FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Food Systems and Nutrition: Emerging Evidence and Research Opportunities

Version Date: 29 October 2019

Acknowledgements: The authors thank the input and insights from experts and advisors from the USAID Bureau of Food Security and the Bureau of Global Health who reviewed different drafts of the report. This review was prepared by the USAID Feed the Future Innovation Lab for Nutrition (www.nutritioninnovationlab.org) under grant contract AID-OAA-L-10-00006.

Proposed Citation: Ilana Cliffer, William A. Masters, Johanna Andrews Trevino, Patrick Webb and Shibani Ghosh. Food systems and nutrition: emerging evidence and research opportunities, Nutrition Innovation Lab, October 2019.

USAID FROM THE AMERICAN PEOPLE

Tufts UNIVERSITY
Friedman School of Nutrition Science and Policy

Acronyms

A4NH	Agriculture for Nutrition and Health
ASF	Animal-source foods
CGIAR	Consultative Group for International Agricultural Research
CoNA	Cost of Nutrient-Adequacy
EED	Environmental enteric dysfunction
FGIs	Food group dietary diversity indicators
FIES	Food Insecurity Experience Scale
GFSS	Global Food Security Strategy
GLOPAN	Global Panel on Agriculture and Food Systems for Nutrition
GMOs	Genetically modified organisms
HFIAS	Household Food Insecurity Access Scale
HLPE	High Level Panel of Experts
IFPRI	International Food Policy Research Institute
IGF-1	Insulin-like growth factor I
LANSA	Leveraging Agriculture for Nutrition in South Asia
LCIRAH	London Centre for Integrative Research on Agriculture and Health
MAHFP	Months of Adequate Household Food Provisioning
MDD	Minimum dietary diversity
MDD-W	Minimum Diet Diversity score for Women
PICS	Purdue Improved Crop Storage
SPRING	Strengthening Partnerships, Results, and Innovations in Nutrition Globally
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WASH	Water, sanitation, and hygiene
WEAI	Women's empowerment in agriculture index
WHO	World Health Organization

Abstract

This evidence review summarizes recent thinking and research findings on how agriculture and food systems affect diets and nutrition. It identifies gaps where new work is needed to guide policies and the investment in evidence-based programs in low-income countries.

Since 2008, the primary focus of agriculture-nutrition research has been how a household's production may affect the nutrition of women and children, mainly through eating their own produce or selling commodities and using that income to purchase more diverse, sometimes higher-quality diets. Key findings of this work concern the generally positive value of productivity and production diversity; the value of livestock ownership for potential consumption of animal-source foods; the importance of gender roles in time-use, decision-making and control of own-produced products; the importance of access to markets (for sale and purchase); 'market literacy' when selling higher value (nutrient-rich) foods; the importance of food safety (particularly managing mycotoxin risks); 'next generation' technology adoption that adds value to nutrient-dense foods (moving towards innovations in processing, drying, storage and transportation); and the importance of linking agricultural and market interventions to effective behavior-change communication to achieve nutrition gains.

At a more macro level, recent research has also provided insights into the role of climate shocks and seasonality on birth outcomes and child growth, which links to growing concerns about the importance of building resilience for agricultural livelihoods, and smoothing diet quality and nutrition outcomes. There is also realization of the importance of rural markets and infrastructure relative to the delivery of nutritious commodities.

Emerging priority issues requiring deeper research-based understanding include: i) empirical evidence of pro-resilience interventions at different points in the food system that protect diets and nutrition in the face of shocks and climate change; ii) innovations and scale-up of productivity-enhancing technologies/practices along the value chain relating specifically to nutrient-dense foods; iii) impacts of agriculture-based interventions for adolescent girls' diets, micronutrient status and energy expenditure, and those of women of reproductive age; iv) drivers of consumption choice among low-income smallholder households close to markets (with access to diverse and nutritious foods to purchase); v) comparison of cost-effectiveness of alternative approaches and entry points in the food system for changing behaviors on adoption of new inputs, behaviors regarding food choices, and impetus to market farm outputs; vi) combined food safety threats in relation to health and nutrition at household level; and vii) untangling WASH elements to gain better understanding of which interventions can have measurable impacts on nutrition

Underlying all such research streams has been important emphases on the validation of appropriate metrics, whether in the realm of agricultural production, food markets, or nutrition and health, to better understand problems and promote solutions focused on determining the relative cost-effectiveness of multisector versus single-sector approaches, and on meeting appropriate thresholds of empirical evidence to underpin informed policy and program designs.

Summary of Findings

Food systems are changing rapidly due to globalization, urbanization, demographic shifts and climatic conditions. These changes pose emerging threats to the food system that point to an urgent need for rigorous research on cost-effective strategies to ensure adequate, safe and sufficient nutritious foods for all. Since many low and middle-income countries are now faced with a triple burden of malnutrition (undernutrition coupled with obesity and micronutrient deficiencies), understanding the role of food systems in determining population health has never been more important. Food systems and nutrition outcomes are linked through several food and time-use pathways, involving agricultural supply chains that bring foods from production to consumption through processing, distribution, and marketing, as well as through the drivers of physical and economic access to different types of foods.

The aim of this review was to identify opportunities for action that could contribute to systemic change that improves diet quality, particularly for nutritionally vulnerable people in low income settings. The review summarizes research findings and presents future research opportunities around the production of nutrient-dense foods, agriculture-nutrition linkages at population scale, food processing, food safety, and food loss and waste. It also reviews evidence on several cross-cutting issues that have implications across the food system for nutrition and health, such as gender, resilience, and sustainability. A summary of the key findings of the synthesis follow.

<u>Agricultural production of nutrient-dense foods</u>

1. *How do crop genetics, biotechnologies, and agronomic management influence nutritional status?*

Crop technologies, such as biofortification and other genetic improvements, water and soil conservation, and other steps towards improved land productivity, show potential for a positive influence on nutritional status. Steering these changes towards production of more nutrient-dense foods is a key first step towards healthier diets. So far, empirical evidence of impact at scale remains weak. The many papers in this space are often based on small case-studies or theoretical projections derived from modelling. Empirical evidence from large field-based studies remain scarce.

2. *How do livestock interventions influence nutrition?*

Livestock genetic improvement and ownership can complement crop production to improve nutritional status through the supply of animal-source foods; but it can also introduce new risks linked to poor food safety, sanitation and zoonotic disease. The importance of milk, eggs, fish and other animal-source foods (ASF) for growth and development in children is increasingly well-documented and reviews of livestock ownership interventions show these interventions can be successful in improving growth outcomes and micronutrient adequacy. For example, ownership of milk-producing animals is associated with improved linear growth. That said, the greatest gains typically accrue to larger-scale production and already less-poor households. What is more, some studies also find negative effects of livestock ownership on nutritional status, especially under conditions of poor sanitation and animal diseases. There is emerging

research on the role of fecal-oral transmission of pathogens in the pathogenesis of poor gut function with subsequent malabsorption of nutrients. The implication is that management of livestock to prevent pathogen dispersal is key to capturing the potential gains from own-consumption of ASFs and/or great diet quality via sale of livestock products.

3. *What evidence is there to support market access as an intervening variable between agricultural production and consumption?*

Research on food environments, market prices and purchased foods in rural areas of low- and middle-income countries is limited, but there is growing evidence that transitioning from self-provisioning to greater reliance on markets is particularly helpful to improve resilience and stabilize diet quality, by reducing dependence on highly seasonal and unstable local production. Empirical studies in Africa and Asia increasingly show that production diversity and diet diversity from own production are both strongly mediated by access to markets. Greater use of markets poses its own risks, however, necessitating more research on how market actors in the private and public sectors can best improve rural households' access to nutritious diets.

4. *Do homestead food production programs aimed at increasing household production of diverse foods impact nutritional status?*

There have been many studies and reviews of homestead food production and nutrition-sensitive agriculture in recent years. Most report that fruit and vegetable production can reduce anemia and vitamin A deficiency, and in some cases, decrease incidence of diarrhea and wasting in children and women. So far, there is limited evidence of homestead gardening impacts on stunting. While homestead food production and nutrition-sensitive agricultural interventions have been relatively successful at increasing diet diversity and animal ownership, which in turn have led to some measurable decreases in micronutrient deficiencies, the weakness of correlations between these interventions and anthropometric outcomes raises questions about how to set appropriate program expectations.

<u>Agriculture nutrition linkages at a population-wide scale</u>

How do trade policies, markets, and food prices impact food availability, and ultimately nutritional status?

Trade policies, market function, and food prices act together in multiple ways to influence the food environment. There is abundant evidence on how trade affects food security, but its impact on nutritional status are less well-established. There is a clear need for more research about how different kinds and scales of food markets affect diet quality and nutrition for consumers through fluctuations in food prices. At the same time, more evidence is needed of successful policy and program interventions that measurably affect the affordability of nutrient-rich foods relative to starchy staples, and the affordability of healthy diets by low-income households across seasons and years.

What evidence is there about ways to reduce constraints on producing and consuming a variety of nutritious foods?

In low-income countries, existing markets generally deliver relatively expensive perishable nutrient-dense foods to higher-income consumers. There is typically poor market connectivity among rural populations, and limited processing, storage and preservation options, which limits their access to a diverse set of nutritious foods year-round. There are evidence-based options for reducing constraints on production and consumption of many nutrient dense foods, but risk management and market relationships remain significant barriers to specialization and private sector growth. Further research into market information systems that can provide accurate information to farmers, and the use of producer organizations or contract farming to reduce risks and increase access to information could prove important in encouraging production of nutritious foods and improved nutritional status.

What levers can shape consumer demand for nutritious foods?

The food environment is instrumental in shaping demand for nutritious food through the influence of many factors: prices, consumer income, information, beliefs, habits, culture, demographic status (age, education), food preparation time and convenience, storage capacity (refrigeration), and of course taste. Two of the most powerful influencers of demand for nutritious foods are price (relative and absolute) and consumer purchasing power. That said, the food environment can also modify the effect of income on dietary choices. Safety nets as well as taxes and subsidies can alter consumers' purchasing power for healthy foods and discourage the purchase of less nutrient-dense foods. While it is difficult to find evidence of the effects of taxes and subsidies in low- and middle-income countries (LMICs), because few developing countries have implemented such policies, there is promising evidence from higher-income countries that these policies can be effective in improving dietary behaviors and nutritional status.

A common approach to impacting the price/income pathway in LMICs is through the provision of social safety nets or transfers such as food vouchers or cash. Access to information is also important. Consumer education, advertising campaigns, and labeling can impact nutritional status by providing more information about what is in a food product, so consumers can make more informed decisions. While some governments and non-governmental organizations have had success in influencing consumption of nutritious foods through behavior change campaigns and education, more research is necessary on the best ways to convey information about nutritious foods to populations in which many have not had formal schooling. Food-based dietary guidelines can also be used to promote healthy nutritional choices, serve as the basis for educational sessions in food retail centers or workplaces, and set standards for feeding programs such as school feeding; however, most low- and middle-income countries have yet to implement such guidelines, so evidence is lacking on their effectiveness in promoting healthy choices.

Food Processing

What evidence is there about the effects of food processing on nutrition?

Food processing is not inherently bad. Most foods consumed globally are processed, and certain forms of processing (such as drying for preservation, micronutrient fortification, and removal of toxicity) have well-known positive effects on nutrition and health. It is the growth of ultra-processed and packaged foods and consumption away from home that are of concern globally, including across diverse populations in LMICs. Increased use of limited cash for the purchase of ultra-processed foods has been linked in many settings to increases in BMI and non-communicable diseases such as diabetes and cardiovascular disease. This trend is now seen in low-income settings, where infants and young children consume packaged salty snacks, instant noodles and high-sugar/high-fat confectionaries in rural as well as urban contexts. Given the speed of these changes, understanding the nutritional and other effects of food processing is among the urgent elements of food systems research. In addition, it is important to determine how policies and programs can better inform consumers and shift relative prices to empower poor consumers to make better dietary choices, including in remote rural areas.

Food Safety

What is the link between food safety during food production and nutrition?

Application and compliance of food safety standards and sound agricultural practices can help reduce foodborne illness for the members of farming households as well as for buyers and consumers. Further research is called for to better understand the dietary consequences of exposure to food safety issues that occur during production (i.e. pesticide and antibiotic use, or water and irrigation practices), as well as research into mitigation of risks from these food safety issues.

What are the food safety issues that affect nutrition in the post-harvest phase, and how can they be mitigated?

Poor sanitary facilities (e.g., wet markets, warehouses) and poor personal hygiene can result in food contamination during the post-harvest period. Appropriate infrastructure is necessary to facilitate good hygiene practices and protect foods from flies, other insects or rodents that may spread pathogens to food. In addition, poor agricultural practices, inadequate drying, and sub-optimal storage conditions can result in production of mycotoxins, natural contaminants of food and agricultural products. New evidence is emerging of important direct links between foodborne toxins (mycotoxins) and birth outcomes, controlling for wealth and education, and separate from other factors known to underpin birth outcomes. That aflatoxin levels in mothers' blood can impair good births, independent of smoking, maternal stature and other factors, represents a significant new domain for research. Going forward, it will be important to determine if effects seen at birth persist during child growth, how the mother's health and nutrition is affected by high mycotoxin levels (aside from poor birth outcomes), and what cost-effective interventions and practices can help smallholders better understand and manage food safety threats.

How are marketplace food safety issues related to nutritional status?

If markets lack appropriate infrastructure, food safety can be compromised. There is little evidence about food safety in markets in low- and middle-income countries; however, informal markets in low- and middle-income countries often lack storage and cooling facilities for perishable food items, jeopardizing food safety. Studies have also found high microbial loads in market products. Another area of interest in marketplace food safety is that of the sale of expired foods. We find no recent studies about expired products sold by vendors or in markets in LMICs, despite the importance of food expiration for food safety in the marketplace.

How is food safety in the home connected to nutritional status?

Even if foods remain safe throughout the value chain, if they are not properly handled at the household level by consumers, food quality and nutrition can be compromised at this stage, leading to foodborne illness. The water, sanitation, and hygiene (WASH) environment of a household can impact food safety during consumption, which subsequently impacts nutritional status, especially among children. After frequent gastrointestinal infections due to exposure to environmental pathogens, children may develop EED and experience growth faltering. Evidence from two recent large trials, testing the effects of adding WASH interventions to food supplementation to influence nutritional status, have shown null effects of handwashing, water decontamination tablets, and latrine construction interventions on growth outcomes. The lack of evidence for a correlation between improved WASH and growth necessitates further study of the causal pathways for EED, including how environmental contexts and food safety throughout the food system influences health and nutrition outcomes.

<u>Food loss and waste</u>

How have advancements in technologies used at the household level mitigated post-harvest loss and impacted the availability of nutritious foods?

At the household level, post-harvest losses can affect both the income of farmers as well as the availability of sufficient food. A significant research gap has been noted around the mitigation of post-harvest loss, particularly of high-value/nutrient-dense crops such as fruits and vegetables. Within the context of reducing producer constraints due to post-harvest losses, simple on-farm innovations and management practices do exist and have the potential to encourage production of perishable nutrient-dense foods. While these innovations may hold promise, their feasibility, cost-effectiveness and scalability for increasing production, access and availability of fruits, vegetables, and animal-source foods remains to be seen.

How can population-level interventions minimize food loss?

At the population level, major causes of food loss in low- and middle-income countries are lack of market access, poor harvest timing, rough handling of produce, and poor storage facilities. Improvements to market infrastructure and technology could potentially reduce food loss, but better measurement of food loss is needed to evaluate the efficacy of such improvements.

<u>Cross-cutting themes</u>

What evidence is there for the role of gender in food systems-nutrition linkages?

Women represent a large portion of the agricultural sector yet are often subject to barriers such as limited decision-making and mobility autonomy that constrain their agricultural choices. As the primary caregivers, these limitations make it a challenge for women to provide sufficient and adequately nutritious foods to both themselves and their children. Increased access to agricultural assets among women has been shown to increase investments in child nutrition. In addition, while increasing numbers of studies use the Women's Empowerment in Agriculture Index (and related off-shoots) to collect data on women and agriculture, most use this information descriptively as opposed to using it as a basis to determine the impact of nutrition-sensitive or food system-wide interventions on empowerment outcomes or nutrition. Too few have studied energy expenditure and time-use/opportunity costs for women of different interventions to determine the distributed cost-effectiveness of interventions within rather than just across households.

