Climate change–food security nexus in Burkina Faso

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Abstract

Climate change is expected to have far-reaching impacts on food security. Such impacts are likely to be higher in developing countries. This paper analyses the state of research on the nexus between climate change and food security in Burkina Faso. In particular, it sheds light on whether and how the scholarly literature addresses the impacts of climate change on the four dimensions of food security (i.e. food availability, food access, food utilisation and stability). It also explores the synergies and trade-offs between climate change mitigation/adaptation and food security. A search performed in April 2020 on the Web of Science yielded 243 records and 62 of them, which resulted eligible, were included in the systematic review. The literature shows that climate change will affect all the four dimensions of food security. However, most of the analysed literature addresses its effects on food availability. Indeed, it focuses on impacts on crop yields and climate suitability for crops (e.g. maize, millet, sorghum). Moreover, most of the impacts on the remaining food security dimensions stem from the negative effects on food production and supply (cf. food availability). The review also shows that, on the one hand, climate change mitigation can undermine food security and, on the other hand, agriculture intensification and some adaptation strategies, which aim to enhance food security, might increase emissions from agriculture. The dual climate change—food security relationship calls for integrated policies that address trade-offs and optimise co-benefits between 'climate action' and 'zero hunger' in Burkina Faso.

Keywords: climate change mitigation, climate change adaptation, climate-smart agriculture, food availability, food access, food system, Sahel, West Africa

Review Methodology: The paper follows the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and draws upon a systematic review of all documents indexed in the Web of Science, viz. Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index - Science (CPCI), Conference Proceedings Citation Index - Social science & Humanities (CPCI-SSH) and Emerging Sources Citation Index (ESCI).

Introduction

The notion of food security, as well as concerns on food insecurity and malnutrition, is as old as humanity, but it has evolved and been expanded over time [1–3]. According to the Food and Agriculture Organisation of the United Nations [4], 'Food security exists when 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'. As a result of the evolution of the concept of food security, it is widely recognised nowadays that it has four dimensions [1, 5–7]: *food availability* (i.e. adequate food production and supply); *food access* (i.e. physical access and economic accessibility or affordability); *food utilisation* (i.e. correct use of food based on nutrition knowledge); and *stability* over time in food availability, access and use. Over the last decades, food security concept has been central in the debate on sustainable development (cf. Millennium Development Goals—MDGs and Sustainable Development

Goals—SDGs). For instance, the second SDG 'Zero Hunger' aims to 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' [8]. However, despite considerable efforts, food insecurity is still one of the pressing development challenges in many countries, especially developing ones. Indeed, the State of Food Security and Nutrition in the World 2020 [9] shows that about 690 million people (i.e. 8.9% of the global population) were undernourished in 2019. This estimate refers to the period before the COVID-19 pandemic, which is expected to exacerbate food insecurity and malnutrition worldwide. Moreover, it was estimated that over 2 billion people do not have a good food security status, when considering people affected by both severe and moderate food insecurity [10].

Food insecurity is one of the symptoms of the dysfunction of the global food system, which is under the unprecedented confluence of various pressures [11] including climate change [12]. In fact, FAO [12] puts that 'Through its impacts on agriculture, climate change will have negative effects on food security in all of its dimensions […]' (p. 8). Climate change affects the availability of food through its adverse impacts on crop yields, and livestock productivity and fish production. It is also expected to reduce economic access to food (i.e. food affordability) through negative impacts on both food prices (due to food supply shortfalls) and rural livelihoods [12]. Climate change will also affect physical accessibility to food, due to natural disasters and damages to infrastructure, especially in remote rural and mountainous regions [13]. Climate variability may also change food utilisation with impacts on the nutrition status of the populations [12], especially poor and vulnerable groups such as children [14, 15] and women [16]. It will also affect the dietary patterns of indigenous communities [17, 18]. Furthermore, the literature highlights some potential linkages between climate change and diet-related non-communicable diseases (NCDs) [19]. The variability of climate and the increase in the frequency and the intensity of extreme climate events will affect the stability of food availability, access and utilisation [12] as well as the long-term stability and resilience of the whole food system [20]. In this context, Islam and Wong [21] put that 'it seems that research on climate change and food in/security has often been one-sided; with climate change being identified as the cause of food insecurity and not how the systems in place to ensure food security have exacerbated the issue of climate change'. Indeed, agriculture is both a main contributor to climate change, through greenhouse gas (GHG) emissions, and one of the most affected sectors by it [12, 22]; agriculture, forestry and other land uses (AFOLU) amount to about a fifth of global GHG emissions worldwide [12].

