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The effect of climate change across food systems: Implications for nutrition outcomes

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ABSTRACT

A better understanding of the pathways linking climate change and nutrition is critical for developing effective interventions to ensure the world's population has access to sufficient, safe, and nutritious food. The paper uses a food systems approach to analyze the bidirectional relationships between climate change and food and nutrition along the entire food supply chain. It identifies adaptation and mitigation interventions for each step of the food supply chain to move toward a more climate-smart, nutrition-sensitive food system. There are many entry points for "double duty" actions that address climate adaptation and nutrition but they need to be implemented and scaled by governments.

1. Introduction

Humanity is already witnessing the repercussions of climate change. Without mitigation and adaptation, these impacts will intensify as time progresses. Climate change presents unique challenges to the world's ability to meet food security and nutrition needs, which will increase into the future (Lobell et al., 2008; United Nations System Standing Committee on Nutrition Secretariat, 2010). Food systems are highly sensitive to climate, as they are both "victims" and instigators of the effects of climate variability and longer-term climate change.

The future effects of climate change will be most evident among populations in the Global South, especially sub-Saharan Africa and South and Southeast Asia (Intergovernmental Panel on Climate Change, 2014). Many people in these regions are rural and experience poverty, and their livelihoods, as well as many of the systems they engage with, including health, education, and food systems, can be significantly affected by climate change. Countries and communities that do not have adaptation strategies in place will likely see a reversal of previous gains in reducing food insecurity and undernutrition. In 2017, for the first time in over a decade, the number of those who are undernourished has increased due to climate change as well as conflict (FAO. IFAD. UNICEF. WFP. and WHO, 2017).

Climate change, agriculture, and nutrition are interconnected. Climate change and variability affects temperature and precipitation, as well as frequency and severity of extreme weather events. Increases in temperature, heat waves, and droughts will impact agriculture, with the largest effects being decreased crop yields and livestock productivity, as well as declines in fisheries and agroforestry in areas already vulnerable to food insecurity (FAO. IFAD. UNICEF. WFP. and WHO, 2017). There is strong evidence that climate change will affect food quality (diversity, nutrient density, and safety) and food prices (GLOPAN (Global Panel on Agriculture and Food Systems for Nutrition), 2015; Vermeulen et al., 2012).

The effects of climate change on agriculture will, in turn, have significant implications for food security, and thus human diets and nutrition. As climate change affects the ability to move food from production to markets, access to diverse, high-quality diets may become more limited. Reduced access to sufficient nutrient-dense foods will subsequently lead to impaired nutritional status and diminished resiliency, particularly in low-income communities (United Nations System Standing Committee on Nutrition Secretariat, 2010). Even in the "business-as-usual" models, nutrition and health outcomes are likely to worsen (FAO, 2016a; Springmann et al., 2016a; Whitmee et al., 2015).

The purpose of this paper is to examine the relationships between climate change, diets, and nutrition through a food system lens. The paper begins with the impacts of climate change on nutrition. It discusses the interrelated nature of climate change, food systems, and diets: climate variability disrupts food systems and diets, yet food systems and diets also have repercussions for climate change. Thereafter, the paper describes promising "climate-smart, nutrition-sensitive" mitigation and adaptation actions to improve food systems, diets, and

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nutrition.

A recent paper by Myers et al. (2017) nicely outlines these potential relationships (Myers et al., 2017), while this paper provides additional insight into the impacts of climate change on value chains within the food system relevant to the rural poor. The paper focuses on undernutrition in low- and middle-income countries (LMIC), as undernutrition is currently more prevalent among our target population and LMICs account for nearly all the global burden of stunting (Development Initiatives, 2017). Though the alarming rise of overweight, obesity and non-communicable diseases in this population warrants attention, the relationship with climate change has been explored elsewhere and will not be the focus of this paper (An et al., 2018). The primary emphasis is on the rural poor, a group especially vulnerable to the adverse effects of climate change on nutrition. Other populations, including the urban poor and rural populations working outside of agriculture, also face significant vulnerabilities from climate change but are not addressed in depth here. The paper also examines inequities related to the global food system's influence on climate change.

