Does climate change only affect food availability? What else matters?

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Abstract: This paper reviews the studies from various disciplines and countries on the impacts of climate change on food security and its four dimensions, namely food availability, accessibility, food utilisation and the stability of food systems. Reviewed literature has shown that the impacts of climate change on food security would be devastating. If any of these four dimensions of food security is affected, the impacts will vary from local to global. However, most of the studies have focussed on food availability, so the other three dimensions of food security were not given due attention. This paper, therefore, reviews the impacts of climate change in all food security dimensions based on a narrative review approach. In summary, the impacts of climate change at the micro-level, involving households’ food access and utilisation, and food stability were still less discussed and understood as compared to food availability issues. This review consequently emphasises the importance of future researches on climate change and food security to concentrate on other dimensions of food security.

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PUBLIC INTEREST STATEMENT

The current development discourse is increasingly concerned about the impacts of climate change on food security. Climate change has negative impacts on all four dimensions of food security, i.e. food availability, accessibility, utilisation, and stability. However, the focus of climate change research primarily on food availability. Therefore, this paper reviews the climate change impacts on all four dimensions of food security. It further discloses that the effects of climate change on any of the four dimensions mentioned above pose an individual, community, national and even global scale challenges to food security.
1. Introduction

The concept of the vulnerability of human food systems first emerged in the late 16th century in Thomas Robert Malthus’ book titled An Essay on the Principle of Population. According to Malthus, global food scarcity issues are the result of exponential population growth, contrary to Earth’s food production capacity. Thus, increasing productivity alongside population growth is a challenge for the world’s food sector (Malthus, 1798). Recent studies argue that the internal dynamics of the population would have more dominant impacts on population growth than limitations of the environment (de Sherbinin, Carr, Cassels, & Jiang, 2007).

The food security drew particular attention in the 1974 World Food Conference, especially on population density, health, food production and distribution, and poverty (United Nations, 1975). During the 1980s, food security analysis grasped the attention at micro-level, such as access to food, nutrition, and household entitlements to food. Before that, studies were focused on food security at the macro level, such as the country’s food production, stocks and international trade. At the 1996 World Food Summit, the emphasis on food security was shifted to environmental issues such as deforestation, water scarcity, air quality, over-exploitation and climate change (Firdaus, 2015).

Food security according to 1996 World Food Summit is “a situation that exists when people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO, 2008a). Four dimensions of food security are defined as “availability” of enough and quality food, “access” to nutritious and adequate food by individuals, “utilisation” of food to meet all socio-physiological needs and “stability” of availability, accessibility, and utilisation of food (FAO, 2016). Timmer (2017) considered “sustainability” of the overall food systems as a vital component in analysing food security, on top of the four dimensions. Thus, considering sustainability is essential to achieve food security, which should also be considered as a “long-term time dimension” (Berry, Dernini, Burlingame, Meybeck, & Conforti, 2015).

Gregory, Ingram, and Brklacich (2005) and Willows (2005) have asserted that food security has a profound connection to food systems. Gregory et al. (2005) define food systems “as a set of dynamic interactions between and within the biophysical and human environments which result in the production, processing, distribution, preparation and consumption of food”. However, the mounting pressure of the food systems on socioeconomic and environmental systems are among the reasons for global environmental changes (Ericksen, 2008). As seen in Figure 1, this concept is illustrated in a framework. Global environmental change (GEC) and changes at a societal level determine the vulnerability or sustainability of food systems that largely depend on the level of exposure to GECs and capacities to cope with or recover from such exposures. Changes in the cycles of biophysical systems along with political, socioeconomic, cultural and demographic variables are among the drivers of food security status that are possibly influenced by climate change directly or indirectly (Ziervogel & Ericksen, 2010).

FAO (2016) emphasises the necessity of food system-based approaches and new strategies that change the food production, processing and distribution systems and the way people consume food. Nevertheless, previous policies and strategies were highly focused on food availability with less attention to other three dimensions of food security, specifically food utilisation and accessibility (FAO, 2000; Maxwell, 1996; Maxwell & Slater, 2003; United Nations, 1975). Although the world currently produces enough food, the negative impacts on socio-economic, political demographics
and environmental conditions highlight the limitations of global food policies and food systems (Capone, El Bilali, Debs, Cardone, & Driouech, 2014). Food and food systems are part of environmental services and products. Changes in such services and extreme climatic events affect the functions of food systems (FAO, 2008).