The literature shows that the effects of climate change on agriculture, and consequently on food security, will be particularly severe in regions where agriculture is predominantly rain-fed such as in Sub-Saharan Africa [23–40]. In this respect, Webersik and Wilson [40] argue that 'African economies are closely linked to natural resources and rely heavily on agriculture, largely rain fed […]. It is predicted that Africa will be particularly vulnerable to climate change and climate variability associated with biodiversity loss, food insecurity, water scarcity and an increase in drought frequency' (p. 400). Many scholars point out that climate change will also exacerbate food insecurity [41–50] and livelihoods vulnerability [43, 51–59] in Sub-Saharan Africa (SSA).

In the context of SSA, the West Africa and Sahel regions seem particularly vulnerable to the effects of climate change [60–62]. Indeed, Sultan and Gaetani [63] stress that 'West Africa is known to be particularly vulnerable to climate change due to high climate variability, high reliance on rain-fed agriculture, and limited economic and institutional capacity to respond to climate variability and change'. There is a growing body of evidence that climate has been changing across West Africa and Sahel regions [64–70]. Referring to a Sahelian and West African country such as Burkina Faso, Zidouemba [71] puts that the 'economic development in Burkina Faso is potentially vulnerable to climate change, given the country's dependence on rain-fed agriculture' (p. 2797). In fact, Burkina Faso (BF), a landlocked country in the Sahelian West Africa, is considered one of the most vulnerable countries to climate change in SSA [72]. The country has a low Human Development Index (ranking 182/189) [73] and its population suffers from all forms of malnutrition [9, 74–76]. In fact, the prevalence of undernourishment was 14.1% in 2015–2017 period, with about 3 million undernourished Burkinabe people [74]. Recent data from the *State of Food Security and Nutrition in the World 2020* [9] show that, in the period 2017–2019, the prevalence of undernourishment in the total Burkinabe population was 19.2%, while the prevalence of moderate or severe food insecurity was 47.7%, both among the highest in Sub-Saharan Africa region. Moreover, poverty is widespread and 43.7% of the country's population lives below the poverty line (1.90 USD/day) [77]. Agriculture is a leading sector in Burkina's economy and contributes to 28.6% of the gross domestic product [77]. Nevertheless, the sector is extensive and very reliant on rainfall, which makes it particularly vulnerable to climate variability and change [78, 79], thus also affecting food security of the population. All the above reasons make Burkina Faso an interesting case to analyse the impacts of climate change on food security. In this context, the present paper analyses the state of research on the nexus between climate change and food security in Burkina Faso. In particular, the paper casts light on whether and how the scholarly literature addresses the impacts of climate change on the four dimensions of food security and explores synergies and trade-offs between climate change mitigation and food security.

Methods

The paper follows the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [80] and draws upon a systematic review of all documents indexed in the Web of Science, viz. Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index - Science (CPCI), Conference Proceedings Citation Index - Social science & Humanities (CPCI-SSH) and Emerging Sources Citation Index (ESCI). A search was performed on 22 April 2020 using the following string: *(Burkina OR Sahel OR "West Africa") AND ({food security} OR {food insecurity} OR nutrition) AND ({climate change} OR "climate variability" OR "global warming")*. The initial literature search yielded 243 records. During the selection process, documents were checked with respect to two eligibility criteria relating to the topical focus (viz. document deals with both climate change and food security) and geographical coverage (viz. document deals with BF). The document selection process (Table 1) was informed by the methodology suggested by El Bilali [81,82].

The screening of titles allowed excluding 59 documents as they do not refer to BF; records covering wide geographical areas (e.g. Sahel, West Africa, Economic Community of West African States - ECOWAS) were kept. Additional 112 documents were excluded during the analysis of abstracts as they do not meet at least one of the eligibility criteria. Furthermore, 10 documents were discarded following the scrutiny of full-texts. Therefore, 62 records were selected and included in the systematic review (Table 2).

Table 1. Systematic review steps and process: documents identification and selection.

Selection steps	Number of selected documents	Number of excluded documents and ineligibility reasons
Initial search and documents identification	243	—
Screening of records based on titles	243	59 documents excluded because they deal with other countries in West Africa/Sahel (e.g. Benin, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal, Togo), SSA (e.g. Botswana, Ethiopia, Kenya, Madagascar, Sudan, Zambia) and other countries (Canada, China)
Screening of documents based on abstracts	184	112 documents excluded: • 42 documents because they do not deal with BF • 34 documents because they do not deal with food security • 36 documents because they do not address climate change
Scrutiny of full-texts	72	10 documents excluded: • 8 records because they do not address BF • 2 documents because they do not deal with food security
Inclusion of eligible documents in the systematic review	62	—

Table 2. List of selected documents.