2. Impacts of climate change on nutrition outcomes

The implications of climate change extend across all determinants of malnutrition. These determinants range from underlying factors, such as socioeconomic status and environmental conditions, to more direct determinants, such as food and nutrient intake, and disease (Black et al., 2013). The effects of climate change on nutritional status vary based on wealth and livelihood, but overall, the burden of undernutrition is projected to worsen relative to a no-climate-change scenario (Grace et al., 2012).

Climate change can exacerbate undernutrition through three main pathways: household food security (access to safe, affordable, and sufficient food), child feeding and care practices, and environmental health and access to health services (Met Office and WFP, 2012). Climate change affects what food is available and at what price, impacting overall calorie consumption as well as consumption of healthful foods (Nemecek et al., 2016; Springmann et al., 2016b; Whitmee et al., 2015). This in turn can have an impact on stunting and micronutrient deficiencies. Moreover, many responses to climate challenges also have implications for women's labor allocation, which in turn influences women's time available for child feeding and care practices (Bryan et al., 2017). Finally, health status impacts how nutrients in consumed foods are absorbed and used by the body. Decreased water quality and availability in some areas could result in increased sanitation problems and water-borne diseases such as diarrheal disease (Met Office and WFP, 2012), while the transmission of vector-borne diseases is projected to increase with climate change (Akresh et al., 2011). Coupled with a potential disruption in access to health facilities and health care service delivery by climate shocks, these changes in the environment have the potential to affect nutrient utilization and increase undernutrition (Met Office and WFP, 2012).

Undernutrition carries profound, long-lasting consequences, especially for children under the age of five. Stunting affects approximately 155 million children under five and has long-term implications for individuals, households, and communities (UNICEF / WHO / World Bank Group, 2017; Victora et al., 2008). Stunting in the first two years of life can lead to lowered cognitive functioning and reduced adult income (Briend et al., 2015; Victora et al., 2008). Approximately ten percent, or 50 million, of the world's children under five years are wasted (Black et al., 2013; UNICEF / WHO / World Bank Group, 2017). Child wasting is associated with reduced lean mass, increased risk of infection, and mortality (Briend et al., 2015). By some projections, medium-high climate change is expected to result in an additional 4.8 million undernourished children by 2050 (Table 1) (IFPRI, 2017). This is supported by evidence linking the dire effects of malnutrition with productivity and health at different scales, be they individual, household, community, national, or global levels (Victora et al., 2008).

Climate change and variability lead to seasonal effects that have important implications for nutrition and health. Changes in rainfall (level, pattern, or variability) can result in crop failures and flooding, which can affect nutritional status, particularly stunting outcomes (Akresh et al., 2011; Phalkey et al., 2015), potentially due to a loss in livelihood and decreased access to food. Increased temperatures have been shown to increase the risk of heat stress during pregnancy, as pregnant women are hypothesized to be more sensitive to warm temperatures (Grace et al., 2015). The additional physical and emotional stress caused by these temperatures affects the development of the neonate which influences birth weight outcomes (Grace et al., 2015). Studies show that the combination of increased temperatures, regional decreases in rainfall, and unstable food production will result in an increased risk of future low-birth-weight babies in sub-Saharan Africa (Grace et al., 2015). Drought has the potential to lead to food shortages as well as loss of income, resulting in slowed growth in children younger than two (Hoddinott and Kinsey, 2001). Flooding has short- and long-term effects on child growth through changes in food consumption and infectious disease burden (Danysh et al., 2014; del Ninno and Lundberg, 2005; Rodriguez-Llanes et al., 2011).

The effects of climate change also have the potential to worsen the intergenerational cycle of malnutrition. These intergenerational effects have a detrimental impact on child growth: short maternal stature, occurring as a result of poor nutrition in childhood, is associated with low birth weight and child stunting, which thus begins the malnutrition cycle anew (Martorell and Zongrone, 2012). Because climate change results in short-term shocks and long-term stressors, it will have an impact across the entire life cycle (Fanzo et al., 2017b; Thomson and Fanzo, 2015). Interventions are needed for infants and young children before the age of two, when rapid growth faltering typically occurs (Victora et al., 2010), as well as during later childhood, adolescence, and pregnancy (Prentice et al., 2013).