Apart from the impacts on agronomic conditions of crop productions, climate change also affects the economy, food systems and wellbeing of the consumers (Abbade, 2017). Statistics have shown the dragging of long-term reductions in undernutrition incidences worldwide since 2007 due to economic and environmental pressures (Allen & Prosperi, 2016; Wheeler & von Braun, 2013). Vulnerable and low-income groups in pre-disaster situations are affected disproportionately in extreme climate events. This suggests that socio-economic conditions play a significant role in disaster response and prevention (Campbell et al., 2016; Schmidhuber & Tubiello, 2007). Wheeler and von Braun (2013) in a classifying study on impacts of climate change on four dimensions food security found that past researches were skewed towards food availability, accounting for nearly 70 per cent of the literature. The rest of the studies cover other food security dimensions, in particular, food utilisation (13 per cent); accessibility (11.9 per cent); and stability (4.2 per cent).

Consequently, this paper aims to provide an in-depth literature review to discuss some critical issues relevant to four dimensions of food security and to provide broader perspectives on climate change and its impacts on food security. This paper begins by reviewing the impact of climate change on the availability of foods, which ranges from production to processing, storage, distribution, and exchange. The second part of the review elucidates the impacts of climate change on food availability, which include the main factors that determine food accessibility, such as affordability, distribution, and choice. The paper then discusses the impacts of climate change on food utilisation and food system stability briefly. Finally, the paper offers insights into further work based on the research we described in the review.

2. Methodology
This review paper carried out a narrative review of literature in thematic areas such as climate change and agriculture; climate change and food security; adaptation and mitigation of climate change; food security and food systems. The literature covers mostly the time between 2000 and 2019, while few review documents have been carefully selected from the preceding period to lay a foundation for the review. In this review, we utilised academic search engines and databases such as Scopus, Web of Science, JSTOR, ProQuest, Google Scholar, and Microsoft Academic to
discover a broad range of literature. Key terms used to obtain research data among others were agriculture, food availability, dimensions of food security, food systems, food policies, climate change impacts, sustainable development and vulnerability. Based on these thematic areas, this review describes several issues in food security and provides future research priorities regarding climate change and food security.

3. Discussions
Various factors threaten the local and global food security, which climate change has become one of the most influential factors that challenge all dimensions of food security (Vermeulen, Campbell, & Ingram, 2012; Wheeler & von Braun, 2013). Whenever any of the four dimensions of food security is insecure, the entire food systems will be vulnerable (FAO, 2008a; Ziervogel & Ericksen, 2010). The discussion here will, therefore, focus on the effects of climate change on each food security dimension.

3.1. Food availability and climate change impacts
This section sheds light on climate change and its impacts on food availability, including food chain activities from production to process, storage, distribution, and trade. These components are analysed in FAO’s national food balance sheets, among several others. Food balance sheets provide crucial information on a country’s food system in three categories, namely domestic food supply, food utilisation and per capita total food supply values (Mayo, 2008). Food availability, on the other hand, is the amount of total physical quantities of food available in a country or an area in the form of domestic production, import, exchange, processed and stocks after deducting the total exports (FAO, 2008a; Mayo, 2008).

3.1.1. Climate change and food crops production
The effect of the fertilisation of carbon dioxide (CO₂) balances the adverse climate change effects and promotes plant growth (Darwin & Kennedy, 2000; Long, Ainsworth, Rogers, & Ort, 2004; Reilly et al., 2003; Wheeler, Craufurd, Ellis, Porter, & Prasad, 2000). However, several studies have argued against the positive effects of an increase in atmospheric CO₂ levels. When the response of crops and the concentration of CO₂ reaches to a progressive saturation level, the effect of CO₂ fertilisation becomes minimal. Besides, the rise in atmospheric CO₂ level continues, the temperature and rainfall will concurrently experience significant changes. Thus, the impact of CO₂ is unable to stimulate agricultural and food crop productions (Tubiello, Soussana, & Howden, 2007). Moreover, the effects of other factors such as diseases, pests or effects of adaptation were not considered in CO₂ fertilisation studies; hence, predictions may, therefore, be understated (Vermeulen et al., 2012).

Exposure to temperature or water exceeding the threshold levels will impede crop growth and reproduction processes. For example, paddy is highly responsive to hot weather conditions; hence more or less exposure to its threshold levels of temperature for several hours will consequentially damage the crop (Wheeler et al., 2000). Physiological responses of crops towards changes in climate variability can occur on a short-term time scale (Wollenweber, Porter, & Schellberg, 2003). In Nepal, for instance, variability in seasonal weather patterns is considered as the main factor leading to paddy and wheat production instability, (Poudel & Kotani, 2013). An increase in either temperature or precipitation positively impact on wheat yield in Nepal up to a certain level, yet significantly decreases in the event of temperature or precipitation increases exponentially (Thapa-Parajuli & Devkota, 2016).