How can food systems lead to resilience and ensure sustainability?

A focus on resilience and sustainability of food systems is important if we are to achieve food and nutrition security in the face of climate change. A crucial dimension of food systems for resilience and nutrition is the diversity of agricultural production, which also contributes to social and ecological sustainability through decreasing the potential for pest outbreaks and pathogen transmission and increasing crop security in the face of climate change, as diverse crops react differently to different conditions. Few empirical studies focus on actually measuring potential resilience-building facets of food-based interventions, and fewer still consider long-term sustainability.

<u>Metrics and indicators for agriculture, food systems and nutrition</u>

To conduct successful and meaningful research on agriculture and food systems for nutrition, agreement is needed on the most appropriate indicators to measure each step of change, with the indicators chosen appropriately matched to program activities and interventions.

Summary of research opportunities

Topic	Overarching research opportunities
Agricultural production of nutrient-rich foods	▪ Assess the potential for biofortified crops to impact health and nutrition outcomes and to be adopted and scaled up through markets ▪ Establish impacts of use of land productivity inputs and livestock ownership on diet and nutrition outcomes ▪ Invest in research examining the effectiveness of new technologies to improve feed efficiency and yield ▪ Understand relationships among market access, structure and human nutrition and health ▪ Further evidence on theory-driven program design to scale up nutrition sensitive agricultural programs ▪ Assess program scalability (e.g. homestead gardens) and potential for sustainability (e.g. exit strategies)
Agriculture-nutrition linkages at population scale	▪ Research on how trade policies, market infrastructure and intermediaries impact nutritional status ▪ Understand how local markets function and how they can be improved ▪ Understand how market information systems, contract farming and subsidized crop insurance impact risk mitigation and encourage production ▪ Understand the degree to which prices, taxes and subsidies constrain or encourage healthy diets, considering different demographic groups/settings and the effect on private sector engagement ▪ Develop standardized definitions for healthy and unhealthy foods and determine the best ways to convey information about nutritious foods and nudge consumers towards healthier choices
Processing	▪ Research on food processing for better efficiency in production with fewer resources and lower waste production ▪ Cost effectiveness of food fortification on functional outcomes, considering rapid changes in dietary patterns
Food safety	▪ Research impacts of exposure to pesticides, antibiotics and mycotoxins on human health ▪ Research on mycotoxins to test strategies for the prevention and/or reduction of mycotoxin exposure and EED, and promote child growth ▪ Support causal studies for EED exposure and growth faltering using a whole system approach ▪ Generate better data on the influence of intermediaries (e.g., food vendors) on food safety and how they can play a role in improving food safety in the marketplace
Food loss and waste	▪ Rigorous post-harvest loss assessments using systematic methodologies and exploration of holistic approaches to mitigate loss

	▪ Understand how market transformation and improvements to infrastructure affect food loss ▪ Research on drying, packaging and cold chain technologies to reduce post-harvest loss
Cross-cutting themes	▪ Conduct qualitative research examining interplays between gender dynamics and food systems and ways to best design services accessible to women ▪ Understand how food systems can best support healthy diets that promote both resilience and sustainability
Metrics and methods	▪ Support research around guidance development (dietary guidelines, indicators for measuring diet) and harmonize food group and dietary diversity indicators ▪ Define long-term outcome measures to complement existing short- and medium-term measurements

Table of Contents

1. Introduction

1.1 Motivation: Why food systems, diets and nutrition?

Feeding the world's population with safe and nutritious food poses rapidly changing challenges, calling for new and innovative research into cost-effective and sustainable strategies to prevent all forms of malnutrition. Investments to improve nutrition are particularly critical given the changing structure of food systems and evolving profile of malnutrition around the world. Around 800 million people have insufficient food for a healthy life, and more than 2 billion suffer from a lack of adequate vitamins and minerals (Global Panel on Agriculture and Food Systems for Nutrition, 2017). The world is struggling simultaneously with both overconsumption and undernutrition (Haddad et al., 2016), especially among vulnerable populations. According to current global prevalence estimates, a total of 150.8 million children under five are stunted, 50.5 million children under five are wasted, and 20 million newborn babies are low birth weight, while 38.3 million children and 2.01 billion adults are overweight or obese (Development Initiatives 2018).

During the past decade, research and interventions in agriculture and nutrition have focused primarily on pathways by which a household's farm production affects its own nutrition, either through direct consumption, income and gender dynamics, or pathways by which a specific value chain alters the nutritional impact of a target crop or livestock product (Allen & de Brauw, 2018; High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017; Maestre, Poole, & Henson, 2017). A conceptual framework developed through the TANDI project (Tackling the Agriculture-Nutrition Disconnect in India) and adapted and adopted by the United States Agency for International Development (USAID) Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) project emphasized six pathways through which agriculture and nutrition are interconnected (Herforth & Harris, 2014; Kadiyala, Harris, Headey, Yosef, & Gillespie, 2014). This framework, shown in Figure 1, depicts how these pathways are thought to relate to each other. It highlights the complex interplay among the enabling food, natural resources, and health and sanitation environments that dictate food production, agricultural income, and women's empowerment, ultimately influencing nutritional status.

Reviews of research into the USAID SPRING-proposed agriculture-to-nutrition pathways shown in Figure 1 have found limited evidence for how an individual household's agricultural practices affect their own nutritional outcomes (Bird, Pradhan, Bhavani, & Dangour, 2019; Ruel, Quisumbing, & Balagamwala, 2018). Analyses have found significant improvements in nutrition outcomes, such as stunting associated with community-wide improvements in health services and affordability of nutritious foods (Masters, Rosenblum, & Alemu, 2018), while variation among households within each community is primarily associated with differences in household income, education and other measures of capability or entitlements (Finaret & Masters, 2019). Meanwhile, national food systems are changing rapidly, with increasing availability of foods that bring increased risks of diet-related cardiometabolic diseases, such as diabetes and hypertension. Food systems are also coming under further stress from population and income growth, urbanization, globalization, climate change, and increasingly scarce natural resources

(Haddad et al., 2016; Popkin, 2014a). All of these changes have altered our understanding of agriculture-nutrition linkages, as documented in the research findings reviewed in this report.

When farmers are self-provisioning, their dietary intake depends on their own food production, while integration with broader food systems creates the potential for higher and more stable consumption to improve diet quality. Food systems overcome seasonality and spatial variation in production through specialization and exchange, creating opportunities for private sector-led growth from provision of farm inputs and food market services such as transport, storage, processing and retailing. These activities can improve nutrition but also expose farmers and consumers to changes in market prices associated with trade policy and public investment in market infrastructure. When public policies lay a strong foundation for market development, entrepreneurs can invest in agribusinesses and food enterprises that improve food systems through private sector growth. The resulting shift away from self-provisioning can be particularly important in the most vulnerable locations, overcoming production constraints at each place and time through the human and social capital needed for self-reliance.

Food system changes towards increased use of purchased foods has been a driving force behind the dietary transition, with many places experiencing a faster expansion of retail networks for less healthy packaged foods and beverages than for more nutritious items. This may be especially true in places with less developed infrastructure, due to the perishability and higher transport cost for nutrient-dense foods. The resulting changes in both rural and urban food environments has shifted priorities for intervention to prevent all forms of malnutrition including persistent undernutrition in early childhood (stunting and wasting), weight gain later in life (overweight and obesity) and persistent micronutrient deficiencies (WHO, 2017), all linked to poor quality diets. Agriculture and food policies and programs will need to consider how the food available to and consumed by populations has evolved, and how dietary transition relates to the persistence of undernutrition and micronutrient deficiencies alongside the rise of diet-related diseases such as diabetes and hypertension (Popkin, 2014). Many countries experience multiple burdens of malnutrition, as individual deficiencies are addressed and attention shifts towards maintaining balanced diets over time (WHO, 2017).

The High Level Panel of Experts on Food Security and Nutrition (HLPE) provides a useful framework for linking food systems to nutrition and health outcomes through multiple pathways (Figure 2) (High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017). Agricultural supply chains can impact diet and nutrition through transforming commodities into food products with high nutrient density, through appropriate processing, distribution, and marketing. Physical and economic access are elements of the food environment that could affect diets and subsequently nutrition even in well-functioning supply chains. Further, quality and safety of the food that is accessible and available is a major consideration. Each part of the food system plays an important role in determining nutritional outcomes and is influenced by tangential systems such as health, transportation, institutional, and political systems.

The five main drivers of food system changes illustrated in Figure 2 that can impact health and nutrition include: biophysical and environmental, innovation, technology and infrastructure, political and economic, socio-cultural, and demographics (High Level Panel of Experts on Food

Security and Nutrition of the Committee on World Food Security, 2017). Considering this framework and rapidly-evolving food systems, there is an identified need for well-functioning enabling environments to improve dietary choices and consumer behavior, and complementary investments in structural aspects of the food system, diet guidelines, definition and validation of metrics, data generation, and sustainability among other areas for achieving nutrition outcomes (Gillespie et al., 2019; Global Panel on Agriculture and Food Systems for Nutrition, 2016; Haddad et al., 2016). A food systems lens allows assessing how focused investments in each driver of change can most cost-effectively improve nutritional outcomes for target populations across the spectrum of low-, middle-, and high-income countries (Popkin, 2014).

1.2 Definitions

Interpretations of food systems terminology can depend on the context; definitions have been adapted by different industries involved in food systems research to fit their specific needs. This section presents the definitions of certain terms used in this review, to ensure understanding of any terms that may be have flexible definitions.

Food systems: We find several definitions and frameworks of food systems in the literature. For the purpose of this review, food systems are defined using the framework established by the HLPE as: "all the elements (environment, people, inputs, processes, infrastructure, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes" (High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017). The distribution piece of food systems involves both the movement of foods to markets, and the acquisition of foods by consumers.

Sustainable food system: According to the HLPE, a sustainable food system is one that "ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised" (High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017).

Food environment: The food environment is defined as the "physical, economic, political and socio-cultural context in which consumers engage with the food system to make their decisions about acquiring, preparing, and consuming food" (High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017). This includes physical spaces, such as markets, where food is obtained, infrastructure and policies (nutrition, public health, agriculture, trade among others) that influence consumer access to these physical spaces, and contextual determinants of consumer food choices such as prices, income, education, and advertising (High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017).

Food value chain: A food value chain is a type of supply chain that includes transformation as well as production, storage, trade and distribution (including transport), processing and packaging, retailing and marketing, and promotion, labeling, and advertising, with value-adding activities as it goes through this chain. Value-adding activities create opportunities for increasing

the economic value of the product or the benefit offered by the product to consumers in relation to its price (Hawkes & Ruel, 2011).

Food and nutrition security: The most widely accepted definition of food security is the multi-dimensional definition established by the 1996 World Food Summit, that "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (Food and Agriculture Organization of the United Nations, 1996). In 2009, at the World Summit on Food Security, the definition was modified to include a social dimension, to "physical, social and economic access", and was clarified to state that "The four pillars of food security are availability, access, utilization and stability." This definition traces the historical concern for the total quantity of food produced (availability), its distribution to households (access) and intake by individuals (utilization) as well as stability over time (resilience to shocks). The concept of nutrition security adds that, for an active and healthy life, food security must be complemented by adequate water and sanitation, care practices and health services that influence how nutrients are utilized within the body. A state of food and nutrition security thus occurs when the definition of food security is met and supported by a sanitary environment in which people have adequate access to healthcare (Pangaribowo, Gerber, & Torero, 2013).

Nutrition-specific interventions: Interventions aimed at addressing the proximal causes of malnutrition, including inadequate diet and care practices, as well as infectious disease, are considered nutrition specific. Usually such interventions include food or micronutrient fortification, supplementation, promotion of infant and young child feeding, and disease prevention (Ruel & Alderman, 2013b).

Nutrition-sensitive interventions: Nutrition-sensitive interventions are those that address the underlying determinants of nutritional status including food security, caregiving, access to health services, and a safe, hygienic environment. This could include interventions in agriculture, food security, social protection, education and early child development, women's empowerment, water, hygiene and sanitation, among others (Ruel & Alderman, 2013b).

Resilience: The USAID definition of resilience is "the ability of people, households, communities, countries, and systems to mitigate, adapt to, and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth" (USAID, 2012). For the purposes of this review, we narrow down this fairly broad definition to the definition proposed by the Food and Agriculture Organization (FAO), i.e. the ability of people and places to "protect, restore, and improve food and agricultural systems under threats that impact food and nutrition security, agriculture, and/or food safety/public health" (FAO, 2014).

1.3 Structure of this report

The relationship between food systems and nutritional outcomes is a function of the complex overlap between each part of the food system, which influence each other through various intertwined pathways. This document is organized to span the entire food system from production to consumption, with the understanding that the steps along the way are each connected with multiple other steps in a non-linear manner. The objectives and methods of this

review are explained in sections 2 and 3 respectively. Results begin with sections 4 and 5 on food production, followed by sections 6, 7 and 8 on post-harvest aspects of the food system, sections 9 and 10 on cross-cutting concerns that span both production and post-harvest activities, and conclusions in section 11.

Our material on agricultural commodity production starts with section 4 on crop and livestock systems that produce nutrient-dense foods, including farmers' access to markets, followed by section 5 on how those markets link agriculture to nutrition through commodity trade and storage. The agricultural interventions that drive supply, and that are reviewed in section 4, include promotion of improved crop and livestock production methods, homestead gardens and market access, all of which are aimed at improving a target household's diet quality, individual anthropometry or biomarkers. We then zoom out to agricultural interventions, policies and programs in section 5 that impact how much of what foods are produced and marketed anywhere in a given region, and how those systemic changes affect the entire distribution of nutritional outcomes in the population of interest.

Detailed analysis of how food systems link production to consumption after harvest begins with section 6 on the transformation of agricultural output into food products, and how this influences nutrition. Section 7 investigates food safety during each step of the food system, and section 8 does the same with food loss. In Section 9, we broach several cross-cutting issues, such as gender, sustainability and resilience, that cannot be housed at any one particular step in the food system, rather have important implications throughout. Section 10 discusses appropriate measurement and indicators for food systems research. In each sub-section, evidence is presented, and research gaps identified to inform future research opportunities in food systems-nutrition linkages. Finally, section 11 pulls together the common emerging themes identified from the research opportunities at each step.

2. USAID strategies and aims of this report

USAID has long been at the forefront of global agriculture, nutrition, and health, driving improved development outcomes over time. The agency responded to the food price crisis of 2008 with a new approach to agriculture and nutrition, including the Multi-Sectoral Nutrition Strategy 2014-2025 (USAID, 2014) and the Global Food Security Strategy (GFSS) (United States Agency for International Development, 2016) that emphasizes the importance of both nutrition-specific and nutrition-sensitive interventions. Under the GFSS, a whole-of-government Feed the Future initiative was created, which originated from the L'Aquila Global Food Security Initiative declaration in 2009 ("L'Aquila Joint Statement on Global Food Security: L'Aquila Food Security Initiative," 2009). The initiative was subsequently mandated by Congress under the Global Food Security Act of 2016 and involves multiple agencies coordinated by the USAID Bureau for Food Security (Feed the Future, 2019).

The GFSS, whose specific objectives are shown in Figure 3, is supported by a research strategy (Feed the Future, 2017) to develop more cost-effective approaches towards achieving agriculture, food and nutrition goals in the context of food systems illustrated in Figure 2. USAID investments in research include a set of Feed the Future Innovation Labs around the globe, led by universities in the United States, as shown in Figure 4, generating solutions to the

world's challenges in agriculture, food security, nutrition and health (Feed the Future, 2019). Among these, the Feed the Future Innovation Lab for Nutrition works specifically on issues related to agriculture to nutrition linkages, pursuing the three strategic objectives for USAID in agriculture and food systems for nutrition: 1) Inclusive and sustainable agriculture-led economic growth; 2) Strengthened resilience among people and systems; 3) A well-nourished population, especially among women and children (United States Agency for International Development, 2016).

The aims of this evidence review, commissioned by USAID, are to synthesize research findings in agriculture, food systems and nutrition, and to highlight evidence and knowledge gaps to drive future research on how food systems can be made sustainable and provide safe and nutritious food. In doing so, programming can be improved so as to meet U.S. government objectives and the global Sustainable Development Goals (Division for Sustainable Development Goals, n.d.).

