava Safety*; ISHS: Leuven, Belgium, 1994.
45. Ministry of Health, Mozambique. Mantakassa: An epidemic of spastic paraparesis associated with chronic cyanide intoxication in cassava staple area of Mozambique. 1. Epidemiology and clinical and laboratory findings in patients. *Bull. WHO* **1984**, *62*, 477-484.