Physiological responses of terrestrial organisms towards climate variability vary geographically. Areas with a temperate climate would benefit from a moderate warming effect with an average increase of 1° to 3° Celsius. Nevertheless, increase temperature in areas with a tropical climate, low latitude areas, semi-arid and seasonally dry areas are expected to be detrimental to production, especially for grain crops. This is because the climate in these areas is moving towards the maximum threshold for productive grain yields (Deutsch et al., 2008; Leff, Ramankutty, & Foley, 2004; Rosenzweig et al., 2014). Increased temperatures in tropical areas will result in high
evaporative heat and water stress on crops. As a result, the increase in global temperatures will have severe impacts on the agricultural sector in tropical climates, particularly in developing countries (Poudel & Kotani, 2013).

Similarly, Funk and Brown (2009) predict a 14 per cent decline in per capita global cereal production during 2008 and 2030, especially in Asia, Africa and South and Central America. Crop productions in low-yielding areas with lack of technology are expected to be more vulnerable. Furthermore, results of climate change scenario study on 23 different climate settings projected that, by 2100, the summer average temperatures in the tropical and subtropical regions are more than 90 percent likely to exceed the highest temperatures ever recorded between 1900 and 2006 (Battisti & Naylor, 2009). Increase in maximum temperature changes the plants' viability and productivity. Even in the U.S. for example, temperature increase up to 29°C, 30°C and 32°C for corn, soybeans and cotton respectively will increase the yield; yet very harmful when temperate exceeds these thresholds (Schlenker & Roberts, 2009).

Climate change impacts on the hydrological cycle will intensify the prevalence of dry seasons and dry weather (Kundzewicz et al., 2007). Exaggeration and recurring stormy weather patterns cause to change the hydrologic cycle and rainfall patterns, which will result in long-term impacts on world agroecosystem viability and food availability. In countries affected by water conflicts, such conflicts will also affect food production and accessibility of individuals (Gleick, 1993). Some countries will face severe droughts, while others will suffer excessive rains. These will lead about 63 per cent of the world’s population to be hit with water stress by 2025 (Arnell, 1999). Coastal eutrophication in large marine ecosystems will increase by 20 percent by 2050 unless remedial actions are in place (United Nations, 2018).

Droughts in African countries had severe impacts on livestock. Droughts in Niger 1982–1984 (Toulmin, 1986), Borana in Ethiopia 1991–1993 (Desta & Coppock, 2002), and Maasailand in Kenya 2005–2006 (Nkedianye et al., 2011) had resulted in high livestock death. It was projected that a 10 per cent decline of Maize productions in Latin America and African regions by 2055 would pose an enormous loss to global food security (Jones & Thornton, 2003). Climate change and population growth have challenged access to the safe drinking water of about 29 per cent of the world population in 2015. Competition to access water was partly due to the agricultural sector as it contributes for 70 per cent of world water withdrawal, which has increased significantly due to massive increases in food demands (United Nations, 2018).

A study conducted by McClean et al. (2005) on habitat suitability for species distributions predicted that approximately 81 to 97 per cent of crop species’ habitats would experience a decline in terms of size or shift to other places due to climate change. The study further claims that around 25 to 42 per cent of species’ habitat will be entirely lost by 2085. Studies found that extreme water flows and high stream temperatures in summer due to climate change may have severe impacts on the survival of stream-type salmon populations (Mantua, Tohver, & Hamlet, 2010). Such fish types are an integral part of the spiritual, physical and cultural well-being of indigenous people widely (Dittmer, 2013). In the Great Lakes in North America, warming during winter and the changes in water level have affected the ability of wild paddy crops to grow and propagate naturally (Lynn et al., 2013).

3.1.2. Impacts on agricultural food processing, storage, and distribution

Availability of agricultural food relies on activities such as processing, storage, and distribution of food locally, nationally or globally. Several studies indicate that food availability will affect negatively from production, storage, processing, and distribution due to supply chain failures and failures in food donation systems (Chodur, Zhao, Biehl, Mitrani-Reiser, & Neff, 2018; Vermeulen et al., 2012). Countries in high latitude regions will benefit from climate change as the productions of grains expect to increase (Rosenzweig et al., 2014). Moreover, dry or cold weather in these countries allows the bulk
handling of harvested grains without specific measures since humid weather will increase harvested
grain humidity to 12 to 14 per cent, which is suitable for stable storage (FAO, 2008a).

In contrast, climate change will have negative impacts on agricultural productivity in sub-Saharan
Africa (Blanc, 2012; Schlenker & Lobell, 2010) and South Asia (Lobell et al., 2008). The tropical climate
in the African region exposes post-harvest food products to pest attacks, micro-organisms, and
diseases (Nukenine, 2010). Inadequate drying facilities will render post-harvest food to be unsafe to
eat due to microorganism infections (FAO, 2008a). High frequency and intensity of precipitation due to
climate change in countries with inadequate road systems will affect the distribution system and
infrastructure (FAO, 2005; Hendrix & Salehyan, 2012). Investments in logistics and food storage
technology, transportation networks, food waste management (Abbade, 2017) and minimising
wastage in food commodities (Godfray et al., 2010) are crucial in most developing countries.