3. Methods and sources

The evidence reviewed in this report begins with the findings of systematic reviews reporting on impacts of the post-2008 surge of investment by the U.S. and other governments in agriculture for nutrition and health, merging those results with the broader literature on food systems, prices and markets. Evidence is presented and research gaps identified from studies addressing nutrition and food security along each step of the food system, including agricultural production, productivity, production diversity, value chains, food environment, trade, market access and food prices, processing, food safety and food waste. The intent of this review is not to be exhaustive, rather to synthesize important recent findings in food systems-nutrition linkages and identify opportunities for future research based on apparent research gaps.

Given the existence of numerous systematic reviews on subjects concerning food systems-nutrition linkages, search terms were first used to identify appropriate systematic reviews published in the last five years (2014-2019). A second round of searches were then conducted with more refined terminology to search for literature related to the specific sectors associated with food systems nutrition linkages. English language searches were conducted in PubMed, Web of Science, and Google Scholar, between June-August 2019. Terms used in the first round included: food systems + nutrition, global food systems, sustainable food systems. Second round terms included: resilience + food systems, food environment, agriculture + nutrition, food production + nutrition, sustainable diets, nutrition sensitive agriculture, women's empowerment + agriculture, market access, food systems + price, food systems + processing, fortification, food safety, environmental enteric dysfunction, mycotoxins, water + sanitation + hygiene + nutrition, and food waste. In addition to these searches for academic literature, reports from USAID, FAO, and similar organizations with a global focus on nutrition and agriculture were researched and referenced. After all searches, a total of 532 appropriate documents were identified based on titles. The abstracts of each document were read, and ultimately, about 167 documents that added to the discussion of existing evidence and research gaps in food systems-nutrition linkages were read fully and reported on in the evidence review.

4. Agricultural production of nutrient-rich foods

Since the world food crisis of 2008, most research about agriculture-nutrition linkages focused on how a household's own farm activities affect its own nutrition outcomes, and how a specific commodity is altered along its value chain (Sparling et al., 2019). To situate that research in a broader context, this review begins with farm production of foods in general, as different value chains interact to meet nutritional needs within overall environmental and societal constraints.

4.1 Crops

How do crop genetics, biotechnologies, and agronomic management influence nutritional status?

Almost all of the world's potentially cropped land is already under cultivation, with further expansion into the remaining 2.7 billion ha of potentially arable land limited by harsh conditions and poor infrastructure, leading to a focus on increasingly efficient use of areas that are already being planted (Tyczewska et al., 2018). Current cropping patterns do not supply sufficient micronutrients to meet growing human and livestock needs (Allen & de Brauw, 2018), thus investments are aimed at increasing productivity to reduce the area needed for starchy staples and shift resources towards production of more diverse foods as well as towards increasing micronutrient levels in staple crops through biofortification using both traditional breeding and genetic modification (Osendarp et al., 2018).

The history of agricultural intensification is an important consideration for the future of crop genetics and biotechnology. The Green Revolution efforts starting in the 1950s, 1960s and 1970s focused primarily on increasing yields of starchy staples; this was an urgent priority at the time, when preventing mass starvation in Asia was a primary geopolitical concern for the U.S. government (Ickowitz, Powell, Rowland, Jones, & Sunderland, 2019). The successful introduction and spread of Green Revolution technologies has led to widespread poverty reduction and child survival (Gollin, Hansen, & Wingender, 2018). Since then, the focus of research has shifted to dietary diversity and nutrition, to address micronutrient deficiencies and the threat of rising overweight and obesity (Gillespie et al., 2019). The Green Revolution also focused on raising production in places with sufficient moisture and adequate infrastructure to produce surpluses and achieve lower, more stable prices in global and national markets; the focus of genetic improvement now includes innovations for more fragile, vulnerable regions under extreme climatic stress and resource scarcity, to help them achieve not only greater dietary diversity but also greater resilience and sustainability over time (Feed the Future, 2017).

For a few major species such as corn (maize), soybeans, canola (rapeseed) and cotton, genetic engineering has introduced traits from other species leading to the development of GMO (genetically modified organism) crops, which are a focus of intense debate in the agricultural development community including both government and non-government stakeholders. An estimated $167.8 billion in economic benefits resulted from increases in yield from the above mentioned crops, production gains, and cost savings from the use of GMO crops between 1996-2015 (Tyczewska et al., 2018). In addition, many non-GMO and/or non-transgenic innovations have drawn on global biodiversity to improve crop genetics and agronomic management for both direct human consumption and as feed to produce animal-source foods.

Biofortification of starchy staples, which can be achieved either through genetic engineering or traditional plant breeding, is a cost-effective technology to address specific micronutrient deficiencies, as long as the biofortified products are utilized and consumed by the intended population (Bouis & Saltzman, 2017). Evidence from trials in the past five years point to positive effects of biofortified crops such as orange flesh sweet potato and iron rich beans on micronutrient status, especially vitamin A, iron, and zinc, among children but mixed effects in women (Bouis & Saltzman, 2017; Harvey et al., 2014; Ruel et al., 2018; Yadava, Hossain, & Mohapatra, 2018). Effects on child growth are less proven, with only moderate evidence to suggest any effect (Harvey et al., 2014). Additional research on the combined effectiveness of consumption of multiple biofortified crops together on different health outcomes would add to this body of evidence (Bouis & Saltzman, 2017).

Identifying drivers of farmer uptake and consumer acceptability is key to determining how to impact nutritional outcomes to the greatest extent possible. Gaining a better understanding of the impact pathway leading from the technology of biofortification to consumption of biofortified crops and ultimately improved micronutrient status is an important part of this process. This impact pathway has been studied to maximize the effectiveness of biofortification in reducing micronutrient deficiencies for several biofortified crops. An evidence review focusing on HarvestPlus activities identified three main areas along the impact pathway: 1) public-private sector partnerships to provide planting materials to farmers and produce seeds of high quality, 2) conducting field demonstration trials and providing small promotional biofortified seed packs so that farmers can learn about biofortified crops with little risk involved, and 3) nutrition messaging to ensure that the crops are incorporated into people's diets (Bouis & Saltzman, 2017). In a recent study examining the impact pathway from planting of biofortified orange-fleshed sweet potatoes to vitamin A intake, adoption behavior was only minimally impacted by increased nutrition knowledge, and nutrition knowledge subsequently had little effect on vitamin A intake (de Brauw et al., 2018). This suggests either an ease of acceptance of the orange fleshed sweet potatoes due to their similarity to already cultivated white sweet potatoes or the need for identifying alternative ways to influence demand for biofortified products, or both.

Although GMO crops, biofortification, and other technologies have been shown to be cost-effective and safe, public perception and adoption remains a major challenge that could prevent the widespread use of these techniques. Concrete evidence on the diffusion level of new agricultural technologies or improved crop varieties is lacking and needs bolstering. However, there is sufficient evidence about farmer adoption, which indicates that despite input subsidies, many farmers do not adopt yield-enhancing technologies (Macours, 2019). Further studies that investigate the reasons for low-uptake and determine what farmers and consumers desire from new technologies will be useful for increasing adoption of new beneficial techniques. A review on the acceptability of the sensory qualities (color, taste, smell) of modified crops finds that while acceptability can be context specific, overall, the different colors of modified crops do not act as a barrier of acceptability (Talsma, Melse-Boonstra, & Brouwer, 2017). While ongoing work provides a variety of potential approaches for integrating nutrition into agronomic research, suggesting that researchers and programmers consider the specific climatic conditions, fertilizer levels and soil types when training farmers about new agronomic

techniques to increase uptake, (Zuma, Kolanisi, & Modi, 2018) further research to determine the best messaging and education campaigns for acceptance of GMO and biofortified crops could be useful in increasing demand and utilization of these technologies.

Household assets and livelihoods are basic drivers of food production and agricultural income. As such, land ownership and use, including land productivity inputs, are hypothesized to be an important determinant of the impact of household agricultural production on nutritional status (Herforth & Harris, 2014; High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017). However, a 2019 review by Shankar, Poole, & Bird (as part of the Leveraging Agriculture for Nutrition in South Asia- LANSA project) identified 14 studies on production and productivity focusing on South Asia (India, Bangladesh, Nepal) that had little evidence on the effectiveness of land ownership and land productivity enhancing inputs (e.g. use of improved seed, fertilizer, irrigation) on nutritional status. Once wealth is controlled for, neither land ownership nor land size are correlated with dietary diversity or nutritional outcomes (Shankar, Poole, & Bird, 2019). Research from Sub-Saharan Africa on land productivity inputs, in this case irrigation, finds similar results. A two-country study conducted in Ethiopia and Tanzania on small-scale irrigation and diet diversity found that while, in Ethiopia, irrigation was associated with improved diet diversity in households through the income pathway, whereby irrigation leads to higher household income which allows for the purchase of more diverse foods, no such relationship was found in Tanzania. This is potentially due to differences in the type of irrigation technologies used. No association between production diversity and diet diversity were found in either country (Passarelli, Mekonnen, Bryan, & Ringler, 2018). Authors of the LANSA review further note that while researchers have examined associations, they have not explored causal linkages between land ownership and use and nutritional outcomes, nor have the pathways through which relationships may exist been explored.

Overall, technologies such as biofortification, GMOs, and improved land productivity inputs show great potential for having a positive influence on nutritional status, but several areas of future research could help increase their uptake and maximize their effectiveness.

Research opportunities in agricultural production

1. Research on the effectiveness of consuming multiple biofortified crops simultaneously on health and nutrition outcomes, including functional outcomes (Bouis & Saltzman, 2017).
2. Ways to increase consumer demand for and farmer uptake of biofortified products and other GMOs (de Brauw et al., 2018).
3. Quantification of the diffusion level of new agricultural techniques or improved crop varieties (Macours, 2019).
4. Establishing causal linkages and investigating impact pathways between use of land productivity inputs (e.g. improved seed, fertilizer and irrigation) and food security, diet and nutrition outcomes (Shankar et al., 2019).

4.2 Livestock

How do livestock interventions influence nutritional status?

Animal sourced foods are important for growth and development in infants and children, as they contain bioavailable forms of micronutrients (iron, vitamin A, zinc, iodine, vitamin B12) essential to growth that are difficult to find in plant sources (Dror & Allen, 2011). Recent examples of interventions aimed at increasing animal sourced food consumption to impact growth support this idea. An intervention focused on providing an egg a day in Ecuador to infants aged 6-9 months found significant reduction in prevalence of stunting and underweight in the treatment group children compared to the controls (Iannotti et al., 2017). Studies conducted in the former Nutrition Collaborative Research Support Program have shown a strong positive effect of providing milk on growth in younger stunted children and meat on cognitive function of all school children in Kenya (Neumann, Murphy, Gewa, Grillenberger, & Bwibo, 2007). A 2011 review found consumption of red meat reduced iron-deficiency anemia, and that milk supplementation improved linear growth through the provision of higher levels of energy, high-quality protein, minerals, and stimulating growth factors (insulin-like growth factor-I) (Dror & Allen, 2011). However, a recent systematic review investigating the relation between consumption of animal source foods and stunting found only one intervention study (out of 21) with a reduction in stunting and one cross sectional study with an association between animal source foods and stunting. Authors of this systematic review found that aggregation of data from studies around animal sourced foods and growth was difficult due to significant heterogeneity in the intervention studies. They therefore recommend future research be planned in a manner that allows for consistency in the definition and quantification of the exposure and outcomes thereby allowing for interstudy comparisons (Shapiro et al., 2019).

The relationship between livestock ownership and human health and welfare involves both positive and negative effects. Livestock contribute to the livelihoods of over 300 million people in Sub Saharan Africa, representing 2/3^{rds} of the rural poor and 1/3rd of the urban poor (Thumbi et al., 2015). Several systematic reviews have been published on the role of livestock ownership to improve access to animal source foods and thus improve growth outcomes, specifically height and linear growth, and micronutrient deficiencies. Within the context of linking livestock production, ownership, and diversity to nutrition outcomes, the Shankar, Poole and Bird 2019 review found studies wherein ownership of milk producing animals was associated with improved linear growth possibly through both increased consumption of milk in the household and increased income leading to better diets through markets. Further work in Afghanistan using existing data showed an association of meat intake with reduced prevalence of anemia (Shankar et al., 2019). Ruel et al. 2018 reviewing recent livestock ownership intervention trials found mixed results around livestock keeping. Livestock ownership has been shown to increase household diet diversity, intake of essential micronutrients, and specifically more animal sourced food intake, especially among households that live in remote areas with poor market access (Ruel et al., 2018). However, they report that evidence of associations with health and nutritional status, including linear growth, is limited (Ruel et al., 2018).

Possible negative effects of livestock on health and growth outcomes have been addressed through two different pathways: fecal-oral transmission leading to repeated diarrheal disease in

people, and zoonotic transmission of other diseases from animals to humans. Globally, work within the context of the "One Health" platform is examining these pathways including the interactions of human health, livestock health and economic welfare, especially in those communities that are reliant on livestock. The zoonotic transmission pathway increases the risk of malaria, rabies, trypanosomiasis, and foodborne diseases such as brucellosis, which are associated with negative effects on nutrition and health. The fecal-oral transmission pathway involves exposure to animal feces from habitation in close proximity to livestock which translates into poor growth outcomes due to increased prevalence of gastrointestinal infections (Chaccour et al., 2018; Hasyim et al., 2018; Headey et al., 2017; Imbahale et al., n.d.; Mosites et al., 2016; Thumbi et al., 2015). This pathway, with repeated exposure to animal feces combined with poor hygiene and sanitation practices at the individual, household and community levels, may be related to a condition called environmental enteric dysfunction (EED). EED is a condition whereby individuals (adults and children) are consistently in a state of inflammation, independent of their diarrhea status, which leads to increased permeability of the small intestinal walls, increased risk of microbial translocation and subsequent inflammation, and poor absorption of nutrients (Keusch et al., 2014). The relationship of animal-human disease can be further illustrated by a research study examining the relationship of livestock ownership and livestock disease episodes (diarrheal disease in the livestock themselves) and growth in children in Western Kenya. The authors found that livestock ownership was not associated with height or growth rate of the child but that households with livestock suffered from digestive diseases during a certain period of the year (June-November) and were more likely to have children with lower height gain (Mosites et al., 2016). Interventions targeting these issues are emerging areas of research; while there is some evidence of the negative effects on nutrition and health, further study is required.

Different types of livestock, from large and small ruminants to poultry and other animals, play different roles in the food system and have different effects on human nutrition. At least one large review points to milk-producing animals as the most important for stimulating growth in children, but we did not find any studies comparing types of livestock in terms of negative effects. The studies we found aggregated fecal matter from all animals into one variable, although people may live in closer proximity to poultry and smaller animals that can be kept within a household's compound. This is an area that requires further research, as animal-human health connections may differ by type of livestock. In addition, livestock studies have focused on linear growth and stunting as the primary outcomes. While recent studies have looked at dairy and cognition in children and found positive effects on cognitive function after supplementation with milk powder (Lee et al., 2018), future livestock ownership studies should include outcomes beyond anthropometry as well.

Numerous innovations in the last few years have targeted livestock genetics, feed, and veterinary care as pathways for improved nutrition. These include rapid and cost-effective disease detection techniques that can curtail the spread of infectious diseases among animal populations. For example, veterinary medicines and vaccines can use nanotechnologies that reduce pathogen contamination, increasing production efficiency and helping to combat pathogen resistance that can be transferred to humans. Nano-feed additives could improve feed efficiency, reduce feed costs, and increase yield and quality of animal products, and nano-biosensors could be used to detect toxin-producing insects or fungi that contaminate bulk grain

storage silos (El Sabry, McMillin, & Sabliov, 2018). These are mainly newly developed technologies that will require field testing and risk assessment to ensure safety and cost-effectiveness before being put to use.

Research opportunities in livestock ownership

1. In-depth study of the negative effects of livestock ownership on nutrition and health, including animal-health connections disaggregated by type of livestock and evaluation of outcomes beyond anthropometry.
2. Field testing, risk-assessment and cost-effectiveness analysis of newly developed nanotechnologies that may improve feed efficiency, increase yield and quality of animal products, and aid in detecting contaminants in bulk grains.