3. Impacts of climate change on food systems and diets

Food systems include all aspects of the food supply chain, from agricultural production through storage, processing and distribution, retail and marketing, and home food preparation and consumption (HLPE, 2017). Modeling indicates the impact of climate change on food systems will be widespread and variable, both geographically and temporally, as influenced by socioeconomic conditions (Vermeulen et al., 2012).

The *food supply chain* provides a useful framework for examining how climate change will impact our food system and evaluating where nutritional outcomes may be at risk. Each step in the chain can be evaluated for vulnerabilities, and interventions can be designed and "leveraged for change" to address food insecurity and malnutrition (Gelli et al., 2015; Hawkes and Ruel, 2012). Food supply chains determine what food is available, as well as the nutritional quality of those foods (Gelli et al., 2015; Maestre et al., 2017). The food environment, or the distribution of food stands, kiosks, stores, restaurants, or any other retailers where food can be obtained, as well as the cost of food and sociocultural factors around food, determine what food people have access to in terms of availability and price (HLPE, 2017). Additional factors, ranging from personal preference to convenience, further influence what foods people buy and consume (Sobal et al., 2014). The diversity of what people consume is critical for nutritional status and health. Dietary diversity, as measured through the number of food groups and the amount of nutritious vegetables, fruits, and animal source foods (ASF) consumed, is connected to adequate nutrition, especially micronutrient adequacy (Arimond et al., 2010; Ruel et al., 2013). Models estimate more than 500,000 additional deaths in 2050 due to climate–related changes in diets, including decreased food intake and decreased vegetable and fruit consumption, between the years 2010 and 2050, with large regional variations (Springmann et al.,

Table 1
Number (in millions) of undernourished children younger than five in 2000 and 2050 using the National Center for Atmospheric Research climate model and the A2 scenario.
Source: (IFPRI, 2017).

	No. of undernourished children younger than five, in millions			
		2050		Additional no. of children undernourished because of climate change 2010–2050
Region	2010, base climate	Without climate change	With climate change	
Africa south of the Sahara	40.9	37.0	39.3	2.4
South Asia	77.1	50.4	51.9	1.4
East Asia / Pacific	21.9	7.8	8.2	0.4
Latin America & Caribbean	4.3	1.5	1.8	0.3
Middle East / North Africa	4.0	1.7	1.9	0.2
Europe and former Soviet Union	1.8	1.5	1.6	0.1
WORLD	150.0	99.9	104.8	4.8

2016a).

Climate change affects each step of the food supply chain. While these effects are often negative, they can also be positive and may lead to better growing conditions and increased yields at some mid to high latitudes (Parry et al., 1999). However, these positive effects are expected to be overshadowed by negative ones. For food production, climate change is expected to cause wet areas and seasons to become wetter, and dry areas and seasons to become drier (Intergovernmental Panel on Climate Change, 2014). This will increase heat and water stress in the areas already most pressured as well as pests and diseases in crops and livestock (Cheung et al., 2010; FAO, 2016b; Ranganathan et al., 2016; Tirado et al., 2010). While decreased cold constraints at mid to high latitudes, such as in the Andes and East African highlands, may expand growing seasons, increased heat and water stress in most of the Global South is expected to decrease yields and change where food can be produced.

There will also be changes in the nutritional quality of the food supply. Carbon dioxide effects decrease the nutritional quality of many crops, especially wheat, rice, potatoes, soy, and peas. Increased carbon dioxide leads to decreased protein, iron, and zinc in these crops. These cereal crops are the main source of protein and micronutrients in many low-income countries. There are 1.9 billion people who get 70% of their iron and zinc from these crops and 2.3 billion who get 60% (Müller et al., 2014; Myers et al., 2014). Several modeling studies have investigated how this would impact malnutrition and found prospective increases in protein, iron, and zinc deficiencies concentrated in the Global South (Medek et al., 2017; Myers et al., 2015; Smith and Myers, 2017; Smith et al., 2017). Soil quality has also been declining due to intensive agriculture that favors monocrops as well as heavy agrichemical use (UNEP et al., 2010). Degraded soil will also decrease the overall nutritional quality of the food supply.