In an analysis conducted using FAO datasets on Global Agroecological Zones, Constinot,
Donaldson, and Smith (2016) found that world’s GDP will reduce by 0.26 per cent due to macro-
level climate change impacts on agricultural markets of ten crop varieties globally. The loss
accounts for over 17 per cent of the total global crop production value when countries have free
trade rights and cropping patterns are decided by farmers freely. In situations where farmers are
not free to make decisions, then crop harvest reduction is 0.78 per cent of the global GDP, which is
three times higher than the earlier scenario. Table 1 summarises the key points of researches here
discussed relating to climate change impacts on food availability.

3.2. Climate change impacts on food accessibility
Accessibility of food means one’s capacity to safeguard the entitlements to food. Sen (1984)
defined this as “the set of alternative commodity bundles that a person can command in society
by using the totality of rights and opportunities that he or she faces”. An adequate supply of food
does not guarantee that individuals in a society have access to the food they desire as it depends
on the rights and capacities of the individuals. These rights and capacities determine allocation,
affordability, and food preferences (Ericksen, 2008). Therefore, the impact of climate change on
food accessibility often depends on distinct factors such as the functionality of food markets, the
affected geographical environment (Hertel & Rosch, 2010) and differences in socioeconomic
factors (Reidsma, Ewert, Lansink, & Leemans, 2010).

Schmidhuber and Tubiello (2007) describe the access to food as the ability or capacity of
countries, communities or individuals to purchase good quality, nutritious food sufficiently.
However, crop failures due to climate change adversely affect developing countries as they lack
skills and capacities in disaster preparedness (Islam & Wong, 2017). According to FAO (2008a),
increased exposures to climate change events result in reducing people’s entitlement to food,
therefore challenging their food security. Accessibility of food, however, means the availability of the
resources to acquire food. It depends on food production resources, food prices, transport and
trade networks, wholesale and retail systems, proximity to access food, socio-cultural norms, food
preferences and distribution patterns Brown et al. (2015).

By evaluating widely used indicators to assess the food access at individual and household
levels, Leroy, Ruel, Frongillo, Harris, and Ballard (2015) identified nine indicators that classified
under three categories, namely “experienced-based, coping strategies and dietary diversity”. In
a review study on food security in sub-Saharan Africa, Zewdie (2014) found that food availability is
only the well-studied component among four dimensions of food security, while other concepts
such as food access or utilisation are less studied. According to Myers et al. (2017), focus on food
availability than food intakes set several drawbacks as actual food distribution among different
populations, regions and different households are still less studied. Further to that, knowledge
gaps in wild foods, their nutritional compositions and changes in food intakes leave how environ-
mental changes impact on overall health is unclear.
3.2.1. Impacts of climate change on food allocation

Subsistence and smallholder farmers who produce, process and consume food directly from their farms are possibly the most vulnerable to climate change impacts (Morton, 2007; Thorlakson & Neufeldt, 2012) as they mostly depend on farm productions (Harvey et al., 2014). Hence, farmers reduce daily food intake of all members of the household evenly or by prioritising the breadwinners.
of the household in food shortages (FAO, 2008a). Extreme weather events intimidate family assets and reinvesting capacity in agriculture lead them into chronic food insecurity (Alderman, 2010). The impact of hazardous climatic events on farmers in Nyando district in Western Kenya forced them to reduce food intakes by limiting the contents, varieties, and frequency of meals taken daily (Thorlakson & Neufeldt, 2012). Smallholder farmers in Madagascar respond to food shortages by eating less amount, fewer daily meals, changing food contents, and substitute with wild crops (Harvey et al., 2014).

Climate change impacts will cause to alter the geographical distribution of local wild crop species and affect the traditional staple food of indigenous communities (Hertel & Rosch, 2010; McClean et al., 2005). Wild crops are vital for some communities, who struggle to produce food and consume it for a wide range of purposes, including medicinal, spiritual and utilitarian (Lynn et al., 2013). Indigenous people believe that wildlife and plants are tied to their traditional cultures and way of life (Whyte, 2013). Hence, losing traditional crops deny the rights of indigenous people to have access to sources of food that culturally and spiritually accepted (Jernigan, Salvatore, Styne, & Winkleby, 2012; Whyte, 2013).

Deprivation of traditional food gathering rights of tribal communities denies their rights to access nutritious and balanced food sources (Jernigan et al., 2012; Norgaard, 2005). For instance, Karuk people in the Klamath River in California have lost their source of traditional food, such as salmon and acorns. Loss of this vital food sources had resulted in raising diabetes and heart diseases about 21 per cent and 40 per cent, respectively (Norgaard, 2005). A scenario study on climate change impacts on indigenous coastal communities in British Columbia in Canada confirmed commercially, and culturally vital 98 fish species move away from current habitats to cold waters as temperatures of surface water level increases. This change resulted in a sharp decline in the fish harvest of indigenous fishers in coastal British Colombia (Weatherdon, Ota, Jones, Close, & Cheung, 2016).