4.3 Market access

What evidence is there to support market access by the farm household as an intervening variable between agricultural production and consumption?

Increased income has enabled people to acquire more of everything, including more and different foods. People's dietary preferences, market food availability, and dietary intake studies are important not just at the national level, but also at the household and individual level, in order to better understand how the food environment is influencing consumption (Finaret & Masters, 2019; Micha, Coates, Leclercq, Charrondiere, & Mozaffarian, 2018). Agricultural diversification can contribute to improved dietary diversity through consumption, but the role of income and market access are important considerations. A recent review focusing on the dietary and nutritional benefits of production diversification examined the role of markets in explaining (or not) this relationship and found only six studies that included market access as an intervening variable between production diversity and diet quality. All of these studies found that market access was positively associated with diet diversity (Jones, 2017). Further, investments in agricultural diversification are likely to be most effective if they target the poorest households that are least connected to markets (Mulmi et al., 2017; Ruel et al., 2018).

Market access does not necessarily lead to increases in agricultural productivity or diversity of crops produced (Rios, Shively, & Masters, 2009) but may provide opportunities outside of agriculture for stimulating cash income and encourages diet diversity through increased purchasing power for nutritious foods available in markets. Even among populations where subsistence farming is widespread, purchased foods make up a large portion of total energy (in kcal) consumed; one study in Ethiopia found that purchased food accounts for over half of all calories consumed during the lean season, and 42% on average throughout all seasons (Sibhatu & Qaim, 2017). As such, promoting too much farm diversification where markets are accessible could actually decrease time for these opportunities and have negative side effects if farmers cannot purchase as many foods from the market (Sibhatu & Qaim, 2017).

Thus, while research on markets in LMICs is limited, existing evidence highlights the importance of market access within the context of production diversification (crops and livestock), homestead food production and/or livestock programs, and nutritional outcomes (Mulmi et al.,

2017; Ruel et al., 2018). Households with limited market access rely more heavily on their own production, and production diversification efforts are more impactful on dietary intake in these areas, but additional research is needed to clarify these relationships. Lastly, market access is assessed using proxy variables for how close people are to markets or travel time to markets, but these measures do not consider that market access is not just proximity, nor is it restricted to use of markets for consumption. Efforts should be made to better measure all aspects of market participation, including participation as both a consumer and a producer, and access to different types of markets (agricultural input, agricultural output, consumer oriented, etc.) (Jones, 2017).

Research opportunities in market access

1. Collect better data on market access, expanding indicators to measure actual market proximity and not solely distance to markets (Jones, 2017).
2. Conduct studies that examine how access to various types of markets (agricultural input, agricultural output, consumer oriented) intervenes differently between agricultural production and diet and nutritional outcomes (Jones, 2017).

4.4 Homestead food production and nutrition sensitive agriculture

Do homestead food production programs aimed at increasing household production of diverse foods impact nutritional status?

Interventions targeting homestead food production by providing training (gardening and agricultural techniques) and inputs (irrigation, fertilizer, seeds, etc.) have shown positive impacts on intermediate outcomes like diet diversity, animal ownership, and women's empowerment, but findings are weak in terms of impacts on anthropometric nutritional outcomes (Bird et al., 2019; Gillespie et al., 2019; Kennedy, Kershaw, & Coates, 2018; Ruel et al., 2018).

Overall, major reviews of homestead food production and nutrition-sensitive agriculture in the last few years have shown that the most common nutritional success has been reductions in anemia, and in some cases, decreased incidence of diarrhea and wasting in children and women, and that no impact seems to have been made on anthropometric outcomes such as stunting (Gillespie et al., 2019; Ruel et al., 2018). Selection of appropriate outcomes and ensuring that program theory is based on a sound theoretical basis thus requires careful review and consideration as outlined in recent reviews (Frongillo, Leroy, & Lapping, 2019; Leroy & Frongillo, 2019). Further research of exploring alternative metrics (outlined further in the metrics section) is critically needed.

Environmental and economic sustainability of homestead food production and nutrition sensitive agricultural interventions, as well as their cost-effectiveness compared to other nutritional interventions also remain unknown. A meta-analysis of the associations between production diversity, diets and nutrition among smallholder farmers found that, on average, farmers would have to add 16 additional crops to their production to increase diet diversity by just one food group (Sibhatu & Qaim, 2018). This constitutes a significant change, and it is unclear whether or not farmers are capable of adding that many additional crops, or if they can

continue to purchase agricultural inputs post-intervention, and retain their knowledge learned through the education components of the programs. Further research is needed into the maintenance costs, long-term sustainability, and comparative cost-effectiveness of these interventions (Gillespie et al., 2019).

Thus, homestead food production and nutrition-sensitive agricultural interventions have been relatively successful at increasing diet diversity and animal ownership, which in turn have led to decreased micronutrient deficiencies (Ruel et al., 2018). The evidence to date indicates that household-level agricultural production interventions, if integrated with market interventions, women's empowerment, behavior change communication, food safety and environmental concerns, may prove more effective in achieving nutrition wellbeing with the caveat of ensuring the selection of appropriate indicators of success.

Research opportunities in homestead food production and nutrition sensitive agriculture

1. Study the scale up of nutrition sensitive agriculture programs including assessments of sustainability (i.e. post exit, can farmers continue to purchase agricultural inputs, retain knowledge and continue implementing practices/activities?) and cost-effectiveness compared to other nutrition interventions (Gillespie et al., 2019)
2. Support research that focuses on theory driven program design, program fidelity and coverage of the intervention, understanding or elucidating in an empirical manner, the potential for specific program inputs to translate into selected outcomes
3. Determine the effectiveness of integrating homestead food production and nutrition sensitive agricultural interventions into a broader food systems approach.

<u>4.5 Summary of research opportunities</u>

1. Research on the effectiveness of consuming multiple biofortified crops simultaneously on health and nutrition outcomes, including functional outcomes (Bouis & Saltzman, 2017).
2. Ways to increase consumer demand for and farmer uptake of biofortified products and other GMOs (de Brauw et al., 2018).
3. Quantification of the diffusion level of new agricultural techniques or improved crop varieties (Macours, 2019).
4. Establishing causal linkages and investigating impact pathways between use of land productivity inputs (e.g. improved seed, fertilizer and small-scale irrigation) and food security, diet and nutrition outcomes (Passarelli et al. 2018; Shankar et al., 2019).
5. In-depth study of the negative effects of livestock ownership on nutrition and health, including animal-health connections disaggregated by type of livestock and evaluation of outcomes beyond anthropometry.
6. Field testing, risk-assessment and cost-effectiveness analysis of newly developed nanotechnologies that may improve feed efficiency, increase yield and quality of animal products, and aid in detecting contaminants in bulk grains.
7. Collect better data on market access, expanding indicators to measure actual market proximity and not solely proximity to markets (Jones, 2017).

8. Conduct studies that examine how access to various types of markets (agricultural input, agricultural output, consumer oriented) intervenes differently between agricultural production and diet and nutritional outcomes (Jones, 2017).
9. Study the scale up of nutrition sensitive agriculture programs including assessments of sustainability (i.e. post exit, can farmers continue to purchase agricultural inputs, retain knowledge and continue implementing practices/activities?) and cost-effectiveness compared to other nutrition interventions (Gillespie et al., 2019)
10. Support research that focuses on theory driven program design, program fidelity and coverage of the intervention, understanding or elucidating in an empirical manner, the potential for specific program inputs to translate into selected outcomes
11. Determine the effectiveness of integrating homestead food production and nutrition sensitive agricultural interventions into a broader food systems approach.

5. Agriculture-nutrition linkages at population scale

In this section, we take a broader view, going from how a household's own agricultural production influences nutritional status, to how population-level agricultural programs, policies, and infrastructure are related to the food environment. The focus areas include the foods available to consumers, the nutrient quality of these foods, the affordability of those foods, and the information people receive about food. The food environment is central to consumers making healthy and sustainable food choices, and the evolving food environment of today is changing how people interact with food, including the decisions they make about what to eat and how they prepare it (Finaret & Masters, 2019; High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017).

5.1 Trade, markets, and food prices

What does the evidence tell us about how trade policies, market function, and food prices impact food availability, and ultimately nutritional status?

Trade policies, market function, and food prices are heavily intertwined, and act together to influence the food environment. The consensus from agricultural economics research is that open agricultural trade is generally beneficial for food and nutrition security, but that any policy change creates both winners and losers. The "food price dilemma" is that opening trade to more imports of a particular food lowers its price, which helps consumers, but harms the farmers who produce it, while opening trade to more exports of another food raises its price, which helps the farmers who produce that product while harming its consumers (Martin & Laborde, 2018; Wood, Smith, Fanzo, Remans, & Defries, 2018). Opening trade can also have many other effects, either increasing or decreasing energy used and greenhouse gas emissions, as well as other environmental effects (Martin & Laborde, 2018). Critics of free or open trade also blame global increases in obesity and chronic disease partially on the accessibility of cheap, non-nutritious packaged and processed foods made possible through globalization, foreign direct investment, and trade (Martin, 2018). Overall, more open trade tends to stabilize prices and raise living standards including global food and nutrition security, allowing environment problems or health concerns to be addressed directly with policies that incentivize limiting greenhouse gas emissions, that provide public goods to poor consumers to offset higher prices

for exported products, and that discourage the purchase and consumption of foods identified as unhealthy (Martin, 2018; Martin & Laborde, 2018).

Available arable land differs vastly by region, with some regions able to meet their populations' food and nutrient demands more easily than others. While each location could potentially produce its own food, international trade both reduces and stabilizes prices at each place by reducing dependence on local climatic fluctuations and other shocks (Martin & Laborde, 2018). Trade can also be helpful for equity, to give more people access to low-cost items produced at times and places when resources are abundant. The total amount of food available for consumption on earth, after accounting for losses and alternative uses, is sufficient to meet the nutrient demands of the population as long as it is distributed equitably (Wood et al., 2018). Especially in lower income countries, global trade contributes to a country's ability to meet their nutrient needs, diversifying the food products available year-round, and increasing the amount of people who meet their nutrient needs by between 146-934 million people (Wood et al., 2018). In addition, trade leads to increased income at the country level by encouraging regional production of those goods that a country is better at producing versus goods that they are not (comparative advantage). This also lowers the average costs of food worldwide (Martin & Laborde, 2018). When production risk is spread over a larger area, global food supply and prices become more stable, as domestic shocks are absorbed by the global market (Martin, 2017). Thus, policies that allow for international trade increase food and nutrition security through a number of mechanisms, allowing for diversification of the food supply, increased income, and food price stabilization.

Evidence on the impact of trade on nutritional outcomes such as anthropometry is limited (FAO, 2015). Untangling the effects of trade policies from other policies, programs, or unobservable factors is challenging, but one recent study was able to link agricultural trade policy data to child anthropometry. They found a small significant positive effect of government assistance to tradeable agriculture (used as a proxy for level of trade liberalization) on child anthropometry (Adjaye-Gbewonyo, Vollmer, Avendano, & Harttgen, 2019).

Trade is directly connected to markets – traded products are bought and sold on the market, thus markets and how well they function are important for diet quality. Purchased foods play a larger role in diet diversity than subsistence production (Sibhatu & Qaim, 2017), but their role in diet quality is dependent on the market system and how well it functions (Ickowitz et al., 2019). Evidence is sparse in the market system-diet quality arena, but we know that failure to consider market inefficiencies and high transaction costs in some regions make market-reliant interventions such as agricultural diversification counterproductive for improving diets (Allen & de Brauw, 2018; Sibhatu & Qaim, 2017). These inefficiencies due to poor roads and infrastructure, weak institutions, suboptimal transaction and transportation networks, and other market and government failures can also lead to high seasonal price fluctuations. Compared to foods that are more easily stored and transported, such as staple grains and legumes, highly nutritious yet perishable foods such as fruits and vegetables are subject to intense price increases as they get transferred along the food value chain into markets from producers to consumers (Allen & de Brauw, 2018). As little investment has been made in either public or private sector market infrastructure improvements, we find virtually no evidence on how market infrastructure interventions have impacted food prices, safety and quality, nor

nutritional status (Pingali, 2015). In addition, we find no pertinent studies on the role of intermediaries between producers and consumers on nutritional outcomes. We need a more nuanced understanding of how local markets function, how the food redistribution systems work, and what types of infrastructural changes are necessary to strengthen rural markets and shape food preferences in a healthy manner (Ickowitz et al., 2019).

While the evidence around the benefits of open trade for food and nutrition security and its impact on food prices is fairly clear, the direct impact of trade policies on nutritional status are less well-established. In addition, there is a clear theoretical link between market function and diets and nutrition; however, concrete evidence showing how improvements in market infrastructure influence nutritional status is lacking. Understanding how market inefficiencies and high seasonal price fluctuations that happen through poor infrastructure, weak institutions, and other market failures, is necessary to increase effectiveness of market-based interventions (Sibhatu & Qaim, 2017).

Research opportunities in trade, markets, and food prices for nutrition

1. Estimation of the effects of trade policies on nutritional outcomes (Adjaye-Gbewonyo et al., 2019).
2. Studies of how market infrastructure interventions have impacted food prices, safety and quality of foods, and nutritional status (Allen & de Brauw, 2018; Pingali, 2015).
3. Research on the role of intermediaries between producers and consumers on nutrition outcomes.
4. Understanding of how local markets currently function, how the food redistribution system works, and the types of infrastructural changes necessary to strengthen rural markets (Ickowitz et al., 2019).

5.2 Specialization, productivity and risk management

What evidence is there about different ways of reducing constraints on producing a variety of nutritious foods?

Healthy diets require year-round access to a diversity of foods in stable quantities at each location, while agricultural production conditions vary greatly over time and space. Location-specific agroecological resources such as water and soils, interacting with climatic conditions and access to infrastructure, knowledge, and locally-adapted seed varieties or livestock breeds have led to a high degree of geographic specialization, while both storage and trade help smooth outcomes over time to shape what is available to consumers. Producing a wider variety of more nutrient dense foods at each location can be risky for smallholder farmers who may be poorly connected to markets, often do not have access to information about market prices and climate predictions, and lack access to capital or credit to finance inputs. As previously discussed, farmers thus tend to produce and market cereals and starchy staples, because these products have low transaction and transport costs and are less risky, so more nutritious foods such as fruits, vegetables, pulses, and animal sourced foods have been largely neglected (Allen & de Brauw, 2018; Sibhatu & Qaim, 2017).

Even with improvements to infrastructure and advancements in production and storage technologies, legal or social constraints, and imperfect access to information can limit producers from accessing markets or making strategic production and marketing decisions. Poor connectivity between rural, peri-urban, and urban supply and demand can limit production of and thus consumer access to a diverse set of nutritious foods. A study conducted in Kenya identified access to market price information and warnings, as well as to services such as contract farming as successful mechanisms for encouraging smallholder farmers to produce a variety of nutrient dense crops (Ngenoh, Kurgat, Bett, Kebede, & Bokelmann, 2019). Further research into market information systems that can provide accurate information to farmers, and the use of producer organizations or contract farming to reduce risks and increase access to information could prove important in encouraging production of nutritious foods and improved nutritional status (Allen & de Brauw, 2018). Weather-based insurance has also been studied as a mechanism for risk reduction, however, smallholder farmers have been shown to be reluctant to purchase such insurance without subsidies, and before governments use limited funds for insurance subsidies, more research on returns on investment are warranted to ensure that insurance policies would actually encourage uptake of new technologies and diversified production (V. H. Smith, 2016).

There are a variety of evidence-based options for reducing constraints on production of a variety of nutrient dense foods; however, more research is needed to better understand how best to address risk management for farmers and encourage production.

Research opportunities in production and supply

1. Establish how investment in market information systems could help bridge the information gap that prevents farmers from making strategic marketing and production decisions (Allen & de Brauw, 2018; Ngenoh et al., 2019).
2. Understand returns on investment from subsidizing crop insurance to smallholder farmers (V. H. Smith, 2016).
3. Better understand the pros and cons of contract farming and other similar services in risk mitigation to encourage production (Allen & de Brauw, 2018).

5.3 Consumption preferences and food demand

What evidence is there about different levers that can shape consumer demand for nutritious foods?