Subsequent stages of the food supply chain will also experience climate-related challenges. For the food storage, processing, and transportation stage, climate change is expected to increase foodborne pathogens and mycotoxins (Battilani et al., 2016; Tirado et al., 2010), cold storage requirements (Carlsson-Kanyama, 1998; Vermeulen et al., 2012; WRI (WRI (World Resources Institute)), 2013), and food waste from extreme weather events. The effects of climate will also pose new transportation challenges such as sea level rise or increases in temperature making some roads or rail lines on the coast or that travel over permafrost or ice unusable. Extreme weather events also acutely damage infrastructure (Arndt et al., 2011; Brown et al., 2015; Jones, 1991; Wakeland et al., 2012). Such effects of extreme weather particularly impact the transportation of food because it is time sensitive and delays can cause spoilage and increase waste. As temperatures and precipitation change, some geographic areas will become less productive while others will become more so, forcing crop production to move and transportation systems to adapt in order to move food from new production locations to areas where it is needed (Brown et al., 2015). Changes in temperature and precipitation, and extreme weather events, may also limit access to retailers, especially for the most vulnerable populations, those living where poor roads and access to transportation already limit access. For food marketing and retail, climate change and increased energy costs are expected to cause decreased food availability and increased food prices, which will have the greatest impact on those who are already food insecure. In rural areas where retail infrastructure is basic and access to water or cold storage is limited, temperatures increase and decreased water availability create problems for food quality and safety, including more food spoilage and waste (Vermeulen et al., 2012). At the consumption and utilization stage, decreased consumption paired with increased nutritional needs and decreased intestinal absorption due to increased infectious diseases will lead to serious nutritional challenges. These effects will again be the most severe in the most vulnerable populations (Brown et al., 2015; Checkley et al., 2000).

4. Influence of food systems and diets on climate change

The relationship between climate change and food systems is bidirectional: food systems and diets are highly sensitive to climate, but they also act as a major driver of climate change. Food systems contribute an estimated 19–29% of global anthropogenic greenhouse gas emissions (GHGe) (Vermeulen et al., 2012). Including indirect emissions associated with land-cover change, agricultural production contributes 80–86% of these emissions (Garnett et al., 2013).

Evidence suggests some ASF production practices, especially for beef cattle, create enormous negative impacts on the environment. Negative effects include GHGe and other air pollutants, contamination of surface and groundwater, and degradation of ecosystem services (Gerber et al., 2013; Marlow et al., 2009; Ranganathan et al., 2016; Sjörs et al., 2016; Tilman and Clark, 2014). These impacts arise directly from the animals, such as from enteric fermentation and waste, and indirectly from the production of animal feed (Bouwman et al., 2013; Walker et al., 2005).

The effect of livestock production on the environment is a complex issue. Ruminants, primarily beef cattle, have a much greater impact than animals with higher feeding efficiencies, such as pigs and chickens (Foley, 2011). Ruminants are able to utilize grazing lands with no alternative uses in a way that other livestock are not; however, many ruminants are instead raised on grain that people could eat and is grown on arable land that could be used to grow other crops (Ranganathan et al., 2016). Additionally, cattle that are grazed on pasture produce more methane than those raised on concentrated grain feeds because pasture is high in fiber and more difficult to digest (Harper et al., 1999). However, livestock raised in concentrated animal feeding operations produce significant amounts of air and water pollution (Garnett et al., 2013). Further, the production of grain feeds for livestock is resource intensive and diverts that food source from human