Year	Number of selected documents	References of selected documents
2020*	2	Ayantunde *et al.* [83]; Tankari [84]
2019	8	Belesova *et al.* [15]; Egbebiyi *et al.* [85]; Egbebiyi *et al.* [62]; Lelievel *et al.* [86]; Rhodes and Atewamba [87]; Sultan *et al.* [88]; Sultan *et al.* [89]; Zampaligré and Fuchs [90]
2018	13	Antwi-Agyei *et al.* [91]; Belesova *et al.* [92]; Blaser *et al.* [93]; Callo-Concha [94]; Fanzo *et al.* [95]; Faye *et al.* [96]; Hasegawa *et al.* [44]; Parkes *et al.* [97]; Parkes *et al.* [98]; Partey *et al.* [99]; Richardson *et al.* [46]; Zidouemba and Gerard [100]; Zougmoré *et al.* [101]
2017	10	Belesova *et al.* [102]; Gahi *et al.* [103]; Gaisberger *et al.* [104]; Guan *et al.* [105]; Hadebe *et al.* [106]; Koffi *et al.* [107]; Niles and Brown [47]; Palazzo *et al.* [108]; Rigolot *et al.* [109]; Zidouemba [71]
2016	10	Cramer *et al.* [110]; Di Leo *et al.* [111]; Douxchamps *et al.* [112]; Garcia de Jalon *et al.* [113]; Henderson *et al.* [114]; Nawrotzki *et al.* [115]; Salack *et al.* [116]; Sorgho *et al.* [14]; Sultan and Gaetani [63]; van Wesenbeeck *et al.* [117]
2015	5	Ahmed *et al.* [118]; Bizikova *et al.* [119]; Haile [68]; Tesfaye *et al.* [120]; Waongo *et al.* [121]
2014	2	Epule *et al.* [122]; Johnson and Brown [123]
2013	2	Sultan *et al.* [124]; Warner and van der Geest [125]
2012	3	Jarvis *et al.* [126]; Katikiro and Macusi [127]; Tatsidjodoung *et al.* [128]
2011	2	Roudier *et al.* [129]; Sissoko *et al.* [58]
2010	1	Garrity *et al.* [130]
2009	1	Brown *et al.* [131]
2008	1	Vrieling *et al.* [132]
2007	1	Paeth and Thamm [133]
2005	1	Huntingford *et al.* [134]

*Only articles published by 22 April 2020.

The systematic review of the selected records regarded both bibliometrics and topics addressed in the literature on climate change and food security in BF (Table 3).

Results and discussion

Bibliometric analysis

The bibliometric analysis (Table 4) suggests an increasing interest of the academic community in the nexus between climate change and food security in BF and beyond (e.g. West Africa, Sahel). The average annual output of articles in the considered period (2005–2020) is about 4; it ranges from nil in 2006 to a maximum of 13 in 2018. As for sources and journals, the highest number of papers was published in Regional Environmental Change (5 documents), Climatic Change (4 documents), Climate (3 documents) and Environmental Research Letters (3 documents) so mainly in journals dealing with climate change and environmental research. Nonetheless, it should be highlighted that the results of the research on climate

Table 3. Bibliometric and topical analyses of the selected literature.

Analysis type	Items analysed
Bibliometric analysis	Research areas, sources/journals, authors, affiliation institutions and affiliation countries
Topical analysis	Climate change and food availability - Effects on agricultural production (crop production, animal production, fisheries) and productivity/yields - Climate change as a determinant and cause of food insecurity and hunger - Climate change and agricultural losses Climate change and food access - Effects on economic accessibility/affordability - Effects on physical accessibility (cf. natural disasters and climate-induced migration) - Impacts on livelihood assets and household resources Climate change and food utilisation - Effects on diets and food consumption patterns - Climate change and malnutrition (obesity and overweight, micronutrient deficiencies) Climate change, long-term food security and food system stability/resilience Climate change mitigation and food security: synergies and trade-offs - Impacts of the quest for food security (cf. agriculture intensification, agricultural land expansion) on GHG emissions - Implications of climate change mitigation policies and strategies in terms of food security

Table 4. Bibliographical metrics: top 10 journals, research areas, authors, affiliations and countries.