Equally as important as the availability of nutritious foods are consumer choices about what they consume. The food environment is instrumental in shaping demand for nutritious foods through the influence of many factors; prices, consumer income, information, beliefs, habits, culture, demographic status (age, education), food preparation time and convenience, storage capacity (refrigeration), and of course taste (Finaret & Masters, 2019). These factors may lead consumers to make food choices that are contrary to their own health and nutritional status. Policies and programs should consider how supporting the modification of any or all of the factors might encourage consumer behavior change towards healthier choices (Global Panel on Agriculture and Food Systems for Nutrition, 2017).

Two of the most powerful influencers of demand for nutritious foods are price and consumer income, though the food environment can also modify the effect of income on dietary choices (Herforth & Ahmed, 2015). Since the food price crises of 2008 and 2011, food prices and their influence on food affordability have become the focus of much international attention, and price volatility is only expected to increase in the future as climate change and food production becomes more volatile (Finaret & Masters, 2019). Already, insufficient supply of nutrient-dense foods due to producer constraints, combined with high post-harvest transaction costs, induce high prices that put consumers under constraints for what they can afford to purchase (Global Panel on Agriculture and Food Systems for Nutrition, 2017). Under a limited budget, consumers may be constrained to eating more high calorie dense foods than desired, as these foods tend to have lower prices due to longer shelf lives and lower transaction costs (Allen & de Brauw, 2018; Finaret & Masters, 2019). Research into understanding the cost of nutritious diets through innovative price indices such as the Cost of Nutrient-Adequacy (CoNA) which calculates the lowest-cost diet that includes foods from each of the five categories of the minimum diet diversity for women, is instrumental in determining the degree to which prices constrain healthy diets (Masters, Bai, et al., 2018).

Taxes and subsidies are levers that could be used to allow consumers more purchasing power for healthy foods and discourage the purchase of less nutrient-dense foods; however, taxes may be regressive, and substitution effects are largely unknown (Allen & de Brauw, 2018; Finaret & Masters, 2019). The effects of taxes and subsidies also depend on the income and price elasticities of demand, or the extent to which changes in price and income influence changes in consumption of a good. Multi-country estimates have shown heterogeneity among income, prices, and different types of foods, as well as among different age and sex categories; while elasticities tend to decrease as national income decreases, there are some food categories for which this does not happen in certain age or sex categories. For example, fruit intake increased with rising incomes across all regions and demographic groups globally, although income effects were highest for older women, and lowest for younger men, especially those in higher income countries. Milk intake increased most with rising income in Sub-Saharan Africa. These food categories may represent strong preferences for certain types of foods in certain regions among some population groups and would influence the effectiveness of taxes or subsidies on these goods. Such considerations are important to understand when developing ideas for combatting the effects of rising income on food choices worldwide (Muhammad, D'Souza, Meade, Micha, & Mozaffarian, 2017). Subsidies on healthier foods may be more equitable than taxes on unhealthy foods, as would subsidizing or taxing specific nutrients instead of whole foods. To accomplish this, it would be necessary to estimate specific nutrient elasticities across multiple contexts (Finaret & Masters, 2019).

While it is difficult to find evidence of the effects of taxes and subsidies in LMICs, as few developing countries have implemented such policies, there is promising evidence from high income countries that these policies can be effective in improving dietary behaviors and nutritional status. A systematic review on the effects of healthy food subsidies and unhealthy food taxes on dietary behaviors and nutritional status indicators found that both taxation and subsidy policies were effective ways of increasing consumption of healthy foods and decreasing purchase of foods high in fat, sugar, and salt. Authors caution against the potential effects of these policies on inequality (Niebylski, Redburn, Duhaney, & Campbell, 2015a). One study cited

in the review found that low-income women in France saw fewer benefits from food taxes and subsidies than their higher income counterparts. Relatively few studies had looked at health outcomes, but those that did found that when healthy food uptake was increased, improvements were also seen in body composition and blood pressure indicators (Niebylski, Redburn, Duhaney, & Campbell, 2015a). Authors note that many of the included studies were based on modeling and price elasticity, rather than experiments in the real world, that the interplay between taxes and subsidies and private sector engagement remains unclear, and that the definitions of healthy and unhealthy foods have not been standardized and remain the subject of debate. A later study (post review publication) on sugar-sweetened beverage purchases in Mexico before and after the implementation of an excise tax on sugary drinks, found a 6% decline in purchases of taxed sugar beverages, and a 4% increase in the purchase of untaxed other beverages. This represents a short-term change; more studies are needed on the longer-term effects of tax and subsidy policies (Colchero, Guerrero-López, Molina, & Rivera, 2016).

A more recent modeling exercise by Wilde et al., though limited to the United States, found that a 10% price reduction in fruits and vegetables could prevent 2.6% of cardiometabolic disease related deaths, and that a 10% tax on sugar-sweetened beverages and processed meats could prevent up to 5.9% of cardiometabolic related deaths (Wilde et al., 2018). A similar modeling exercise was conducted to estimate the effects of a 20% tax on sugar-sweetened beverages in South Africa on obesity among adults, and found that obesity could be reduced by 3.8% with the implementation of this tax, which was proposed in 2016 and implemented in 2018 (Manyema et al., 2014; National Treasury, 2016).

Another common method of impacting the price/income pathway is through provision of social safety nets or transfers such as food vouchers or cash (Global Panel on Agriculture and Food Systems for Nutrition, 2017); however, the transfer impact on diet quality may be small due to substitution effects within staple food groups (Finaret & Masters, 2019). Food price spikes have different effects on the dietary patterns of different people, depending on their livelihoods; in general, net producers will gain from rises in food prices, whereas net consumers will suffer. It is thus important to determine how the welfare of different groups is impacted in various political and environmental contexts (Finaret & Masters, 2019).

Access to information is important on the consumer (demand) side as well as the producer (supply) side. Consumer education, advertising campaigns, and labeling can impact nutritional status by providing more information on the nutrient value of a food product allowing consumers to make more informed decisions. More complex behavior change interventions can do more than simply provide information — they can help transform people's ideas about making healthy choices. Marketing campaigns can also be used to promote the purchase and consumption of particular widely available nutritious foods such as milk, local fruits and vegetables (Global Panel on Agriculture and Food Systems for Nutrition, 2017). However, evidence is mixed for the actual effects of these informational interventions[1] in LMICs, especially when it comes to links to overnutrition. While some governments and

[1] The term informational intervention is used to encompass all forms of behavior change communication, individual counseling, advertising and mass media hence the generic term informational.

non-governmental organizations have had success in influencing consumption of nutritious foods through behavior change campaigns and education (Global Panel on Agriculture and Food Systems for Nutrition, 2017), fruits and vegetables remain expensive, and as cheap, processed, and highly palatable foods become more available, consumers need information on what constitutes a healthy food choice. More research is necessary on the best ways to convey information about nutritious foods to populations, which many have not had formal schooling (Allen & de Brauw, 2018).

A potential reason for the mixed results of informational and behavior change campaigns is the time burden of purchasing and preparing nutritious foods. Time costs incurred through food preparation make convenience foods attractive; even if healthy foods are available at low cost, the time cost associated with preparing the food may deter consumers from purchasing and preparing it. Those that are poor in income also tend to be poor in time. Especially in low income countries where women's time, as the primary caregivers, is constrained and refrigeration is scarce so foods perish quickly, time costs can pose a significant burden and may push people towards processed, shelf-stable foods that do not require refrigeration (Herforth & Ahmed, 2015). Though convenience has emerged as a potentially important factor in dietary decision-making, further research is necessary to elucidate the role of convenience, time costs, food storage, and refrigeration in nutritious diets, and the ways in which programs and policies may use this to their advantage in promoting nutritious foods.

Food-based dietary guidelines can be used to promote healthy nutritional choices, conduct educational sessions in food retail centers or workplaces, and set standards for feeding programs such as school feeding, however, most LMICs have yet to implement such guidelines, so evidence is lacking on their effectiveness in promoting healthy choices (Global Panel on Agriculture and Food Systems for Nutrition, 2017). Guidelines and educational campaigns in LMICs have different considerations than when implemented in high-income countries. Labeling campaigns, for example, may be useful in countries where the majority of citizens can read, but the use of these types of educational materials needs to be thoroughly thought through in places where many consumers are illiterate (Allen & de Brauw, 2018). Graphic food labels have been used to provide information on food content for those who cannot read words, but these systems require intense educational campaigns and even so, meanings may remain unclear to both literate and illiterate consumers (Chopera, Chagwena, Mushonga, & Chagwena, 2014). In addition, consumer response to food labels varies based on educational and socio-economic status; consumers experiencing higher levels of food insecurity have been shown to be more concerned with micronutrient intake, compared with richer consumers in urban areas who are more worried about high fat, sugar, and sodium content (Global Panel on Agriculture and Food Systems for Nutrition, 2017). Understanding what motivates interpretation of food labels or other promotional education campaigns designed to nudge consumers towards healthier choices can influence the effectiveness of actions to promote healthy food choices in LMICs.

There is a fair amount of evidence pointing to positive effects of leveraging interventions to affect each of the drivers of consumer choices to encourage demand for nutritious foods, but much research is left to be done to fully understand how to best use these levers to influence nutritional status in LMICs.

Research opportunities in consumption and demand

1. Research into understanding the cost of nutritious diets through innovative prices indices such as the Cost of Nutrient-Adequacy (CoNA), to determine the degree to which prices constrain healthy diets (Masters, Bai, et al., 2018).
2. Gain a better understanding of the regressive nature of food taxes on unhealthy products (Allen & de Brauw, 2018; Finaret & Masters, 2019).
3. Determine any substitution effects that happen with food taxes and subsidies (Allen & de Brauw, 2018; Finaret & Masters, 2019).
4. Estimate specific nutrient elasticities across multiple contexts to determine how different demographic groups in different regions would react to food taxes or subsidies on certain categories of foods, based on the various income elasticities of demand (Finaret & Masters, 2019; Muhammad et al., 2017).
5. Conduct real-world experiments that determine the effects of taxes and subsidies on diet quality and nutritional outcomes (Niebylski et al., 2015b).
6. Investigate the interplay between taxes and subsidies and private sector engagement (Niebylski et al., 2015b).
7. Develop standardized definitions for healthy and unhealthy foods so that policies regarding taxes and subsidies on different qualities of food can have a clear justification (Niebylski et al., 2015b)
8. More studies are needed on the longer-term effects of tax and subsidy policies (Colchero et al., 2016).
9. Determine the best ways to convey information about nutritious foods to populations in which many have not had formal schooling (Allen & de Brauw, 2018).
10. Elucidate the role of convenience, time costs, food storage, and refrigeration in nutritious diets, and ways in which programs and policies may use this to their advantage in promoting nutritious foods (Herforth & Ahmed, 2015).
11. Understand what motivates interpretation of food labels or other promotional education campaigns designed to nudge consumers towards healthier choices (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

5.4 Summary of research opportunities

1. Estimation of the effects of trade policies on nutritional outcomes (Adjaye-Gbewonyo et al., 2019).
2. Studies of how market infrastructure interventions have impacted food prices, safety and quality of foods, and nutritional status (Allen & de Brauw, 2018; Pingali, 2015).
3. Research on the role of intermediaries between producers and consumers on nutrition outcomes.
4. Understanding of how local markets currently function, how the food redistribution system works, and the types of infrastructural changes necessary to strengthen rural markets (Ickowitz et al., 2019).
5. Establish how investment in market information systems could help bridge the information gap that prevents farmers from making strategic marketing and production decisions (Allen & de Brauw, 2018; Ngenoh et al., 2019).

6. Understand returns on investment from subsidizing crop insurance to smallholder farmers (V. H. Smith, 2016).
7. Better understand the pros and cons of contract farming and other similar services in risk mitigation to encourage production (Allen & de Brauw, 2018).
8. Research into understanding the cost of nutritious diets through innovative prices indices such as the Cost of Nutrient-Adequacy (CoNA), to determine the degree to which prices constrain healthy diets (Masters, Bai, et al., 2018).
9. Gain a better understanding of the regressive nature of food taxes on unhealthy products (Allen & de Brauw, 2018; Finaret & Masters, 2019).
10. Determine any substitution effects that happen with food taxes and subsidies (Allen & de Brauw, 2018; Finaret & Masters, 2019).
11. Estimate specific nutrient elasticities across multiple contexts to determine how different demographic groups in different regions would react to food taxes or subsidies on certain categories of foods, based on the various income elasticities of demand (Finaret & Masters, 2019; Muhammad et al., 2017).
12. Conduct real-world experiments that determine the effects of taxes and subsidies on diet quality and nutritional outcomes (Niebylski et al., 2015b).
13. Investigate the interplay between taxes and subsidies and private sector engagement (Niebylski et al., 2015b).
14. Develop standardized definitions for healthy and unhealthy foods so that policies regarding taxes and subsidies on different qualities of food can have a clear justification (Niebylski et al., 2015b)
15. More studies are needed on the longer-term effects of tax and subsidy policies (Colchero et al., 2016).
16. Determine the best ways to convey information about nutritious foods to populations in which many have not had formal schooling (Allen & de Brauw, 2018).
17. Elucidate the role of convenience, time costs, food storage, and refrigeration in nutritious diets, and ways in which programs and policies may use this to their advantage in promoting nutritious foods (Herforth & Ahmed, 2015).
18. Understand what motivates interpretation of food labels or other promotional education campaigns designed to nudge consumers towards healthier choices (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

6. Processing

Food processing links agricultural production with food consumption by turning fresh foods and raw materials into more shelf-stable and palatable food products (Augustin et al., 2016). Common practices in food processing include: milling, cooling/freezing, smoking, heating, canning, fermentation, drying, and extrusion cooking (Augustin et al., 2016). Depending on the methods and processes used, food processing can play both negative and positive roles in food systems-nutrition linkages through its impacts on food quality. The definition of processed and ultra-processed foods is the subject of heavy debate. A processed food, according to the United States Department of Agriculture (USDA) is any food that has been through any procedure that alters it from its natural state, including: washing, cleaning, milling, cutting, chopping, heating, pasteurizing, blanching, cooking, canning, freezing, drying, dehydrating, mixing, or packaging (USDA, 2019). This definition is clearly broad and cannot be used to differentiate between

types of processing that can aid with food safety and quality, and types that can degrade the quality of foods. Perhaps one of the most widely recognized, but still controversial, definitions intended to identify how processing affects food quality is derived from the NOVA food classification system set out by the School of Public Health of the University of Sao Paulo, Brazil, which defines processed foods as products made by adding sugar, oil, salt or other refined culinary ingredients to raw foods, and ultra-processed foods as those that contain five or more added ingredients whose purpose is to increase palatability by disguising undesirable sensory qualities (Monteiro et al., 2016). Though food processing has been an essential part of the food production chain to some degree since prehistoric times, intake of "processed foods" and "ultra-processed foods" has increased worldwide and their influence is spreading more and more into LMICs (Augustin et al., 2016). The goal of the following section is to review the evidence about both the detrimental and positive effects of food processing on nutrition and identify areas where further research is needed. In this section, research opportunities are not given by sub-section, rather they are reported only in section 6.3 in the summary of research opportunities, due to the nature of the topical division of the sub-sections.

6.1 Detrimental effects of food processing on nutritional status

What evidence is there about the detrimental effects of food processing on nutritional status?

The detrimental effects of food processing on food quality are relatively straightforward. Heat treatment can reduce food quality through degradation of certain nutrients (including water- and fat-soluble vitamins), introduce trans fats, and form acrylamide (Barrett, 2007). The additions of sugar, fat, salt, and refined starches in formulated foods not only increases intake of these nutrients that should be limited in people's diets, but also increases palatability which may lead to overconsumption (Augustin et al., 2016). On the other hand, processing, including new technologies such as high pressure processing, pulsed electric field, cool plasma, and UV radiation, is used to destroy food-borne microbes and toxins, improve bioavailability of nutrients, and improve shelf-life, increasing both food safety and food quality (Augustin et al., 2016).

The growth of the processed food sector is driving a rapid transition of the agricultural sector and diets of both rich and poor people in LMICs; increased use of such processed foods has been linked to increases in BMI and non-communicable diseases such as diabetes and cardio-vascular disease (Augustin et al., 2016). Researchers should now seek to understand what these changing trends in consumption of processed foods means for the agricultural sector and its food value chain as well as health (Popkin, 2014b).