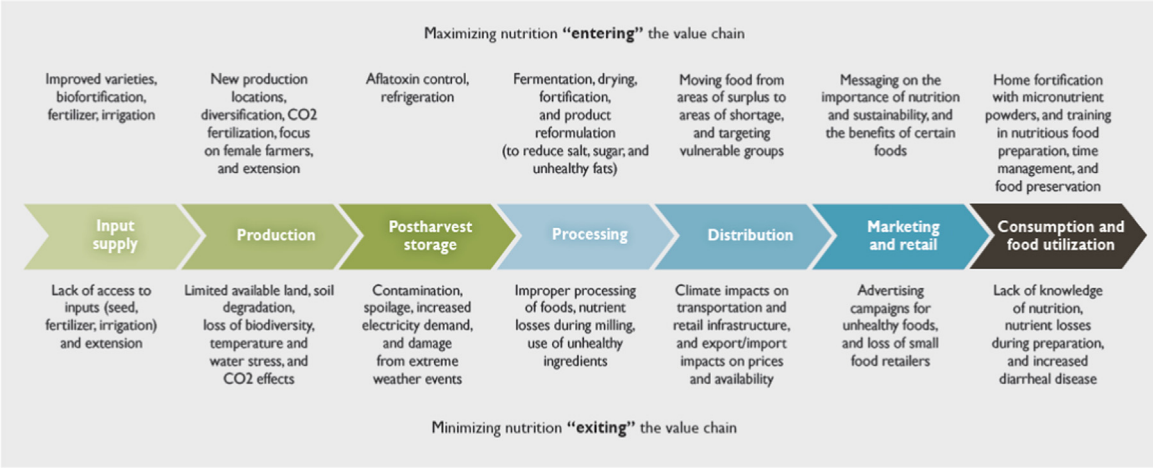

Fig. 1. Entry and exit points for increasing net nutrition along the food supply chain under climate change.
Sources: (Fanzo et al., 2017a, 2017b).

consumption (Herrero et al., 2010).

Despite their environmental impacts, ASF are an important part of the food system. Consumed in moderation, these foods are healthful and provide protein as well as micronutrients such as iron, zinc, and vitamin B_{12} in meat, and calcium and B_{12} in dairy (Black et al., 2013; Dewey and Adu-Afarwuah, 2008). Deficiencies in these nutrients lead to anemia, immunodeficiency, rickets, neuromuscular deficits, impaired cognitive performance, morbidity, and mortality. Livestock are also positively valued as sources of fertilizer and energy in many agricultural contexts as well as being critical assets for the rural poor. Livestock generate income directly through the sale of the animal or its products as well as allowing increased access to financial services (Pica-Ciamarra et al., 2011; Steinfeld et al., 2006).

Current consumption of ASF is inequitable: access to these foods by the poorest, who are highly vulnerable to the effects of climate change, remains limited (Keats and Wiggins, 2014; Zeisel and da Costa, 2009). Overconsumption of ASF is concentrated in HICs; in the United States the average meat consumption is three times the global average, and in many European countries it is twice the global average (de Boer et al., 2016). The demand for ASF from HICs is a significant driver of climate change that disproportionately affects the Global South. This

illustrates how food choices can reverberate around the world in ways that reinforce inequity. As LMICs become wealthier and shift from plant-based diets to more animal-source foods as well as shifting from home cooked meals to packaged food and fast food, the risk is that they will adopt the excessive meat consumption habits of high-income countries (FAO, 2016a; GLOPAN, 2015; Ranganathan et al., 2016).

In order to ensure human health and planetary well-being, the production and consumption of ASF needs to be made more sustainable and equitable. If current consumer demand for ASF continues to rise, there could be an 80% increase in agricultural GHGe by 2050 from overall food production and land clearing (Ranganathan et al., 2016). Moreover, these dietary shifts increase the incidence of non-communicable diseases related to overconsumption and obesity (Bouvard et al., 2015; You and Henneberg, 2016). The challenge is to encourage consumption of ASF for nutritionally vulnerable groups, while simultaneously encouraging reductions of ASF consumption in wealthier contexts and promoting strategies for improved livestock productivity that reduce environmental impacts.

5. Climate-smart, nutrition-sensitive mitigation and adaptation to protect nutrition

Climate-smart food systems engage producer and consumer decision making through "triple-win" scenarios that improve food productivity and minimize loss, reduce GHGe from agriculture, and implement adaptation strategies for the most vulnerable (Lipper et al., 2014). Producers can grow more nutrient-rich foods, such as fruits, vegetables, and legumes, while reducing food losses and curbing GHGe. Food companies can create more nutritious processed products. Consumers around the world can also make better choices: in middle- and high-income countries, they can buy and eat only what is needed as every year nearly one-third of the food produced globally is wasted and 95–115 kg/capita of food in Europe and North America is wasted by consumers (FAO, 2011a), and consume foods with lower environmental impacts (Scherr et al., 2012). In low-income countries, both processors and consumers can use food processing and preservation techniques that ensure food safety and nutrition while minimizing the need for cold storage (FAO, 2016a).