Journals (a)	Research areas (b)	Authors (c)	Countries (d)	Affiliations (e)
Regional Environmental Change (5)	Environmental Sciences—Ecology (29)	Sultan B (8)	Burkina Faso (16)	CNRS (7)
Climatic Change (4)	Meteorology—Atmospheric Sciences (14)	Brown ME (4)	USA (16)	IRD (7)
Climate (3)	Science Technology (10)	Belesova K (3)	France (13)	*Sorbonne Université* (7)
Environmental Research Letters (3)	Agriculture (9)	Ciais P (3)	Germany (13)	International Food Policy Research Institute - IFPRI (6)
Agricultural and Forest Meteorology (2)	Geography (4)	Douxchamps S (3)	England (12)	*Museum National d'Histoire Naturelle* (MNHN), France (6)
Agricultural Systems (2)	Food Science Technology (3)	Herrero M (3)	Kenya (8)	*Université Paris Saclay* (6)
Applied Geography (2)	Public Environmental Occupational Health (3)	Ouedraogo M (3)	Mali (6)	French Agricultural Research Centre for International Development - CIRAD (5)
Food Security (2)	Business Economics (2)	Parkes, B. (3)	Netherlands (6)	International Crops Research Institute for the Semi Arid Tropics - ICRISAT (5)
Global Environmental Change Human and Policy Dimensions (2)	Engineering (2)	Sauerborn R (3)	Australia (4)	International Livestock Research Institute - ILRI (5)
International Journal of Climate Change Strategies and Management (2)	Forestry (2)	Sie A; Thornton PK; van Wijk M; Wilkinson P (3)	Canada, Ghana (4)	*Université de Montpellier*; *Université de Versailles Saint Quentin en Yvelines* (5)

Legend: figures refer to the number of documents by journal (a), research area (b), author (c), country (d) or institution (e).

change and food security in BF were published in 44 journals and sources. Most of the selected documents can be included in the research areas of environmental sciences—ecology (29 documents), meteorology—atmospheric sciences (14 documents), science technology (10 documents) and agriculture (9 documents). Nevertheless, the selected articles can be categorised in 19 research areas (e.g. business economics, demography, engineering, forestry, geography, geology, plant sciences, social sciences), which suggest that the research field is rather multidisciplinary. The most prominent scholar in the research field is Benjamin Sultan (8 documents). Meanwhile, the analysis of affiliation countries shows that most of the research on climate change and food security in BF was performed by researchers based in other countries, especially USA (16 documents), France (13 documents), Germany (13 documents) and England (12 documents). Affiliations also include other countries in Africa (Cote d'Ivoire, Ghana, Kenya, Mali, Niger, Nigeria, Senegal, South Africa), Europe (Austria, Cyprus, Denmark, Italy, Netherlands, Spain, Switzerland), North and Latin Americas (Argentina, Canada, Colombia), Oceania (Australia) and Asia (Japan). The most prominent affiliation institutions are *Centre National de la Recherche Scientifique* (CNRS, Burkina Faso), *Institut de Recherche pour le Developpement* (IRD, France) and *Sorbonne Université* (France) (7 documents each).

Climate change and food availability

The most direct and straightforward effect of climate change is on crop yield, and livestock and fishery productivity. The analysed literature shows that climate change will reduce the yields of different staple crops such as maize, millet and sorghum (Figure 1), which are of high importance with regard to food security. Jarvis *et al.* [126] examine the impacts that climate change will likely have on the major staple food crops in Africa and found that they are all projected to experience negative impacts [beans (−16%+/−8.8), potato (−14.7+/−8.2) and sorghum (−2.66%+/−6.45)] by 2030. However, the effects of climate change on crop yields will vary across the Sahel and West Africa. Sultan *et al.* [89] show that 'The reduction of crop yield is more important in the eastern part of the Sahel where the warming is more intense than in the western part of the Sahel' (p. 2400). Similarly, Roudier *et al.* [129] put that the impact of climate change on crop yields is projected to be larger in the Sudano-Sahelian zone (northern West Africa) than in the Guinean zone (southern West Africa). What is even more alarming is that the impacts of climate change on crop yields and productivity are expected to increase in the future. In this respect, referring to sorghum and millet yields in West Africa (Burkina Faso, Mali, Niger, Senegal), Sultan *et al.* [124] highlight that 'the potential future climate impacts on yields are very different from those recorded in the recent past. This is because of the increasingly adverse role of higher temperatures in reducing crop yields, irrespective of rainfall changes'.

However, the negative effects of climate change on crop yields and productivity might be moderated by the increase of carbon dioxide concentrations in the atmosphere or the so-called 'carbon fertilisation' [89, 122, 129]. For instance, Sultan *et al.* [89] argue that 'CO_2 concentration increase has a positive impact on crop yield due to the fertilization effect' (p. 2400) but underline that the positive effects of CO_2 concentration increase on maize yields are weaker and more uncertain than the negative effects. Roudier *et al.* [129] point out 'the pivotal role that the carbon fertilization effect may have on the sign and amplitude of change in crop yields' (p. 1073). Meanwhile, Sultan and Gaetani [63] argue that 'a robust evidence of yield loss in West Africa emerges. This yield loss is mainly driven by increased mean temperature while potential wetter or drier conditions as well as elevated CO_2 concentrations can modulate this effect'. Similarly, climate