6.2 Positive effects of food processing on nutritional status

How has food processing positively impacted nutritional status?

Food fortification is a type of processing used to add micronutrients to food products and has proven effective at reaching vulnerable populations through existing food delivery systems; however, mass fortification may not reach the most vulnerable populations, as fortified foods are not affordable for some (Osendarp et al., 2018). Although the efficacy of fortification has

been proven, with major success stories in iron, iodine, and folic acid fortification, the effectiveness of fortified foods in improving population food quality is dependent on the monitoring of quality assurance and compliance with standards in order to ensure adequate fortification and avoid overconsumption of nutrients such as fats and trans fats (Osendarp et al., 2018). And while universal fortification with folic acid has been successful in reducing neural-tube defects where implemented, evidence suggests that increased folate intake may also have adverse health effects (Choi, Yates, Veysey, Heo, & Lucock, 2014); it is therefore important to determine how targeting can help minimize risks. Also unknown is the effectiveness of fortification in terms of functional outcomes such as growth, cognition, morbidity and mortality (Osendarp et al., 2018). In addition, changes in dietary habits may influence the effectiveness of fortification if consumption of the fortified vehicle changes, and the effects of such dietary shifts should be considered in future fortification efforts (Osendarp et al., 2018).

To enhance the effectiveness of processing strategies in the future, consideration should be given to strategies that provide incentives, either financial or promotional, for processors and retailers to sell foods made with less sodium and a higher proportion of fruits and vegetables and healthy oils (High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017). In addition, efforts should be made to increase energy efficiency of processing to reduce environmental effects. Changes to processing strategies will require better government coordination, reformulations, public education, food labeling, and robust monitoring and evaluation (Augustin et al., 2016; High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017).

6.3 Summary of research opportunities

1. Determine how different types of incentives to processors and retailers can influence food processing (High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017).
2. More research into technologies that disrupt microbial cells but retain nutrients and flavor molecules (Augustin et al., 2016).
3. Understand how food processing can be better applied to create food products more efficiency, with fewer resources and lower waste production (Augustin et al., 2016).
4. Assess the cost-effectiveness and monetary benefits of food fortification (Osendarp et al., 2018).
5. Determine the effectiveness of food fortification for functional outcomes such as growth, cognition, morbidity, and mortality (Osendarp et al., 2018).
6. Understand how changes in dietary patterns influence the effectiveness of fortification (Osendarp et al., 2018).

7. Food safety

Foods that are important to high quality diets are often associated with food safety hazards. Fresh, perishable, micronutrient-dense foods such as vegetables, fruits, meats and dairy products are at high risk of being contaminated by harmful micro-organisms (bacteria, viruses) and chemical residues (pesticides and/or any chemicals used in improving shelf life) associated with foodborne diseases. In addition, staple crops can be contaminated with natural toxins

(mycotoxins), and chemical residues (pesticides) associated with foodborne diseases (Global Panel on Agriculture and Food Systems for Nutrition, 2016). These are often traded in local, informal markets in LMICs, posing a risk to public health (Delia & Roesel, 2014; Jaffee, Henson, Unnevehr, Grace, & Cassou, 2018). Rapid changes in global food systems have altered exposure to contaminants, with important consequences for nutrition and health. As food supply chains become more complex, detection and removal of unsafe foods becomes more challenging.

Low food safety throughout the various segments of the food supply chain from production to storage to consumption can lead to malabsorption of nutrients, diarrhea, infectious disease, poor birth outcomes, growth faltering, and in some cases result in mortality. The global burden of foodborne disease is known to fall disproportionately on children under age five and in populations of low- and middle-income countries in Asia and Africa (Jaffee et al., 2018). Persons living in LMICs, where regulatory, surveillance, and control systems are unable to address the array of potential hazards, are at higher risk for foodborne diseases.

The global burden of foodborne disease is considerable. In 2010, foodborne diseases were responsible for 33 million disability adjusted life years. According to the World Health Organization's (WHO) 2015 report on the global burden of foodborne disease (World Health Organization (WHO), 2015), foodborne hazards caused 600 million cases of foodborne illness and 420,000 deaths in 2010, and 40% of the foodborne disease burden occurred among children under five years of age (World Health Organization (WHO), 2015). Unsafe water, poor food-production and food-handling practices, inadequate food storage infrastructure and poorly enforced regulatory standards contribute to high foodborne disease risk environments (Global Panel on Agriculture and Food Systems for Nutrition, 2016). In addition to negative health effects, consumption of unsafe foods can have economic costs (Hoffmann & Moser, 2017). Food safety issues can affect trade, rural incomes and purchasing power, worker productivity, and consumer confidence (Global Panel on Agriculture and Food Systems for Nutrition, 2017).

This section presents evidence around food safety issues throughout the food system, and identifies research opportunities for mitigation of these risks, which are critical considerations for food systems-nutrition linkages.

7.1 Production

What is the link between food safety during food production and nutrition?

Application and compliance of food safety standards and sound agricultural practices can help reduce foodborne illness for the members of farming households as well as for buyers and consumers. Poor food handling, including the inappropriate use of agricultural pesticides, herbicides, and other chemicals, is an area of concern in crop production processes. The health effects of occupational exposure to pesticides are well-documented, yet dietary consequences of exposure remain poorly understood. Some evidence has pointed to a relationship between pesticides and stunting (Food and Agriculture Organization, 2012; Neff et al., 2012; Shankar et al., 2019), but more evidence is needed to better understand this relationship and determine

what types of interventions could help reduce pesticide exposure without compromising crop production.

Water and soil use during production can also affect food safety. Certain soil contaminants, such as (groundwater) arsenic, can be damaging to human health (Murcott, 2012). Foodborne arsenic has been estimated to contribute to 70,000 cases a year of bladder, lung and skin cancer in LMICs (Oberoi, Barchowsky, & Wu, 2014). Another important risk to public health is the use of unsafe irrigation water to grow fruits and vegetables (Ensink, Mahmood, & Dalsgaard, 2007; Pachepsky, Shelton, McLain, Patel, & Mandrell, 2011). Water used for irrigation purposes can be contaminated with helminths, protozoa, viruses and disease-causing bacteria, especially in regions where wastewater is being used in farming due to the rising scarcity in irrigation water (Antwi-Agyei et al., 2015). Water-based foods like shellfish can also be contaminated if the water source has pathogenic organisms, such as Vibrio spp. or enteric viruses (WHO, 2015).

Production of animal sourced foods is another critical point for mitigating food safety risks. While animal sourced-foods (ASF) are excellent sources of protein and key micronutrients (i.e. iron, zinc, vitamin A, vitamin B_{12}, and calcium) that are essential for physical and cognitive growth, intensification of animal production systems, as a response to a growing demand for ASF particularly in LMICs, is generating food safety concerns (Global Panel on Agriculture and Food Systems for Nutrition, 2016). Per capita expenditure on perishables is set to quadruple by 2040 and the total market size will increase by a factor of eight in East and South Africa (Tschirley, Reardon, Dolislager, & Snyder, 2015). ASFs are perishable and highly susceptible to foodborne pathogens (Vipham, Chaves, & Trinetta, 2018). For example, consumers may become ill if they consume milk produced by cows infected with Salmonella (Delia & Roesel, 2014). Consumers can also be exposed to environmental toxins if they consume milk or meat products from cows that have consumed aflatoxin-contaminated feed. Although another public health concern related to livestock production is the spread of antimicrobial resistance resulting from widespread antibiotic use in livestock production, there is limited evidence on the impacts of antibiotic use on human health (Delia Grace, 2015b). In many LMICs, most animal source foods and produce are produced by smallholders and sold in informal markets (Gómez & Ricketts, 2013), which often lack adequate resources and infrastructure to safely handle and process animal products and a lack of food safety hazard controls in animal value chains can result in compromised health and nutrition.

Food safety during production is clearly important for health and nutrition, and more pointed research is called for to better understand the dietary consequences of exposure to food safety issues that occur during production, as well as research into mitigation of risks from these food safety issues.

Research opportunities in food safety during production

1. Investigate dietary consequences of exposure to pesticides (Neff et al., 2012).
2. Determine interventions that would limit pesticide exposure without compromising crop production (Neff et al., 2012).

3. Determine methods of reducing water and irrigation related food safety issues during production, including testing of the effectiveness of regulations (Antwi-Agyei et al., 2015).
4. Research the impacts of antibiotic use in livestock production on human health and nutrition (Delia Grace, 2015b).
5. Study food safety concerns related to livestock sold in informal markets by producers to better understand what types of interventions may be necessary to reduce risks (Gómez & Ricketts, 2013).

7.2 Post-harvest

What are the food safety issues that affect nutrition in the post-harvest phase, and how can they be mitigated?

Poor sanitary facilities during storage and poor personal hygiene during handling and processing may result in food contamination in the post-harvest period. Adequate infrastructure is necessary to facilitate good hygiene practices and protect foods from flies, other insects or rodents that may spread pathogens to food. Infected food handlers should be kept away from fresh foods. Use of unsafe water to wash or process fruits and vegetables is another common source of contamination with harmful bacteria, and measures to encourage people to use clean water to wash fruits and vegetables are important if contamination is to be reduced (WHO, 2015).

Poor agricultural practices, inadequate drying, and sub-optimal storage conditions can result in mycotoxin production. Mycotoxins, natural contaminants of food and agricultural products, have recently garnered attention for their potential role in impairing growth outcomes and linear growth impairment in children. While aflatoxins are the most studied mycotoxin, other mycotoxins such as fumonisins and deoxynivalenol are also suspected to contribute to poor child health and development. Associations have been shown in recent human studies between aflatoxins and adverse birth outcomes and impaired growth (Andrews-Trevino et al., 2019; Hoffmann, Jones, & Leroy, 2018; Lauer et al., 2019; Lombard, 2014; Christopher P. Wild & Gong, 2010; Christopher Paul Wild, 2007). Mycotoxins are also associated with stunted growth and health problems in animals (Omotayo, Omotayo, Mwanza, & Babalola, 2019). Two proposed causal pathways for the relationship between mycotoxins and poor growth are through the propagation of environmental enteric dysfunction (EED) and disturbance of the insulin-like growth factor I (IGF-1) axis. While there may be a small but significant relationship between aflatoxins and growth, a recent study reported that this relationship could not be explained by aflatoxin induced changes in the IGF-axis (L. E. Smith et al., 2015; Watson et al., 2018). To date, little is known of the role of mycotoxins in mediating enteropathy (L. E. Smith, Stoltzfus, & Prendergast, 2012). A better evidence base is needed on how to best prevent mycotoxin exposure from impacting human and animal health.

Regulations that do exist for mycotoxin control are difficult to enforce in subsistence farming communities (Christopher P. Wild & Gong, 2010). Stringent regulations characteristic of high-income countries that could reduce exposure to mycotoxins are lacking in LMICs, despite the

fact that exposure in these countries is highest and have a high probability of contributing to the health burden because of trade restrictions (Christopher P. Wild & Gong, 2010).

Proven methods of reducing exposure to mycotoxins include removal of mold from agricultural products, improved drying facilities, chemical acids, bases, salts, and oxidizing agents, and biological control strategies (i.e. Aflasafe) (Unnevehr et al., 2013). Some recent work has shown low cost tools and technologies, such as DryCards and hermetic containers (e.g. Purdue Improved Crop Storage (PICS) bags) can help prevent aflatoxin accumulation in storage (Feed the Future Innovation Lab for Horticulture, 2019; Williams, Baributsa, & Woloshuk, 2014). High heat can also reduce mycotoxin content, but the trade-off is that it can also result in the loss of essential nutrients.

Food safety issues in the post-harvest phase, especially those related to mycotoxins, have been linked in empirical studies to growth deficits and adverse birth outcomes.

Research opportunities in post-harvest food safety

1. Determine the role of mycotoxins in the pathogenesis of EED and childhood stunting.
2. Determine methods to enforce mycotoxin regulations among farmers in LMICs (Christopher P. Wild & Gong, 2010).
3. Add to the evidence base on how to best prevent mycotoxin exposure from impacting human health, including growth (Christopher P. Wild & Gong, 2010).
4. Determine how effects seen at birth persist during a child's growth.
5. Determine how the mother's health and nutrition is affected by high mycotoxin levels (aside from poor birth outcomes).
6. What cost-effective interventions and practices can help smallholders better understand and manage food safety threats.

7.3 Marketplace

How are marketplace food safety issues related to nutritional status?

While hazards can also be introduced during processing and retailing of food, well-functioning markets can provide an array of incentives for farmers and food business operators to provide safe products for consumers. However, if markets lack appropriate infrastructure, food safety can be compromised. We find very little evidence on food safety in markets in LMICs; however, informal markets in LMICs often lack storage and cooling facilities for perishable food items, jeopardizing food safety (Delia Grace, 2015a). A series of studies by the International Livestock Research Institute found high microbial loads of pathogens responsible for diseases such as tuberculosis, listeriosis, and salmonellosis (among others) in meat and milk products in multiple Sub-Saharan African countries (D Grace, Makita, Ethe, & Bonfoh, 2010). Additionally, poor hygiene practices by traders and vendors can result in a transfer of pathogens to produce. While improving hygiene practices in informal markets can be challenging, and "command and control" regulations, involving inspection of products backed by litigation if harm occurs, have not been effective at reducing risks, there have been certain promising participatory approaches that have engaged informal food traders and vendors (D Grace et al., 2010). These approaches

involve risk analysis in which potential hazards are assessed and points deemed critical to food safety are monitored regularly and remedial actions recommended if the hazards are not contained. Training and increasing capacity of those operating food businesses have helped bring the informal sector under the food safety regulatory systems, but additional research about how more participatory approaches that involve the vendors' input can increase food safety are needed (Alonso, Muunda, Ahlberg, Blackmore, & Grace, 2018).

Another area of interest in marketplace food safety is that of the sale of expired foods. We find no recent studies on expired products sold by vendors or in markets in LMICs, despite the importance of food expiration for food safety in the marketplace. Studies should be conducted to determine the prevalence of expired foods in marketplaces, as well as any effects of the sale of these foods on nutrition.

Research opportunities in marketplace food safety

1. Updated research on hygiene practices among food vendors, and how this is related to nutritional status (Delia Grace, 2015a).
2. Understand how to better encourage food vendors to achieve food safety in the marketplace with limited infrastructure (D Grace et al., 2010).
3. Studies on expired foods in the marketplace, and their role in nutrition.

7.4 Utilization

How is food safety during utilization in the home connected to nutritional status?

The way that consumers handle foods in the home is the last food safety step along the food value chain. Even if foods remain safe throughout the value chain, if they are not properly handled at the household level by consumers, food quality and nutrition can be compromised at this stage, leading to foodborne illness (Lagerkvist, Amuakwa-Mensah, & Tei Mensah, 2018). Various factors have been shown to influence food safety at the household level.

For one, poor personal hygiene and use of unsafe water can result in microbial contamination of perishable foods at home. The water, sanitation, and hygiene (WASH) environment of a household can impact food safety during consumption, and subsequently nutritional status, especially among children. The condition of EED is a major public health concern in LMICs due to its association with impaired growth in young children (Campbell, Elia, & Lunn, 2018; Kosek et al., 2013; Ordiz et al., 2016; Weisz et al., 2012). After frequent gastrointestinal infections due to exposure to environmental pathogens, children may develop EED (described previously in the livestock ownership section) and experience growth faltering (Cunningham et al., 2019; Finaret & Masters, 2019; Headey et al., 2017; Lauer, Duggan, Ausman, Griffiths, Webb, Agaba, et al., 2018; Lauer, Duggan, Ausman, Griffiths, Webb, Bashaasha, et al., 2018). EED biomarkers that reflect microbial translocation were associated with poor birth outcomes in a longitudinal study conducted on pregnant women in Uganda (Lauer, Duggan, Ausman, Griffiths, Webb, Agaba, et al., 2018) While the exact definition of EED has yet to be established, two conditions have been proposed as pathways by which EED can inhibit growth in young children – malabsorption of nutrients and systemic immune response (Keusch et al., 2013; Lunn, 2000).

The role of the gut microbiome in facilitating (or impeding) growth is being assessed by several studies and changes in the gut microbiome have been proposed as other potential consequences and markers of EED. However, this is a relatively new area of research and it is not yet clear if observed changes are signs of EED or are a function of host characteristics such as age or genetics (Gough, Prendergast, Mutasa, Stoltzfus, & Manges, 2015; Keusch et al., 2014).