The entirety of the food supply chain as well as each link in the chain can be "nutrition sensitized" to ultimately increase the consumption of nutritious foods (Fanzo et al., 2017a; Hawkes and Ruel, 2012). The way food is produced and passed along the supply chain creates both entry and exit points for nutrition (Downs and Fanzo, 2016; Gelli et al., 2015). These entry points can enhance, restore, or prevent losses in the nutritional value of foods during processing. Entry points can also raise awareness among different actors in the supply chain to stimulate demand for nutritious products. However, entry points can just as easily become exit points when nutrients are removed from foods as they move along the chain (Fig. 1). Economic constraints, lack of knowledge, and related lack of demand are critical factors that limit the access of poor populations to nutritious foods (Downs and Fanzo, 2016; Fanzo et al., 2017a).

Agriculture must be "smarter" in the context of climate change: it needs to be sensitive to food and nutrition needs, while also minimizing negative effects on climate. Both the Sustainable Development Goals, adopted in 2015, and the Paris Climate Agreement of 2015 under the United Nations Framework Convention on Climate Change call for significant action on climate change. Climate-smart agriculture is an effective means of responding to this call and reducing the sector's impacts on climate change. Though costly, sustainable development must include interventions that jointly promote climate-smart agriculture, health, nutrition, and environmental resilience. Moreover, agriculture and climate change adaptation strategies also need to be gender-sensitive knowing that agriculture, gender and nutrition are interlinked through various pathways (Bryan et al., 2017). The literature on gender and climate change suggests that the ways in which gender intersects with vulnerability and resilience to climate change are very context specific, but some common themes that emerge include men and women's varying preferences and response options,

Table 2
Recommendations for action.
Source: (Fanzo et al., 2017b)

Theme	Action
1. Food supply-chain inputs	• Increase access to seed varieties and livestock breeds that are diverse and resilient to variable weather conditions (heat and drought), pests, and diseases • Use agricultural extension programs to improve access to information and training about these varieties and breeds • Improve soil quality through the use of cover crops, crop rotation, balanced use of fertilizers, and manure • Increase irrigation systems to protect crops and livestock from loss due to changes in seasonal precipitation and extreme weather events
2. Food (agriculture) production	• Invest in and provide education on integrated land-use policies and mixed crop and livestock systems • Expand access to services and financing to support farmers, including farmer risk-management tools, insurance, and loans
3. Post-harvest storage and processing	• Improve infrastructure, especially in rural areas, including roads, warehouses, and processing plants • Provide training on safe storage and processing techniques, such as drying
4. Distribution, marketing, and retail	• Improve retailer access to water, electricity, and cold storage • Create networks of food producers to increase market access and help limit food waste • Improve transportation infrastructure in areas where the effects of climate change will limit people's ability to access markets
5. Food consumption and utilization	• Expand access to social protection services, including unconditional cash transfers and supplementary food allowances • Increase consumption of animal-source foods in low- and middle-income countries, while educating the public about the health risks associated with overconsumption of these foods • Improve access to safe and energy-efficient cookstoves • Increase access to healthcare for vulnerable populations, especially the rural poor, by increasing healthcare facilities and staff
6. Early warning systems	• Improve early warning systems and increase farmers' access to them • Provide training to producers on how to protect crops, store food, and otherwise prepare for extreme weather events
7. Evidence for and inclusion of nutrition in climate research	• Conduct research, and collect and analyze data on how climate change affects the food system and how to maximize nutrition amid these effects

responsibilities (including livelihood strategies, labor roles), and access to resources and institutions that are likely to affect climate change adaptation (Bryan et al., 2017). It is therefore important to further explore different approaches to achieve nutrition- and climate-smart food production that are also gender-sensitive and promotes social equity (Beuchelt and Badstue, 2013).