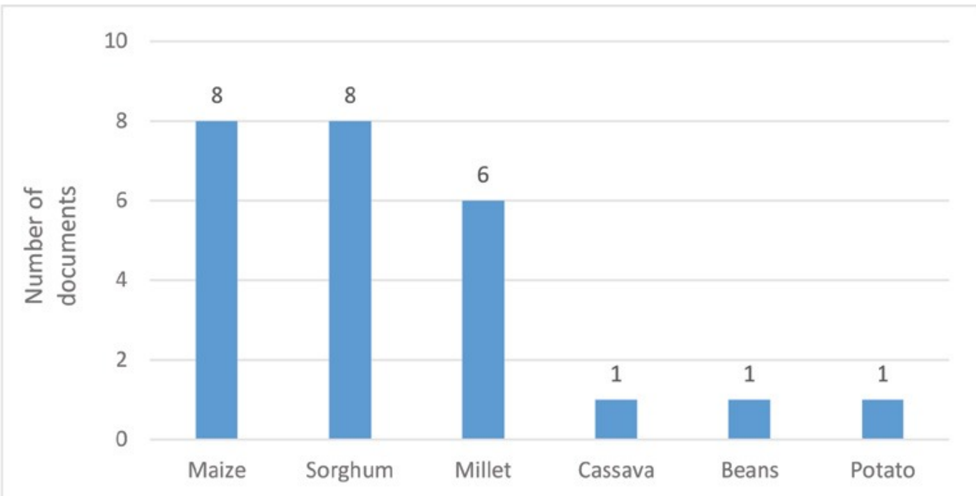

Figure 1. Literature addressing the impacts of climate change on the yields of the main crops in Burkina Faso.

change might improve the climate suitability for some crops in the Sahel region. For example, Egbebiyi *et al.* [85] point out that 'A potential for the northward expansion of maize is projected by the end of the century, suggesting a future opportunity for its growth in the southern Sahel zone', while Egbebiyi *et al.* [62] suggest that cereals and legumes might benefit from the expansion in suitable areas into the Sahel zone. Climate change will also affect the incidence of crop pests and diseases, which might increase damages on crops. For instance, Jarvis *et al.* [126] found that both the geographic distribution and the severity of cassava pests and diseases (e.g. cassava mealybug, whitefly, cassava mosaic disease, brown streak disease) will change across Africa. Declines in yields and productivity caused by climate change are expected to have serious implications for the other dimensions of food security, especially food access and food use.

Climate change and food access

Climate change is expected to affect food economic accessibility (i.e. food affordability) through its combined effects on both food prices and livelihoods. Indeed, climate change might increase food prices and, at the same time, reduce the means that people have to acquire food. Food supply shortfalls, due to the negative impacts of climate change on food availability, would increase food prices. Such increases in food prices are particularly detrimental for millions of low-income people such as in SSA [135, 136]. In this respect, Tamako and Thamaga-Chitja [135] argue that 'Sub-Saharan Africa is faced with a range of climate risks, which include rapid and uncertain changes in rainfall and temperature patterns that threaten food production, and could lead to an increase in food prices and food insecurity' (p. 16). Zidouemba and Gerard [100] highlight the strong linkage between agricultural productivity (cf. crop yields) and food access in Burkina Faso, and put that 'positive agricultural productivity trends may help alleviate poverty and food insecurity. Agricultural productivity may indeed affect the poor's food consumption mainly through large changes in agricultural prices and real incomes' (p 103). Poor urban and rural people, who already spend a high share of their income on food, would find it more difficult to meet their dietary needs when food prices increase. The situation is particularly alarming for populations whose livelihoods depend on agriculture, especially smallholders [47, 112, 137, 138]. In fact, climate change might also decrease the income of farming households [109]. Sultan *et al.* [88] found that 'the average annual production losses across West Africa in 2000–2009 associated with historical climate change, relative to a non-warming counterfactual condition (that is, pre-industrial climate), accounted for 2.33–4.02 billion USD for millet and 0.73–2.17 billion USD for sorghum'. Williams *et al.* (138) argue that 'The impacts of changing climate on agriculture have consequences on livelihoods and food security. Smallholder farmers, who have heterogeneous farming systems and limited resources, compounded with multiple risks, are greatly affected'. Meanwhile, Akinseye *et al.* [137] put that 'Climate variability and change will have far reaching consequences for smallholder farmers in sub-Saharan Africa, the majority of whom depend on agriculture for their livelihoods'.