It has been hypothesized that poor WASH conditions, such as lack of clean water, lack of hand washing facilities, lack of safe and sanitary food storage and preparation, result in changes to intestinal microbiota and the structure and function of the small intestine (Keusch et al., 2014). Studies have shown evidence of a link between WASH and EED (A. Lin et al., 2013; L. E. Smith et al., 2015), and a growing body of literature has shown that subclinical infections and exposure to specific enteric pathogens may contribute to growth faltering (Lauer, Duggan, Ausman, Griffiths, Webb, Bashaasha, et al., 2018; Prendergast et al., 2014; Syed & Duggan, 2016). However, evidence from two recent large trials testing the effects of adding WASH interventions to food supplementation to influence nutritional status have shown null effects of handwashing, water decontamination tablets, and latrine construction interventions on growth outcomes (Humphrey et al., 2018; Null et al., 2018). The lack of evidence for a correlation between improved WASH and growth necessitates further study of the causal pathways for EED, including how environmental contexts and food safety throughout the food system influences health and nutrition outcomes (Finaret & Masters, 2019; Headey et al., 2017).

In addition, foods that have reached consumers can also be contaminated with mycotoxins. As mycotoxins are highly resistant to destruction through processing and cooking, if primary prevention at earlier points in the food chain fail, and foods are contaminated with mycotoxins once they reach consumers, the only solution at that stage is modifying the effects of mycotoxins once they have been ingested by preventing absorption or modifying metabolism (Christopher P. Wild & Gong, 2010). Prevention of absorption of aflatoxin has been achieved with clay-filled feeds and foods (Wang et al., 2008). More research on the scalability and feasibility of widespread use of these techniques is necessary.

Research opportunities for food safety during utilization

1. Investigate individual health and diet consequences of exposure to pesticides (Neff et al., 2012).
2. Research about the casual pathways from poor food safety (pathogenic and/or contaminant exposure in consumption), WASH (poor individual practices and risk factors) and health and nutrition outcomes such as childhood stunting (Finaret & Masters, 2019; Headey et al; 2017).
3. Assess the potential to scale up the prevention of absorption of aflatoxin (after ingestion) (Christopher P Wild & Gong, 2010, Wang et al., 2008).
4. Determine interventions that would limit pesticide exposure in individuals at the utilization stage without compromising crop production (Neff et al., 2012).
5. Research the impacts of antibiotic use in livestock production on human health and nutrition at the point of consumption (Delia Grace, 2015b).

6. Study food safety concerns related to livestock sold in informal markets by producers to better understand what types of interventions may be necessary to reduce risks (Gómez & Ricketts, 2013).

7.5 Summary of research opportunities

1. Investigate dietary consequences of exposure to pesticides (Neff et al., 2012).
2. Determine interventions that would limit pesticide exposure without compromising crop production (Neff et al., 2012).
3. Determine methods of reducing water and irrigation related food safety issues during production, including testing of the effectiveness of regulations (Antwi-Agyei et al., 2015).
4. Research the impacts of antibiotic use in livestock production on human health and nutrition (Delia Grace, 2015b).
5. Study food safety concerns related to livestock sold in informal markets by producers to better understand what types of interventions may be necessary to reduce risks (Gómez & Ricketts, 2013).
6. Determine the role of mycotoxins in the pathogenesis of EED and childhood stunting.
7. Determine methods to enforce mycotoxin regulations among farmers in LMICs (Christopher P. Wild & Gong, 2010).
8. Add to the evidence base on how to best prevent mycotoxin exposure from impacting human health, including growth (Christopher P. Wild & Gong, 2010).
9. Updated research on hygiene practices among food vendors, and how this is related to nutritional status (Delia Grace, 2015a).
10. Understand how to better encourage food vendors to achieve food safety in the marketplace with limited infrastructure (D Grace et al., 2010).
11. Studies on expired foods in the marketplace, and their role in nutrition.

8. Food loss and waste

Food loss and waste estimates range from about one third to one quarter of food that is produced for human consumption lost within the food supply chain, meaning that roughly 1.3 billion tons of food are lost each year (Gustavsson, Cederberg, Sonesson, van Otterdijk, & Meybeck, 2011; Kummu et al., 2012). The distinction between what is considered food loss and what is considered waste is generally made based on where in the supply chain the loss is happening. Food losses take place during production, harvest, storage, transportation, and distribution to consumers. Waste, however, refers to what happens to the food once it is in the hands of the consumers, and is more related to consumer behavior than to supply chain issues (Parfitt, Barthel, & MacNaughton, 2010).

By 2050, we will need to feed 9 billion people, and reducing food losses is considered a critical step towards ensuring food security in the coming decades (Kummu et al., 2012). Reduction of food loss is essential for sustainable production and consumption (Caron et al., 2018), as food loss impacts scarce natural resources such as freshwater, cropland, and fertilizers (Kummu et al., 2012). In LMICs, the bulk of food that does not end up getting consumed gets lost due to

inadequate technology or lack of appropriate infrastructure and knowledge during the agricultural and post-harvest steps of the food supply chain. Very little waste is observed at the consumer level, where losses typically occur in higher income countries (Kumar & Kalita, 2017; Kummu et al., 2012; Willett et al., 2019). We thus focus in this review on evidence about food losses and the effectiveness of technologies designed to limit losses. As in section 6 of this review, due to the organizational content of this section, the research opportunities for this section are summarized at the end of the section.

Globally, there are numerous drivers of food loss: a) urbanization, b) dietary transitions, and c) consumer choices. Urbanization and reductions in the proportion of the world's population involved in agriculture has required more food products to be transported over longer distances. Up to 70% of the global population is expected to live in urban areas by 2050, increasing the potential for food loss (Parfitt et al., 2010). This is compounded by the dietary transition including the shift from shelf-stable cereals to more diverse foods such as fruits, vegetables, and animal sourced foods, which have shorter shelf lives (Parfitt et al., 2010). In addition, increased market liberalization, globalization and trade provides opportunities for exports, but threatens the development of internal markets, which suffer fewer losses, as imported foods are less expensive to consumers and of higher quality. Lastly, at an individual level, consumer choice has increased as the proportion of income spent on food has decreased, increasing wasteful behavior (Parfitt et al., 2010). If a "minimum loss scenario" is achieved, meaning the lowest loss and waste percentages in any region in each step of the food supply chain, global food supply losses could be cut in half, increasing food availability to reach one billion extra people (Kummu et al., 2012).

8.1 Household level pre and post-harvest loss and effectiveness of technologies

How have advancements in technologies used at the household level mitigated post-harvest loss and impacted the availability of nutritious foods?

At the household level, post-harvest losses can affect both the income of farmers as well as the availability of sufficient food. Spillage during harvesting and degradation during storage are big issues for agricultural products, and for animal products, losses in output can occur if animals die or if they become ill and produce less milk (Gustavsson et al., 2011). Cereals are still a majority of the food supply and account for most of the food loss. Technologies and infrastructure improvements that lower transactions costs and minimize post-harvest losses due to inadequate cooling, supply chain damage, and sub-par drying and storage are needed to shift this bias and encourage production and marketing of the often more perishable nutrient-dense foods that contain key micronutrients of concern (vitamin A, zinc, iodine, iron) (Allen & de Brauw, 2018; Horticulture Innovation Lab World Food Center & Program in International and Community Nutrition, 2018).

A significant research gap has been noted around the mitigation of post-harvest loss particularly of high value/nutrient dense crops such as fruits and vegetables (Bill and Melinda Gates Foundation & UKAID, 2019) and there is consensus in the development community that investment in post-harvest loss reduction could be a quick impact intervention for enhancing food security and thus improving nutrition (Affognon, Mutungi, Sanginga, & Borgemeister,

2015). Reducing post-harvest loss also has positive impacts on the environment and climate, enhancing farm level productivity and reducing utilization of production resources in fragile eco-systems. A meta-analysis by Affognon et al. 2015 found spotty and scanty data from Sub Saharan Africa across commodities and points in the value chain; those data that exist are of poor quality. Most of the post-harvest loss estimates (weight of edible mass lost or volume of food discarded) are focused on one commodity (maize). Authors recommend supporting complementary post-harvest loss assessments along the value chain for food commodities of nutritional importance (Affognon et al., 2015).

Nevertheless, within the context of reducing producer constraints due to post-harvest losses, simple on-farm innovations and management practices do exist and have the potential to encourage production of perishable nutrient dense foods. These include shade structures to house recent harvests, evaporative charcoal coolers and zero energy cool chambers, small-scale insulated rooms that use low-cost CoolBot™ controllers, solar dryers, and DryCard™, a technology that uses cobalt chloride as an indicator showing whether or not the products have been sufficiently dried (Horticulture Innovation Lab World Food Center & Program in International and Community Nutrition, 2018). While these innovations may hold promise, their feasibility, cost-effectiveness and scalability for increasing production, access and availability of fruits, vegetables, and animal-sourced foods remains to be seen. For farmers to take on the risk of investing in and adopting these new technologies, they need to be confident that their investments will pay off and that benefits of the technologies at production level, for example, will not be thwarted by later breaks in the cold chain. In depth analysis of cold chain systems in different contexts is essential to determining which technologies farmers should invest in to minimize losses and maximize benefits (Kitinoja, 2013).

8.2 Population level interventions to minimize losses

How can population level interventions minimize food loss?

At the population level, major causes of food loss in LMICs are lack of market access, poor harvest timing, rough handling of produce, and poor storage facilities (e.g. refrigeration) (Willett et al., 2019). Research on minimizing food losses has shown that the largest potential for reducing food losses is in agricultural losses in regions where there is the least need for extra food supply, and the smallest potential is in post-harvest losses and in regions where there is rapid population growth and high prevalence of malnutrition (Kummu et al., 2012). Improvements to market infrastructure and technology could potentially reduce food loss, but better measurement of food loss is needed to be able to evaluate the efficacy of such improvements (Parfitt et al., 2010). Food loss measurement methods vary over different regions and contexts, and loss measured over time as a constant proportion of food consumed could be inaccurate (Parfitt et al., 2010).

Some examples of population level interventions to minimize losses are transportation and infrastructural improvements (roads), local processing, storage facilities for perishable foods, and temperature-controlled supply chains. There is some evidence that transportation development, known to be a driver of economic growth, could be related to nutrition outcomes in children under five. Thapa and Shively 2018 found a dose response function for

height for age and weight for height Z-scores, suggesting that roads and road quality do matter for short term and long-term nutrition outcomes (Thapa & Shively, 2018). More evidence is needed, however, on the impact of market transformations and improvements to infrastructure on food loss.

8.3 Research opportunities

1. Better measurement of food losses to establish a firm evidence base from which to assess food loss and waste globally (Kummu et al., 2012; Parfitt et al., 2010).
2. Understand the impact of market transformation and improvements to infrastructure on food loss (Parfitt et al., 2010).
3. Determine different types of incentives for growers to adopt on-farm practices (improved harvesting and storage techniques) to reduce food loss (Kitinoja, 2013).
4. Rigorous post-harvest loss assessments throughout the value chain of multiple commodities of nutritional importance (Affognon et al., 2015).
5. In-depth systems assessment of cold chains in various contexts to determine how farmers' investments in cold-chain technologies at the production level are supported throughout the cold chain (Kitinoja, 2013).
6. Assess the feasibility, cost-effectiveness and scalability of innovations in post-harvest technologies for increasing production, access and availability of fruits, vegetables, and animal-sourced foods (Horticulture Innovation Lab World Food Center & Program in International and Community Nutrition, 2018).

9. Cross-cutting themes

There are several cross-cutting issues that have important implications throughout the food system. These themes and research opportunities therein are explored in this section.

9.1 Gender

What evidence is there for the role of gender in food systems nutrition linkages?

That gender plays an important role along the food systems to nutrition pathways has been clearly articulated across the different reviews and research initiatives around agriculture, food systems and nutrition (Haddad et al., 2016; Malapit et al., 2014; Ruel et al., 2018). Women represent a large portion of the agricultural sector yet are often subject to barriers such as limited decision making and mobility autonomy that constrain their agricultural choices. As the primary caregivers, these limitations make it a challenge for women to provide sufficient and adequately nutritious foods to both themselves and their children (Kjeldsberg et al., 2018). Three pathways have been proposed through which gender mediates the relationship between agricultural production, livestock, diet diversity, and nutritional status; 1) agricultural production can itself be a way of empowering women farmers, 2) agricultural time requirements and labor can have trade-offs with childcare practices, and 3) risks associated with women's agricultural labor could contribute to intergenerational undernutrition. At each of the steps along these pathways, women's empowerment can serve to either block or facilitate the connection between agriculture and nutrition (Kjeldsberg et al., 2018).

Studies on gender in agriculture and food systems have been mainly quantitative in nature. The FAO estimates that increasing women's access to resources for agricultural production could increase farm yields by up to 30% (FAO, 2011). A study on the relationship among livestock, women, and child nutritional outcomes in India found that acquisition of livestock assets by illiterate women increases their intra-household bargaining power and results in greater investments in child nutrition (Jumrani & Birthal, 2016). The incorporation of the WEAI (Women's Empowerment in Agriculture Index) in the baseline surveys of the Feed the Future initiative, across at least 20 countries, provides interesting insights on the relationship of women's empowerment, poverty, health and nutrition outcomes (Malapit et al., 2014). Key findings from the analysis of WEAI data from 13 FTF countries are that women often have lack of access to credit and power to make credit related decisions, excessive workloads and a low prevalence of group membership. Evidence from other studies points to the negative implications that production interventions can have on diet diversity and nutritional status due to women's time and energy stress that lead to reductions in caregiving practices and risks for women's own health (Gillespie et al., 2019; Nitya & Raju, 2017; Ruel et al., 2018). A recent systematic review that aimed to parse the ways women's empowerment is quantitatively measured and summarize evidence for the various pathways between women's empowerment and child nutrition found 62 quantitative studies using 200 unique indicators of women's empowerment with 1316 associations being tested with various child nutrition outcomes. Authors of this review found a significant absence of indicators of time resource allocation, reproductive decision making as well as indicators for men's engagement in child care and nutrition (Santoso et al., 2019).

While these studies provide important insight into gender as a mediator among agriculture, food systems, and nutrition, there is a need for more qualitative studies to elucidate the complex and likely context-dependent interplays between gender dynamics and the agriculture to nutrition pathways. While increasing numbers of studies use the WEAI (and related off-shoots) to collect data on women and agriculture, most use this information descriptively as opposed to using it as a basis to determine the impact of nutrition-sensitive or food system-wide interventions on empowerment outcomes or nutrition. Too few have studied energy expenditure and time-use/opportunity costs for women of different interventions to determine the distributed cost-effectiveness of interventions within rather than just across households. In addition, more robust quantitative methods are needed to establish causal relationships within the pathways (Gillespie et al., 2019; Kjeldsberg et al., 2018; Nitya & Raju, 2017). The impacts of agricultural interventions on women's workload, childcare, and time burdens has yet to be understood (Gillespie et al., 2019; Nitya & Raju, 2017). To be able to better leverage the ways in which gender can facilitate agriculture-nutrition linkages, and mitigate ways in which it is a barrier, we need a better understanding of its role as a mediator (Kjeldsberg et al., 2018).

Research opportunities in the role of gender in food systems and nutrition

1. Understand how to better design services that engage with and can be accessed by women producers.
2. Qualitative studies on the context-dependent interplays between gender dynamics and food systems nutrition pathways.

3. Gain an understanding of the impacts of agricultural interventions on women's workload, childcare, and time burdens.

9.2 Resilience and sustainability

How can food systems lead to resilience and ensure sustainability?

Accounting for how the food system mediates between agricultural production and nutrition outcomes can be particularly helpful for resilience and sustainability. Resilience links short-run changes to long-term sustainability, and links socioeconomic security to agroecological changes (Bird, Pradhan, Bhavani, & Dangour, 2019; Caron et al., 2018), building on new measurement methods (Barrett & Constas, 2014; Zaharia et al., 2019) to meet the full range of USAID research objectives (Feed the Future, 2017).