3.2.2. Impacts on food affordability

Food affordability is typically determined by food availability, household income and purchasing power, since foods are mostly not produced by households but acquires through buying, borrowing or trading (Ericksen, 2008). In urban or suburban areas, functions of the retail structure on food affordability are crucial (Maxwell & Slater, 2003). For non-farm households, the market systems are the crucial determinant of food affordability, yet the accessibility of food is critical in rural settings and remote areas. Wang, Touboulic, and O’Neill (2018) identified that affordability of fresh products for disadvantaged communities in Wales, UK depends on “social interaction, choice and price, and ease of delivery”. They further emphasise that current studies on food supplies are mainly focused on access to supermarkets and claimed that few studies are focused on how other means of supplies can resolve the issues in areas of food deserts.

Local food supplies in many countries mostly depend on global food markets, yet climatic factors changing the agriculture products at the national and local levels (FAO, 2015). When climate change affects income sources, household allocations for food purchases are challenged (Campbell et al., 2016). Extreme climate events could also affect food product availability; hence trigger the food price hikes and affect the earnings of poor people specially in low-income countries. The purchasing power of the poor, thus, will significantly affect as they allocate a higher percentage of earnings on food supplies (Hertel & Rosch, 2010; Nelson et al., 2009). Soaring prices make some food items are unaffordable or unavailable, hence impact on individuals’ social well-being while escalating the inequalities (Ivanic & Martin, 2008). High food costs, climate extremes and variabilities, and poor access to food, therefore, will intensify global hunger and food insecurity (FAO, IFAD, UNISEF, WFP & WHO, 2018).

3.2.3. Impacts on food preferences

Preferences of local communities towards staple food crops mostly determine by traditional cultural norms (Ericksen, 2008). Climate change impacts on agricultural products affect food
availability and consumers’ capability to purchase certain types of commonly preferred food. When the price of a preferred food item increases, households may alter their food basket to maintain the purchasing power or reduce their disposable income significantly to maintain the same food basket (Ziervogel & Ericksen, 2010). Even though poor people and subsistence farmers might not afford their food through market systems, most people depend on markets for food supplies. Therefore, any threat to the availability of food leads to a collapse of social trust in food systems, which might even trigger food riots (Timmer, 2017).

During dry seasons, subsistence farmers in Southern Africa cultivate maize in the dry season as it is tolerant to less water condition, yet harvest is low compared to sorghum (Ziervogel & Ericksen, 2010). Inuit communities in the Western Canadian Arctic have forced to increase Muskox hunting to compensate for the decline in Caribou meat, even though Muskox is less favourable and provides different nutritional combination (Wesche & Chan, 2010). On the other hand, changes in food consumption patterns and diets affect health while altering the environment, thus contribute to climate change. Therefore, healthy consumption and dietary patterns could bring positive impacts on climate change (Niles et al., 2018). Table 2 provides a summary of relevant studies relating to climate change impacts on food accessibility.

### 3.3. Climate change impacts on food utilisation

Food utilization is defined as “the nutritional value of the diet, including its composition and methods of preparation; the social values of foods, which dictate what kinds of food should be served and eaten at different times of the year and on different occasions; and the quality and safety of the food supply, which can cause loss of nutrients in the food and the spread of food-borne diseases if not of a sufficient standard” (FAO, 2008a). In brief, an individual’s food utilisation refers to the personal capacity to get benefits from the food consumed (Ericksen, 2008). However, the evidence on the impacts of climate change on food stability and utilisation is limited (Schmidhuber & Tubiello, 2007). In the Sub-Saharan African context, Zewdie (2014) found that food utilisation is the least studied, yet most significantly affected component of food security in changing climatic conditions.

Climate change impacts on food utilisation by declining the availability of wild crops and the production of small-scale farmers. In a literature review on climate change and its impacts on childhood undernourishment among subsistence farmers in low-income countries, Phalkey, Marx, Hofle, and Sauerborn (2015) found that links between variations in weather and child stunting at households are significant. However, studies on the impacts of climate change on food quality concerning human consumption or animal fodder are minimal, while studies on assessing the crop sensitivity towards climate change have made considerable progress (Gregory, Johnson, Newton, & Ingram, 2009).

Kettlewell, Sothern, and Koukkari (1999) found that climate variability affects the quality of grains, particularly in Europe, while Gooding, Ellis, Shewry, and Schofield (2003) explain that drought stress may decrease the total protein content in wheat, hence affects its nutritional content. Apart from that, a series of studies claim that new pests and predators brought by climate change are also affecting food quality and availability (Anderson et al., 2004; Nelson et al., 2009; Rosenzweig, Iglesias, Yang, Epstein, & Chivian, 2001). Further, economical access to food has a strong relationship with food utilisation than physical access (Abbade, 2017).