Production decrease caused by climate change is often combined with the loss of livelihoods assets due to climate-related disasters [125, 139]. Indeed, climate change will also affect the livelihood assets of rural households and might increase the rate of migration [115]. For instance, Paeth and Thamm [133] show that climate change will affect vegetation loss, soil degradation and freshwater availability across Africa. Water is one of the most important production factors and assets that will be affected by climate change, especially in arid and semi-arid countries such as BF [103, 133]. These negative effects of climate change further erode the income earning capacity of rural households. Zampaligré and Fuchs [90] suggest that the adoption of climate-smart agro-pastoral adaptation practices, to enhance household food security and livelihoods in the Sudano-Sahelian zone of Burkina Faso, is affected by different factors such as the possession of household and farm assets and equipment, access to credit and farmland size. This finding might imply that the poorest, who have already vulnerable livelihoods, will find it difficult to adapt to climate change, which might further increase their poverty and, consequently, their food insecurity. Moreover, as underlined by Johnson and Brown [123], 'Poverty limits options for adaptation to unpredictable weather and resultant food insecurity' (p. 209). Tankari [84] show that both short- and long-term rainfall variabilities affect the livelihoods of rural farm households in Burkina Faso so that climate change results as an important determinant of farm households' food insecurity; also, there is a negative correlation between the rainfall average and farm households' food insecurity level. Climate change will also increase poverty in West Africa and SSA at large, thus restraining further access to food by the poor. In this regard, Zougmoré *et al.* [101] warn that 'without appropriate interventions, climate change and variability will affect agricultural yields, food security and add to the presently unacceptable levels of poverty in sub-Saharan Africa'. Sissoko *et al.* [58] add that due to changing climate in the West African Sahel, 'The vulnerability of livelihoods based on agriculture is increased and most likely exacerbate and accelerate the current "downward spiral" of underdevelopment, poverty and environmental degradation' (p. 119). Only a few articles [117, 122] address the role of remittances in adaptation to climate change and their impacts on food security and access to food in times of changing climate. For instance, Epule *et al.* [122] point out that the remittances from migrant urban workers may make farming more sustainable and resilient, which can help mitigating the impacts of climate change on food security. While most of the focus in the analysed literature is on the impacts of climate change on economic accessibility (i.e. affordability), climate change will also affect food physical accessibility, especially in remote regions. For instance, Katikiro and Macusi [127] put that 'Extreme drought or flooding may make roads impassable notably in the Sahelian zones of Mali, Niger and Burkina Faso. The fact that much of the region is already characterized by a lack of existing infrastructure for processing, transporting, and marketing fish, climate change is likely to reverse any recent improvements in this aspect' (p. 90).

Climate change and food utilisation

Climate variability is expected to affect food utilisation through its impacts on the nutrition status and the health of the population, especially poor and vulnerable people. For example, droughts and water scarcity might affect water quality and hygiene, particularly in arid and semi-arid areas, thus favouring pathogens development and further increasing the diseases burden, especially among the poor children. Indeed, the impacts of malnutrition caused by global warming might be particularly severe among vulnerable groups such as children [14, 15, 92, 123] and women [110]. Belesova *et al.* [15] show that lower crop yields in the scenario of 1.5°C warmer climate in 2100 would increase the mortality of children in a subsistence farming population of Nouna district (western Burkina Faso). Furthermore, greenhouse gases are associated with human health risks and increase mortality rate [86]. The impacts of climate change on the suitability of climate for crops in BF and West Africa will affect not only food availability and food access (mainly through impacts on production) but also food utilisation. Indeed, the change in the regional climate will render it less suitable for many crops that constitute the pillars of the diets of local communities, which might lead to dietary changes as well as the erosion of the knowledge associated with the use of certain foods. In this context, different scholars show that climate suitability for agriculture (especially crop production) has been changing and will further change across the region [62, 85, 126]. Egbebiyi *et al.* [62] found that horticultural crops (cf. vegetables) were the most negatively affected by a decrease in the suitable area over West Africa. Therefore, this differentiated impact of climate change on crops might induce not only decreases in daily calorie intake but also variations in local diets. In this respect, Tesfaye *et al.* [120] suggest that 'Climate change may worsen food insecurity in SSA in 2050 through its negative impact on maize consumption and reduction in daily calorie intake' (p. 247).