The food value chain encompasses every step that ultimately determines what foods are eaten and how the nutritional value from these foods is utilized, and who participates in these different activities. Each link in the chain provides an opportunity for adaptation that also addresses diets and nutrition (Fanzo et al., 2017b). The effects of climate change can exacerbate undernutrition at all stages of chain: they decrease agricultural yields, affect the nutritional quality of crops, limit access to food, increase foodborne pathogens, and necessitate greater cold storage (FAO, 2016a; Mason and Shrimpton, 2010; Smith and Haddad, 2015; Vermeulen et al., 2012). This section identifies seven focal areas for interventions to reduce nutrition risks under climate change along with mitigation and adaptation actions (Table 2) (Fanzo et al., 2017b).

5.1. Food supply chain inputs

Crop production, nutrition, and dietary diversity benefit from a diversity of seed and livestock varieties that are resilient to variable weather conditions, pests, and diseases (FAO, 2016a, 2007; Swiderska et al., 2011). These varieties may include traditional or indigenous varieties, wild plants, and newly developed varieties. Irrigation is increasingly necessary as more areas experience water variability from extreme rainfalls or droughts (HLPE, 2012). Given the finite, vulnerable nature of existing freshwater resources, irrigation should be complemented by other water management techniques, such as rainfall capture, as well as increased training and technology for producers (Domènech, 2015; FAO, 2016a). Poor soil quality contributes to declines in crop productivity and nutritional quality, particularly micronutrients (Davis et al., 2004; Mayer, 1997; Parr et al., 1992). Improving soil quality has additional benefits beyond nutrition and health: even small positive changes in soil quality can lead to more significant carbon sequestration, which is an important method of climate change mitigation (Vermeulen et al., 2012).

5.2. Food (agricultural) production

Production has largely been the focus of existing adaptation and mitigation strategies. Mixed crop and livestock systems minimize the impacts of livestock on climate and improve the nutritional quality of food (Herrero et al., 2013). Mixed systems also provide additional income that is more stable than income from crops or livestock alone, and they offer resilience to crop losses (Herrero et al., 2013). Integrated land-use policies are an innovative adaptation approach to improving soil and water quality while simultaneously protecting agricultural lands. These policies take a holistic landscape approach through a range of active and passive methods, such as capturing precipitation from extreme weather events and paying communities for ecosystem services. However, this approach requires a great deal of political will and financial support (HLPE, 2012).

5.3. Post-harvest storage and processing

Food storage and processing strategies can address climate-related food safety concerns while also reducing waste and ensuring nutrition. As temperatures increase, cold storage will be necessary in certain countries to preserve the storage life and quality of nutrient-dense foods (Vermeulen et al., 2012). In some contexts, fossil fuel–intensive cold storage can be replaced by alternative processing techniques, such as drying, that increase stability (FAO, 2016a; GLOPAN, 2015). Storage and processing techniques can also reduce food waste and the risk of foodborne pathogens, such as aflatoxin (FAO, 2011b; Razzaghi-Abyaneh et al., 2014).

5.4. Distribution, marketing, and retail

Climate change is expected to create challenges for rural smallholder farmers, fishers, and pastoralists in the distribution, marketing, and retail access of their products (Arndt et al., 2011; Brown et al.,

2015; Vermeulen et al., 2012). For the many producers whose markets lack infrastructure, climate-proofed facilities can improve market access, protect nutrient density, and reduce waste (Vermeulen et al., 2012). Markets need to be better integrated with communities, and, in areas with greater density of small farms, farm networks can be used to increase access (FAO, 2016a; Vermeulen et al., 2012). Transportation infrastructure is necessary as well, both in areas that currently lack reliable transit and in new areas, as crop production areas shift due to temperature changes (Brown et al., 2015).