Climate change disrupts the crop production and distribution, affects the nutritional values of food, and heighten the risks of vector and waterborne diseases (Islam & Wong, 2017). Climate change alters the vector diversity, spread and richness of vector population. Such conditions expose crops and livestock to vector-borne diseases (Anderson et al., 2004). Unhealthy food eventually affects human physiology in terms of food intake and human capacity to obtain the required nutrients from food consumed (Rosenzweig et al., 2001) while cause to sustain severe health impacts (Tirado, Clarke, Jaykus, McQuatters-Gollop, & Frank, 2010). For example, about
Table 2. Studies on climate change and its impacts on food accessibility

| Main themes                                                                 | Key issues                                                                                                                                                                                                 | Studies                                                                 |
|----------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| CC impacts on food access, markets and policies. CC impacts on food affordability, allocation and food preferences. | • Access to food depends on socio-political, cultural, economic and market structures of society.  
• Sub-Saharan Africa suffers from more CC impact on crop yields, hence challenge the access to food.  
• Damaged crop products and farm assets by CC force farmers and the poor to reduce food intake.  
• CC impacts on household food costs hikes.                                                                                   | Campbell et al. (2016), Hertel and Rosch (2010), Reidema et al. (2010), Schlenker and Lobell (2010), Schmidhuber and Tubiello (2007) |
| Food access as a socio-cultural, spiritual and economic act.                | • Resources availability, capacities of individuals, societies, and countries define food access.  
• Crop failures in developing countries and lacks disaster preparedness challenge food access.  
• Regional variations of CC cause different impacts on food access and diversity and food culture.  
• Limited studies in CC impacts on food culture, spiritual and nutritional values.                                             | Brown et al. (2015), Islam and Wong (2017), Leroy et al. (2015), Myers et al. (2017), Schmidhuber and Tubiello (2007), Zewdie (2014) |
| Impacts of CC on food affordability define food preferences and food allocation. | • Issues of purchasing power, needs of specific populations and food allocation within households.  
• Food availability, market systems, price, and choice are vital for non-farm households.  
• When market systems or social trust collapse due to the insufficiency of food, it may trigger food riots.  
• Changes in food patterns challenge the lifestyle and health, exaggerate the CC, while healthy food patterns bring positive impacts on CC. | Alderman (2010), Harvey et al. (2014), Ericksen (2008), Niles et al. (2018), Timmer (2017), Wang et al. (2018), Ziervogel and Ericksen (2010) |
| CC impacts on wild foods, traditional crops, and food varieties hence challenge cultural values. | • CC alters the local wild crops and food species hence affect the traditional food, medicines and cultural and spiritual values.  
• Food in tribal and indigenous communities is cultural, so changes in wild food challenge cultural heritage, food allocation, and preferences.  
• Loss of traditional food due to CC challenges health and cultural values so denies the right to food. | Hertel and Rosch (2010), Jernigan et al. (2012), Lynn et al. (2013), Norgaard (2005), Weatherdon et al. (2016), Whyte (2013) |
70 per cent of the 1.5 million diarrhoea patients identified worldwide annually were infected with bio-contaminated food (Maxwell & Slater, 2003). Further, climate impacts will cause to escalate diarrhoea about 10 per cent by 2030 in some geographical regions by water scarcity while high temperatures escalate the development of pathogens (FAO, 2016).

Assessing literature on the impact of climatic factors on food safety, Tirado et al. (2010) summarised that climate-related events had stimulated microbiological contamination in food through bacteria, viruses, and parasites, which resulted in foodborne diseases. Increased temperature influences the transmission cycle of parasites such as Trematodes hence can be transmitted when raw or undercooked freshwater fishes are consumed. Such diseases have cyclical effects as the cause to trigger the hunger, and by then, affected are susceptible to infections again, which in result to labour productivity decline and upsurge the poverty and mortality (Schmidhuber & Tubiello, 2007). Moreover, the intensive use of pesticides, antibiotics and other chemicals to overcome all forms of attacks will cause high chemical contamination in crops and livestock (Bernardes, Pazin, Pereira, & Dorta, 2015).

Food utilisation also represents the socio-cultural, religious, spiritual and nutritional values of the food that society may obtain (Cvitanovic et al., 2016; O’Brien & Wolf, 2010). When climate change directly impacts on social values, it relates to food availability while indirect impacts are associated with affordability. Unavailability of food sources in communities that cultural practices are essential will causes to forget such practices while affects the coherence and sustainability of the culture itself (FAO, 2008a). Loss of fish sources such as sharks, rays, and dolphins, for example, leads to depriving the symbolic value of magic and spiritual beings among the Melanesians (Foale, 2008).