Climate change, long-term food security and food system stability

The effects of climate change on food availability, food access and food utilisation imply that it will also affect the stability dimension of food security. Indeed, climate change will affect both the elements (e.g. water, soil) and activities (e.g. production, processing, distribution, consumption) of the food system [140] so its current functioning and performance [95] as well as its long-term stability and resilience. In particular, the effects of climate change on crop yields [63, 96, 97, 118] and climate suitability for different staple crops [62, 85] suggest that long-term food security is at risk in Burkina Faso and beyond (cf. West Africa, Sahel). Indeed, projections show a further decrease of crop yields in the coming future [97, 98], which will affect food production and availability and, consequently, also other dimensions of food security (viz. access, utilisation). Of particular concern in this respect is the variability of yields; referring to cereal yields in West Africa, Ahmed *et al.* [118] put that 'Without adaptation, the long-term mean of crop yield is projected to decrease in most of the countries [...] by the middle of the century, while the inter-annual variability of yield increases significantly. This increase of yield variability is attributed to an increase of inter-annual variability of growing season temperature and/or precipitation in future climate scenarios. The lower mean yield and larger year-to-year variation together make the regional food security extremely volatile' (p. 321). Palazzo *et al.* [108] stress that 'For West Africa, climate change is projected to have negative effects on both crop yields and grassland productivity, and a lack of investment may exacerbate these effects' (p. 227). Climate change represents a serious threat not only for annual, staple crops (e.g. wheat, rice) but also for food tree species [104, 107]. Climate change is also projected to increase the instability of the world food prices and their volatility with negative impacts on the poor in BF [71]. Furthermore, the projected direct impact of climate change on crop yields will be exacerbated by the increasingly frequent and intensive extreme climate events [103, 115, 125], which are expected to affect the stability of food availability, access and use. In this context, Richardson *et al.* [46] show that the vulnerability to food insecurity is projected to increase. Moreover, Burkina Faso, as a landlocked country, is highly vulnerable to disruptions in food supply and trade. Population growth is a further factor that will increase pressure on the food system in the region and its capacity to ensure food security for all. Indeed, Guan *et al.* [105] put that 'In the coming decades, the already fragile agricultural system in West Africa will face further challenges in meeting food security, both from increasing population and from the impacts of climate change' (p. 291). Moreover, even strategies adopted by farming households to adapt to climate change are often driven by short-term economic returns [94], rather than long-term sustainability, which might jeopardise the long-run stability of the agriculture and food systems in the region. In addition, forests, which are one of the major carbon sinks, represent a safety net for poor Burkinabe households during food shortage periods and are used as a source of food but also fuelwood [107] with the risk of deforestation and land degradation.

According to this vicious cycle, food insecurity contributes to climate change and vice-versa so that climate change mitigation and poverty eradication policies should be integrated to achieve their interrelated, interlinked objectives.

Climate change mitigation and food security: synergies and trade-offs

Antwi-Agyei *et al.* [91] point out that there is a good alignment between the mitigation and adaptation actions proposed in the Nationally Determined Contributions (NDCs—2015 Paris Climate Agreement) and the SDGs (including SDG2 'Zero Hunger') in West African states. More specifically, different papers address agricultural intensification in BF and West Africa in relation to climate change and food security [83, 96, 114]. The West Africa region is experiencing two parallel phenomena with the aim to increase its agricultural production; intensification and cropland expansion. Indeed, Rhodes and Atewamba [87], referring to the increase of agricultural production in ECOWAS during the period 2003–2013, put that 'Overall increases in the production of rice, maize, sorghum, cassava, yam and groundnut and cattle, sheep and goats were mainly due to increased crop area harvested (42%) and livestock numbers (44%)' (p. 35). Referring to the intensification of mixed crop-livestock systems in the Sahelian zone of Burkina Faso (cf. Seno and Yatenga provinces), Ayantunde *et al.* [83] confirm the 'advantage of intensification practices in terms of increased crop and livestock productivity which is critical to improving food security' (p. 84). However, Guan *et al.* [105] argue that crop intensification might not be enough to completely offset the negative effects of climate change on yield. In particular, they point out that 'Intensification of fertilizer inputs can dramatically benefit yields in the historical/current climate […], but does not reduce negative climate change impacts except in scenarios with substantial rainfall increases' (p. 291). Henderson *et al.* [114] suggest that intensification can help closing yield gaps, increasing food production (with a positive impact on food security) and reducing the GHG emission intensity (with a positive impact on climate change).

In this context, different articles deal with climate-smart agriculture (CSA) [90, 93, 99, 101], which is presented as a strategy to combine sustainable intensification of agriculture production (cf. food security) with climate change mitigation and/or adaptation. Indeed, Partey *et al.* [99] argue that 'Adopting CSA seems to be a suitable strategy to achieving food security while also mitigating and adapting to climate-related risks' (p. 285) and enumerate among CSA technologies, agroforestry, conservation agriculture as well as numerous soil and water conservation technologies (e.g. half-moon, zai, tie/contour ridges). Zougmoré *et al.* [101] include among CSA innovations, agroforestry, high-yielding drought-tolerant varieties, water harvesting techniques, climate information services, integrated soil fertility management practices and agricultural insurance. Zampaligré and Fuchs [90] point out that rural households in the Sudano-Sahelian zone of Burkina Faso adopted a combination of climate-smart agro-pastoral adaptation practices to enhance their household food security and livelihoods in a changing climate. However, CSA still faces a number of challenges such as limited financing and the lack of clear conceptual understanding and enabling policy [99]. Moreover, some authors point out to some trade-offs between food security and climate change mitigation even in the context of CSA. Referring to the example of agroforestry, as one of the CSA practices, Blaser *et al.* [93] demonstrate that agroforestry cannot simultaneously achieve production, climate and sustainability goals but might help optimising the trade-off between these goals. Douxchamps *et al.* [112] highlight that adaptation strategies improve the food security status of some households, but not all, in the study countries (viz. Burkina Faso, Ghana and Senegal). Meanwhile, Hasegawa *et al.* [44] highlight that also stringent climate change mitigation measures can increase food insecurity risk, mainly due to indirect impacts on prices and supplies of staple food products. Indeed, they argue that 'A robust finding is that by 2050, stringent climate mitigation policy, if implemented evenly across all sectors and regions, would have a greater negative impact on global hunger and food consumption than the direct impacts of climate change' (p. 699). Henceforth, one of the challenges ahead is how to balance climate change mitigation and food security. Indeed, Richardson *et al.* [46] highlight 'the dual requirement for mitigation and adaptation to avoid the worst impacts of climate change and to make gains in tackling food insecurity' (p. 327).