5.5. Food consumption and utilization

Social protection services are necessary to protect the most vulnerable from short-term shocks and long-term stresses that threaten food security. Programs and policies that promote increased dietary diversity and access to fortified foods are also important tools for improving nutrition and health in nutritionally deficient populations (Arimond et al., 2010; Ruel et al., 2013). As mentioned earlier, while consumption of ASF may need to increase in certain contexts, overconsumption of ASF, which is especially prevalent in high-income countries, has negative consequences for human and planetary health (Bajželj et al., 2014; FAO, 2016a; GLOPAN, 2015; Ranganathan et al., 2016), so policies need to be considerate of this balancing act.

Moreover, climate affects disease, which can increase nutrient demands and reduce nutrient absorption (Watts et al., 2015; WHO, 2009). Increasing the number of healthcare facilities and staff can improve access to healthcare for vulnerable populations, especially the rural poor.

Finally, energy-efficient methods of food preparation, especially those that reduce the use of biomass, are also necessary to improve human health and mitigate the effects of climate change (IPCC, 2011; World Bank, 2011).

5.6. Financing, risk management, and social services

Financing and income diversification can also reduce nutrition risks under climate change. Small-holder farmers, who are the most vulnerable to the effects of climate change, are also the most disenfranchised from the financial system. These farmers often have the lowest financial literacy; little to no credit history or collateral; and poor access to insurance, credit, and loans (FAO, 2016a). Most farmers, especially smallholders, rely on other sources of income in addition to farming. As farming livelihoods are increasingly threatened from climate change, these off-farm sources of income will become even more important. Income diversification protects farmers from farm losses and price fluctuations (Vermeulen et al., 2012).

Improved early warning is needed for both extreme weather events and long-term shifts in temperature and precipitation. Modeling and geographic information systems (GIS) can be used to predict weather and soil conditions (Pitesky et al., 2014). This information, where available, can be used to modify planting, harvest, and irrigation schedules. Farmers and producers need gender-sensitive and context-specific information to protect crops and stored food during extreme events and to modify planting and harvesting schedules in response to changing weather patterns (Bryan et al., 2017). In some contexts, men prefer predictions of rainfall onset because they have priority access to animals for field preparation, while women need forecasts on rainfall cessation and dry periods (HLPE, 2012).

Social protection services, such as public works programs, transfers, supplementary food, food vouchers, and school meals, also help producers mitigate risks and manage shocks. Public works programs can offer employment in times of need, thereby bolstering household food security, and agricultural activities have significant impacts on crop yields and vegetation diversity. Transfers provide food, cash, vouchers, or other resources during crisis periods. These support programs can also help support future resilience, as was the case with innovative resource transfers implemented by the FAO in Pakistan and the WFP in Kenya that provided resources in exchange for work on soil and water conservation programs (FAO, 2013).

5.7. Research

Research is needed to determine evidence-based interventions that maximize nutrition at all steps of the food supply chain. Although research on mitigation and adaptation in the food system exists, current studies primarily focus on food production. There is little information, let alone specific guidance, on how to mitigate and adapt to climate change at other stages in the value chain. Hess and others (2014) looked at applying an evidence-based framework from the public health arena to climate change adaptation and found that a modified version would be effective but is limited by a current lack of evidence. They argued for increased evaluation of and reporting on current adaptation efforts (Hess et al., 2014).

The literature on the impacts of climate change on nutritional status is growing, but it could be strengthened and expanded further. Many studies are limited by their cross-sectional analysis, use of secondary data not meant to measure the potential effects of climate change on nutrition, inability to detect results in subgroups, or lack of important potential confounders (Phalkey et al., 2015; Strand et al., 2011). Despite these limitations, there are promising future avenues for solutions, such as geographic information analysis and other spatially oriented techniques to investigate malnutrition (Marx et al., 2014).

6. Conclusions

Climate-smart agriculture is one promising approach to address the challenges from climate change, but more action is needed to link climate-smart approaches to diets and nutrition—especially for the most vulnerable. Moreover, agriculture needs to be not only climate-smart, but also gender- and nutrition-sensitive.

Governments, nongovernmental organizations, and the private sector must take action to maximize nutrition in the face of climate change. These actions must target the urban and rural poor in low- and middle-income countries because they will be the most affected by climate change and the least able to respond on their own. It is also essential to evaluate the unique needs and priorities of each situation and recognize the trade-offs inherent in these actions.

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Declarations of interest

None.

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