Cultural elements are significant as they play a crucial role in the process of socialisation, and even in climate change adaptation and mitigation (O’Brien & Wolf, 2010). On the other hand, addressing cultural values is critical in framing mitigation and adaptation strategies to address climate change as such approaches may cause to undermine what matters to the society (Adger, Barnett, Brown, Marshall, & O’Brien, 2013; Cvitanovic et al., 2016). Further, Table 3 summarises the content and the focus of significant studies on food utilisation.

3.4. Impacts of climate change on food systems stability
Climate-induced events such as floods and droughts will be more frequent and extreme due to climate change (Kundzewicz et al., 2007). These create critical threats to the stability of food systems, especially for households with limited capacity in their food consumption (Reilly & Willenbockel, 2010; Parker, Bourgoin, Martinez-Valle, and Laderach, 2019). For instance, temperature increases and a sharp decline in rainfall in the semi-arid zone of Northern Nigeria caused to drop crop and livestock productivity. It further contributes to loss of farm and grazing lands while intensified the water scarcity, which negatively affected livelihood, household income while artificial food shortages, malnutrition and diseases (Jibrillah, Choy, & Jaafar, 2018).

Socio-economic development processes will be a critical factor in food utilisation (Schmidhuber & Tubiello, 2007). The global efforts during the last decades were on maximising the cereal crop yields and optimise the value chains instead of establishing resilient food systems locally or regionally. Such efforts have assumed that complex agricultural value chains increase efficiency while reducing the risks (Jahn et al., 2018). However, relatively a small shock in 2008 on world food supply and demand systems had enormous implications as global food stocks were at precariously a lower level (Gilbert & Morgan, 2010). If such a situation remains, extreme climate-related events in the future would intensify the local and global food price volatility, which consequently affects the overall stability of food systems (Wheeler & von Braun, 2013).

Productivity declines, food supply shortfalls and climate variability are caused to increase food prices. Hence smallholder food producers, subsistence farmers and agricultural workers will be among the most vulnerable (FAO, 2016). Price volatility in the food markets will trigger instabilities
in peasants’ income while burdening the costs of the consumers on essential food commodities. Escalating food prices will force consumers to limit their food intake, especially poor households who mostly spend quite a higher portion of the income on food (De Brauw, 2011; Hertel & Rosch, 2010; Phalkey et al., 2015). Food price volatility also generates economic and financial shocks, as it leads to job redundancies, constraints in credit systems (Smith, Thomas, Frankenberg, Beegle, & Teruel, 2002). It further disrupts political stability, which triggers food insecurity further (Berazneva & Lee, 2013).

Climate change and its impacts on demographic patterns, urbanisation, population movements and changes in food consumption patterns intensify the food system risks globally (Jahn et al., 2018). Other than endogenous factors, Beckman, Hertel, Taheripour, and Tyner (2012) implied that stability in food systems expose to exogenous pressures towards demand due to the aggressive subsidies and quota policies. Such policies were initiated in the European Union and in the United States of America a decade ago to address the climate mitigation objectives and problems in energy security (Wheeler & von Braun, 2013). Accordingly, climate change and energy policies affect the food systems and destabilise four dimensions of food security in many instances; hence,

| Main themes | Key issues | Studies |
|-------------|------------|---------|
| Existing knowledge in food utilisation and knowledge gaps. | • Limited studies of climate change impacts on food utilisation, food quality and their determinants. • Food utilisation and nutritional values of food were adversely affected yet least studied. • Food utilisation represents the socio-cultural values of food and economic access to food. | Cvitanovic et al. (2016), Ericksen (2008), FAO (2008a), Gregory et al. (2009), Zewdie (2014) |
| Food quality, safety, and diversity. Infectious diseases and pests impact on nutritional values of food. | • CC impacts on health and nutritional outcomes, issues of food, vector, and water-borne diseases. • CC impacts on food utilisation challenge labour productivity, incomes and health conditions. • CC increases poverty and mortality. It also affects balanced diets and caused child stunting. • CC increase vector diversity propel the vector spread and impacts on the quality of food. • Pests and pest controls pose health impacts. | Anderson et al. (2004), Bernardes et al. (2015), Campbell et al. (2016), Islam and Wong (2017), Nelson et al. (2009), Tirado et al. (2010), Schmidhuber and Tubiello (2007) |
| Considering food utilisation as sociocultural, religious and spiritual values of a society. | • Food utilisation has nutritional, socio-cultural and religious values. • Loss of such food varieties causes to forget socio-cultural diversities and spiritual values. • Some food species have mythical and spiritual values and crucial in the socialisation process. • These challenge the mitigation & adaptation to CC. | Adger et al. (2013), Cvitanovic et al. (2016), FAO (2008a), Foale (2008), O’Brien and Wolf (2010) |
Climate change has prevalent, multi-faceted and temporal impacts on food security. The reviewed literature implies that climate change has several adverse effects on all four dimensions of food security (availability, accessibility, utilisation, and stability). Therefore, climate change does not only affect food availability, but other dimensions are also highly susceptible. However, review founds significant research gaps between food availability and other dimensions of food security. Accordingly, this review considers that food accessibility, utilisation, and stability merit further investigation.