Biofuels have been promoted in many countries, including Burkina Faso [128], to reduce emissions from the energy sector. However, the development of biofuels can have negative implications in terms of food security. Referring to biofuel development in Burkina Faso, Tatsidjodoung *et al.* [128] argue that 'Biofuels represent opportunities, e.g., energy independence and security, new national income and employment sources, as well as potential food security problems' (p. 5319). Therefore, beside agriculture, the energy sector is another arena where it is necessary to address the trade-offs between climate change mitigation and food security.

Conclusions

Burkina Faso is experiencing climate change, characterised by a widespread warming, rainfall variability and an increase in the occurrence of climate extremes. These climate tendencies are projected to continue in the twenty-first century, which might have adverse effects on the socio-economic development of the country. In this context, the present article provides a comprehensive review on the multifaceted relationship between climate change and food security in Burkina Faso. It shows an increasing academic interest in the nexus between climate change and the four dimensions of food security (viz. food availability, food access, food utilisation, stability). Indeed, the scholarly literature shows that climate change will affect all the four dimensions of food security in Burkina Faso. The article identified a twofold gap in the research on the relations between climate change and food security in Burkina Faso; first, the research field is not sufficiently addressed despite the fact that climate change and food insecurity are among the main challenges facing the country, and second, the scholarly literature focuses on climate change impacts on food availability, while impacts on food access, food use and stability are generally overlooked. Indeed, most of the analysed literature deals with the effects of climate change on food availability, which are exacerbated by the high dependence of the country on rain-fed agriculture thus making it highly vulnerable to droughts and rainfall variability. In fact, the lion's share of articles addresses the impacts of climate change on crop yields and changes in climate suitability for crops (e.g. maize, millet, sorghum). Moreover, most of the impacts of climate change on food access, utilisation and stability stem from its negative effects on food production and supply (cf. food availability). The review also shows that, on the one hand, climate change mitigation measures can undermine food security, and, on the other hand, agriculture intensification and even some adaptation strategies aiming to enhance food security might increase GHG emissions from agriculture, forestry and other land uses.

Furthermore, climate change will affect all the elements of and activities within the food system with cascading effects and far-reaching implications in terms of all dimensions of food security in Burkina Faso. The short-term effects of temperature increase and rainfall variability on crop yields and animal productivity can have long-term effects on food system stability. Indeed, the stability of the whole food system is at risk under climate change because of the short-term variability in food supply. Furthermore, climate variability could also increase the volatility of food prices, with negative impacts on food affordability by the poor, who are already vulnerable to food insecurity. The recognition of the intricate and multifaceted impacts of climate change on food availability, access and utilisation as well as their stability over time highlights the need for adopting a food system approach in dealing with the nexus between climate change and food security. Indeed, achieving food security for all requires action beyond building climate-smart agricultural and food production systems to a holistic, systemic approach to ensure climate resilience of the whole food system while addressing concerns relating to food consumption, nutrition and diets as well as food waste. The alignment of the NDCs, in the framework of the 2015 Paris Climate Agreement, and the SDGs (cf. SDG2 'Zero Hunger') is crucial in this respect. Moreover, efficient, effective and sustainable responses to the twin challenge of food insecurity and climate change require a full understanding of the spectrum of potential climate impacts on food availability (cf. food production and supply), access (cf. physical and economic accessibility) and utilisation (cf. nutrition and diets) as well as of the underlying governance systems at national, local and household levels. Therefore, the paper highlights the need for a better coordination of agricultural, environmental and climate change policies and governance arrangements to achieve the twin objective of food security and climate stability. In this respect, an integrated approach to policy design, implementation, monitoring and evaluation is necessary to effectively address trade-offs and optimise synergies between sectoral policies in Burkina Faso.

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