Table 4. Summary of the research studies on food system stability

| Main themes                                      | Key issues                                                                 | Studies                                                                 |
|--------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------|
| Food systems stability and its impact on other dimensions of food security. | • CC threatens the food system stability as it changes cropping cycles and reduces crop yields.  
   • Global focus on high crop yields and value chains should move to resilient food systems at local levels since complex systems intensify the risks.  
   • Extreme weather events and food systems instability affect vulnerable groups adversely.  
   • CC cause to lost lives and livelihood, income, create food shortages and increase malnutrition and diseases.  
   • Food systems stability requires a balance between human needs and utilising natural resources. | Gilbert and Morgan (2010), Jibrillah et al. (2018), Jahn et al. (2018), Parker et al. (2019), Smith et al. (2002), Wang et al. (2018), Wheeler and von Braun (2013), Willows (2005) |
| Food market volatility, the stability of food systems as well as ecosystem stability and biodiversity. | • CC challenges the food systems, hence, requires shifts in the socio-economic development process.  
   • Decreasing biodiversity, loss of food production resources, loss of crop and farm productivity will impact on households with limited resources and adaptive capacities.  
   • Even small CC shocks challenge the global food stocks, hence intensify food price volatility and challenge the food system stability. | Campbell et al. (2016), Kundzewicz et al. (2007), Reilly and Willenbockel (2010), Smith et al. (2002), Wheeler and von Braun (2013), Willows (2005) |
| Climate change impacts on demographic changes, new development trends, and markets. | • Population dynamics, urbanisation and changes in consumption patterns pose risks to the food systems and environment globally and locally.  
   • Market policies, subsidies and quota systems intensify the risks pose on food systems stability.  
   • Existing CC and energy policies challenge food security dimensions, hence require new policies globally. | Beckman et al. (2012), Jahn et al. (2018), Wheeler and von Braun (2013) |

new policies should consider their impacts on food security and sustainability. Table 4 summaries the reviewed research studies on food system stability.

4. Concluding remarks
Climate change has prevalent, multi-faceted and temporal impacts on food security. The reviewed literature implies that climate change has several adverse effects on all four dimensions of food security (availability, accessibility, utilisation, and stability). Therefore, climate change does not only affect food availability, but other dimensions are also highly susceptible. However, review founds significant research gaps between food availability and other dimensions of food security. Accordingly, this review considers that food accessibility, utilisation, and stability merit further investigation.
research in the future. However, studies that focus on all aspects of food security seems essential, as it helps policymakers, administrators, communities affected and other stakeholders to receive contextual information. Providing farmers and affected communities with accurate information enables them to make informed decisions (Allen & Prosperi, 2016; FAO, 2016; Niles et al., 2018; Parker et al., 2019).

Other factors such as demographic changes, natural resources scarcity and overexploitation, changes in consumption patterns, food wastage, poverty, unfair trade policies and lack of political will on climate change actions will further intensify the impacts of climate change on all dimensions of food security. Several studies indicate that socioeconomic conditions delineate food security than physical conditions. As such, developing countries are vulnerable to climate shocks and food insecurity than in developed countries. However, some studies revealed a positive effect of climate change on food crop productivity to a certain level in some geographical regions, in which most of them are developed countries. Therefore, adaptation and mitigation measures should consider geophysical as well as technological, socioeconomic and cultural elements and conditions.

Accordingly, multifaceted strategies incorporating adaptation and mitigation are therefore required to mitigate impacts of climate change in the food sector. Furthermore, new researches, policy formulations and implementations and financial and technological support should target the low and middle-income countries with particular attention to the poor. Also, more attention should be directed on a small scale and subsistence food producers, peasants, agriculture workers and marginalised and vulnerable communities (Berry et al., 2015; Wang et al., 2018; Weatherdon et al., 2016).

Sustainability of food systems is the basis of food security in its broader perspectives. Analysing sustainability of food systems, therefore, provide multidimensional approaches that apprehend four dimensions of food security. Future research should be comprehensive enough in formulating new policies and interventions to cater to the diversity of climate change issues. New researches focus on ways to reduce communication, and decision-making gaps between different institutions at local, regional, national and international levels are crucial to fast track the information sharing, decision making and follow-up processes.

Nevertheless, it also requires considering the food production and distribution systems with ecological systems, and integrate them with socio-cultural systems at different levels, so that specific issues of grassroots, vulnerable and marginalised communities could be addressed. Further, listening to the affected communities and giving them opportunities to contribute to mitigation and adaptation measures in food production, distribution and consumption systems are the key to make such actions community-driven.

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