A crucial dimension of food systems for resilience and nutrition is the diversity of agricultural production, which also contributes to social and ecological sustainability through multiple means (Jones & Ejeta, 2016). First, diversified crops mean a greater ability to avoid outbreaks of pests and pathogen transmission. Second, having more diverse crops that react differently to different climatological conditions is more secure in the face of increasing climate variability and weather events (B. B. Lin, 2011). Currently, three food crops (rice, maize and wheat) provide 2/3rds of the global dietary energy intake, with the global supply of pulses, fruits and vegetables falling far short of recommended total requirements (Siegel, Ali, Srinivasiah, Nugent, & Narayan, 2014). Not only do our current diets fall short of nutrient requirements, diets heavy in plant-based foods usually require less energy use, less water, and less land compared to diets heavy in meat (Augustin et al., 2016). The resilience and sustainability of our current food system falls short of what it could be if more focus is put on crop diversification.

A recent effort has been made to outline changes in the mix of commodities to meet recommendations for healthy human diets that are also healthy for the planet, in the EAT-Lancet commission findings. This document recommends a global transformation of the food system towards a healthier and also more environmentally sustainable diets that use more diverse and nutrient-dense vegetal foods, less meat especially in high-income settings, and more milk or eggs in settings where current intake is very low especially among children in Africa and South Asia (Willett et al., 2019). Critics of these findings, however, point to several issues with the recommendations in the report, citing the lack of scientific basis for a standard diet for the entire planet, the importance of animal sourced foods for growth in children in developing countries, and the economic risks for poor livestock owners in developing countries (Torjesen, 2019). Needless to say, this is an emerging area of research, and further attempts should be made to determine how our food system can support healthy diets that promote resilience and sustainability.

Few empirical studies focus on actually measuring potential resilience-building facets of food-based interventions, and fewer still consider long-term sustainability. A focus on resilience and sustainability of our food systems is crucial if we are to achieve food and nutrition security in the face of climate change and population growth.

Research opportunities in resilience and sustainability

1. Model scenarios of optimal on-farm crop mixtures and rotations that may be most beneficial for improved resilience in certain regions, considering current patterns in climate variability.
2. What regional farm income support systems to incentivize more diverse cropping systems that support small farmers?
3. Food systems modeling to assess tradeoffs in supporting healthy diets versus promoting resilience and sustainability.

9.3 Summary of research opportunities

1. Understand how to better design services that engage with and can be accessed by women producers.
2. Qualitative studies on the context-dependent interplays between gender dynamics and food systems nutrition pathways.
3. Gain an understanding of the impacts of agricultural interventions on women's workload, childcare, and time burdens.
4. Model scenarios of optimal on-farm crop mixtures and rotations that may be most beneficial for improved resilience in certain regions, considering current patterns in climate variability.
5. What regional farm income support systems to incentivize more diverse cropping systems that support small farmers?
6. Food systems modeling to assess tradeoffs in supporting healthy diets versus promoting resilience and sustainability.

10. Metrics and indicators for agriculture, food systems and nutrition

To conduct successful and meaningful research on agriculture and food systems for nutrition, agreement is needed on the most appropriate indicators to measure each step of change, with the chosen indicators appropriately matched to program activities and interventions (Allen & de Brauw, 2018; Herforth & Ballard, 2016; Verger, Ballard, Dop, & Martin-Prevel, 2019). The framework of food system transformation drivers and impacts proposed by Caron et al, and replicated in Figure 6 (Caron et al., 2018) is a useful tool in developing indicators, as it is important to measure the impact that different forces have on changes in the food system, and the framework clearly lays out these forces.

Earlier evidence reviews such as the mapping study conducted by the London Centre for Integrative Research on Agriculture and Health (LCIRAH) in 2012 focused on the need for measurement of the full pathway of change from agricultural inputs and practices to nutrition outcomes (Turner et al., 2013). Table 1 provides an illustration of the type of indicators that have been utilized in the agriculture-nutrition space (whether research or programming). According to Herforth and Ballard in their 2016 systematic review of ongoing agriculture-nutrition projects (both research and programmatic), many working in this space were using indicators (e.g. stunting) for which the research studies and/or evaluations were not statistically powered. There had however been a shift in the types of indicators being measured from the

past with more measures of dietary quality (both household and individual) being measured; however, there was little emphasis on the measurement of natural resource management namely water access and/or quality, both of which can have significant effects on disease vectors, time and labor and thus subsequently to nutrition (Herforth & Ballard, 2016).

The main gap identified in this review concerns the lack of indicators measuring pathways from agriculture and food systems at the market or systemic level. Over the past decade, researchers have focused on linkages from a household or region's own agricultural production to their nutritional outcomes, and on linkages within a value chain from a raw commodity to the nutritional value of a specific product. New indicators designed to take account of interaction among foods might focus on a population's overall diet, such as the Cost of Nutrient Adequacy (Masters, Bai, et al., 2018), with further need for contextualization and utilization of the methods across different regions and country contexts. A recently published systematic review on the use and interpretation of dietary diversity indicators in nutrition sensitive agriculture projects found 46 studies that were investigating associations between agriculture, food security or nutrition using simple food group dietary diversity indicators (FGIs) and while the individual level FGIs were consistent with published guidance, the measurement of household dietary diversity was not, particularly around classification or interpretation. Authors recommend harmonization around the use and interpretation of FGIs (Verger et al., 2019).

A major consideration within the context of metrics and indicators is the use of anthropometry specifically the indicator of stunting as a major outcome. Herforth and Ballard found more than 43 studies in their 2016 review that measured anthropometry but only six of the studies had adequate power to assess reductions in stunting (20% reduction) compared to a counterfactual group (Herforth & Ballard, 2016). None of the studies were in the realm of agriculture and nutrition and none were powered to observe a decline in stunting of less than 15%. Masset et al in 2012 have also reported an issue of underpowering of evaluations that utilize anthropometric indicators as a primary outcome of interest (Masset, Haddad, Cornelius, & Isaza-Castro, 2012). Both Herforth and Ballard 2016 and Masset et al 2012 noted insufficient duration of intervention as a possible constraint in achieving a change in the outcome of interest (particularly anthropometry) (Herforth & Ballard, 2016; Masset et al., 2012). Furthermore, there is growing discussion on the need to go beyond anthropometry and that striving to promote linear growth may not be the most efficient strategy in all cases, despite its current popularity as an outcome (Leroy & Frongillo, 2019).

Longer term outcomes that are better measures of well-being and the extent to which a person is thriving, such as neurocognition and body composition, should be considered. Additional indicators in the new generation of food systems interventions should also be expanded beyond those measuring success in terms of the first 1,000 days of life, to include adolescents and young females in order to address intergenerational transmission of low birth weight and poor growth (Popkin, 2014b).

10.1 Research gaps and opportunities

1. Guidance and research to harmonize food group and dietary diversity indicators (individual, household, market and systems level indicators).
2. Research about the use and contextualization of standardized indices for evaluating market interventions including affordability of nutritious diets.
3. Defining longer term outcomes and better measures of wellbeing including neuro-cognition, body composition and other anthropometric measurements such as head circumference.

11. Mapping gaps and needs to inform future research priorities

This review provides a synthesis of recent research in food systems and nutrition, to guide new work on food systems to improve nutrition and resilience. Table 2 summarizes the key research opportunities that are presented by section in this review. In the past 15 years, within the nutrition community, there has been significant emphasis on ensuring that nutrition remains on the development agenda. This movement coalesced around the first Lancet series of malnutrition published in 2008 (Bhutta et al., 2008; Black et al., 2008). This series was followed up by the Lancet series of 2013 (Bhutta et al., 2013; Black et al., 2013), which included a paper on nutrition sensitive interventions and programs (Ruel & Alderman, 2013a). That paper by Ruel, Alderman et al 2013 found inconclusive evidence of the nutritional effect of agricultural programs (Ruel & Alderman, 2013a). Similarly, a critical systematic review by Masset et al 2012 found an overall positive effect of producing agricultural goods, and while interventions were successful in promoting nutrient-dense foods, the effect on overall diets was unclear and little evidence was found of a positive effect on the prevalence of stunting (Masset et al., 2012). Webb and Kennedy similarly reviewed literature on agriculture and nutrition and emphasized that an absence of evidence did not equate to evidence of no impact. Their analyses indicated weakness in study designs and survey methods being significant issues that led to weak results and limited generalizability (Webb & Kennedy, 2014).

Significant emphasis and investments have been made in assessing agriculture to nutrition linkages as well as defining the role of policy and governance in supporting multisectoral actions for improving nutrition. Resources have been spent on defining new metrics, developing methods for assessing resilience, and expanding the thinking around the linkages of not only agriculture to nutrition but also to health. Key research groups within this realm include many of the Feed the Future Innovation Labs supported by USAID (including the Nutrition Innovation Lab) as well as LANSA (Leveraging Agriculture for Nutrition in South Asia), IFPRI (International Food Policy Research Institute) and other CGIAR (Consultative Group for International Agricultural Research) centers, A4NH (Agriculture for Nutrition and Health) and LCIRAH among others (Gillespie et al., 2019; Turner et al., 2013; USAID & Tufts University, 2019).

A recent evidence and gap map on publications/research studies around innovative metrics, tools and methods in agriculture-nutrition research (**Figure 5**), shows that much has been developed and researched in terms of primary food production and WASH (within the context of methodologies and analysis), but research (either technologies, methods or metrics) on the

rest of the food system, including food security, diets, nutrition, markets, food environments, food, nutrition and trade policy and governance is sparse (Sparling et al., 2019).

The outcome of the investments and rigorous research conducted in the past decade is apparent from the evidence presented in this review. The challenge now is to determine how to ensure that our food systems will not fail producers and consumers in achieving healthy, sustainable diets that lead to both food and nutrition security. The research opportunities identified here expand the already significant literature base and provide stakeholders, be it USAID, policy makers in the United States and in host country governments, other bi-lateral agencies, UN agencies, researchers, or programmers, the necessary tools to make sound decisions within the realm of agriculture, nutrition, health and food systems.

Tables

Table 1: Indicators and metrics commonly used in nutrition and agriculture research

Type of measure	Indicator
Diet- Individual Level	Minimum dietary diversity for women of reproductive age
	Minimum dietary diversity for young children (MDD age 6-23 months)
	Minimum Acceptable Diet for young children (MAD)
Food Access- Household level	Food Insecurity Experience Scale (FIES), Household Food Insecurity Access Scale (HFIAS)
On farm availability, diversity, and safety of foods	Production of target nutrient rich foods
	Diversity of crops and livestock produced
	Months of adequate household food provisioning (MAHFP)
Food environment in the markets	Availability, affordability and price of targeted nutrient rich foods in local markets
Women's empowerment	Women's access and control over resources
	Women's participation in economic activities
	Women's access and control over benefits
Nutrition and food safety knowledge and norms	Project specific indicators related to knowledge, attitude and practices
Natural resource management practices	Access to improved drinking water
	Presence of animals in/near household
	Sustainability of water availability and water use efficiency measures
	Contamination from water or environment in food supply
Care practices	Breast feeding indicators
	Minimum acceptable diet
	minimum meal frequency
Nutritional status	Stunting
	Wasting
	Underweight
	Maternal weight/BMI
	Iron status
	Anemia
	Vitamin A status
	Head Circumference
	Mid Upper Arm Circumference (MUAC)
Motor and Cognitive Development	Motor skills tests
	Cognitive tests (e.g. Raven's scores)

Source: (*Compendium of indicators for nutrition-sensitive agriculture*, n.d.)

Table 2: Research Opportunities summarized by topic within the context of a food system

Topic	Overarching research opportunities
Agricultural production of nutrient-rich foods	▪ Assess the potential for biofortified crops to impact health and nutrition outcomes and to be adopted and scaled up through markets ▪ Establish impacts of use of land productivity inputs and livestock ownership on diet and nutrition outcomes ▪ Invest in research examining the effectiveness of new technologies to improve feed efficiency and yield ▪ Understand relationships among market access, structure and human nutrition and health ▪ Further evidence on theory-driven program design to scale up nutrition sensitive agricultural programs ▪ Assess program scalability (e.g. homestead gardens) and potential for sustainability (e.g. exit strategies)
Agriculture-nutrition linkages at population scale	▪ Research on how trade policies, market infrastructure and intermediaries impact nutritional status ▪ Understand how local markets function and how they can be improved ▪ Understand how market information systems, contract farming and subsidized crop insurance impact risk mitigation and encourage production ▪ Understand the degree to which prices, taxes and subsidies constrain or encourage healthy diets, considering different demographic groups/settings and the effect on private sector engagement ▪ Develop standardized definitions for healthy and unhealthy foods and determine the best ways to convey information about nutritious foods and nudge consumers towards healthier choices
Processing	▪ Research on food processing for better efficiency in production with fewer resources and lower waste production ▪ Cost effectiveness of food fortification on functional outcomes, considering rapid changes in dietary patterns
Food safety	▪ Research impacts of exposure to pesticides, antibiotics and mycotoxins on human health ▪ Research on mycotoxins to test strategies for the prevention and/or reduction of mycotoxin exposure and EED, and promote child growth ▪ Support causal studies for EED exposure and growth faltering using a whole system approach ▪ Generate better data on the influence of intermediaries (e.g., food vendors) on food safety and how they can play a role in improving food safety in the marketplace

Food loss and waste	▪ Rigorous post-harvest loss assessments using systematic methodologies and exploration of holistic approaches to mitigate loss ▪ Understand how market transformation and improvements to infrastructure affect food loss ▪ Research on drying, packaging and cold chain technologies to reduce post-harvest loss
Cross-cutting themes	▪ Conduct qualitative research examining interplays between gender dynamics and food systems and ways to best design services accessible to women ▪ Understand how food systems can best support healthy diets that promote both resilience and sustainability
Metrics and methods	▪ Support research around guidance development (dietary guidelines, indicators for measuring diet) and harmonize food group and dietary diversity indicators ▪ Define long-term outcome measures to complement existing short- and medium-term measurements

Figures

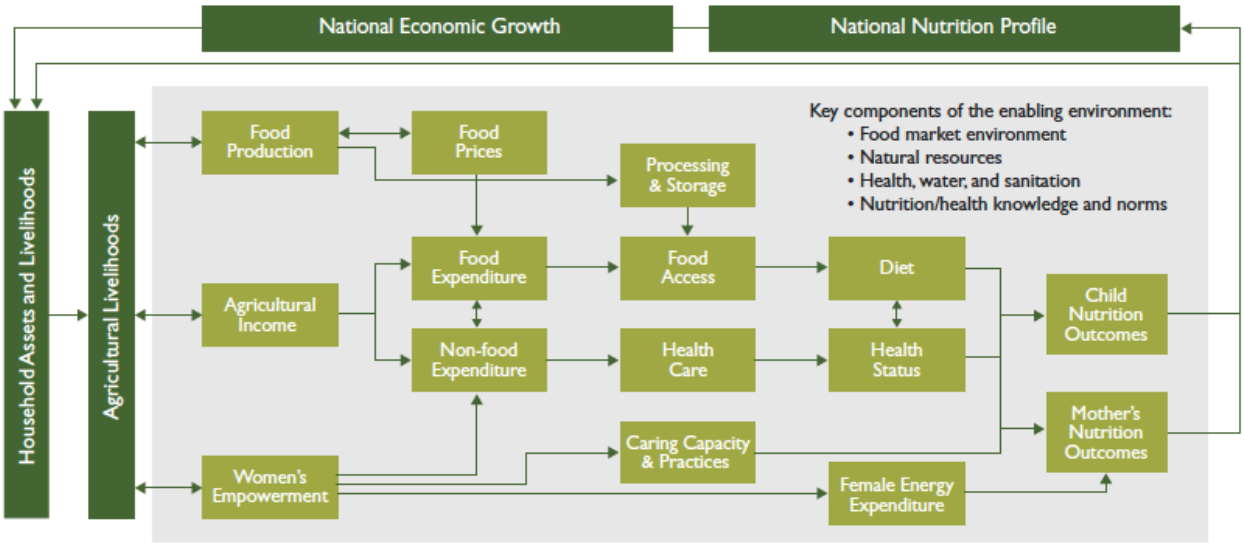

Figure 1. Pathways between agriculture and nutrition
Source: Linking Agriculture & Nutrition: Pathways, Principles, Practice (Herforth & Harris, 2014)

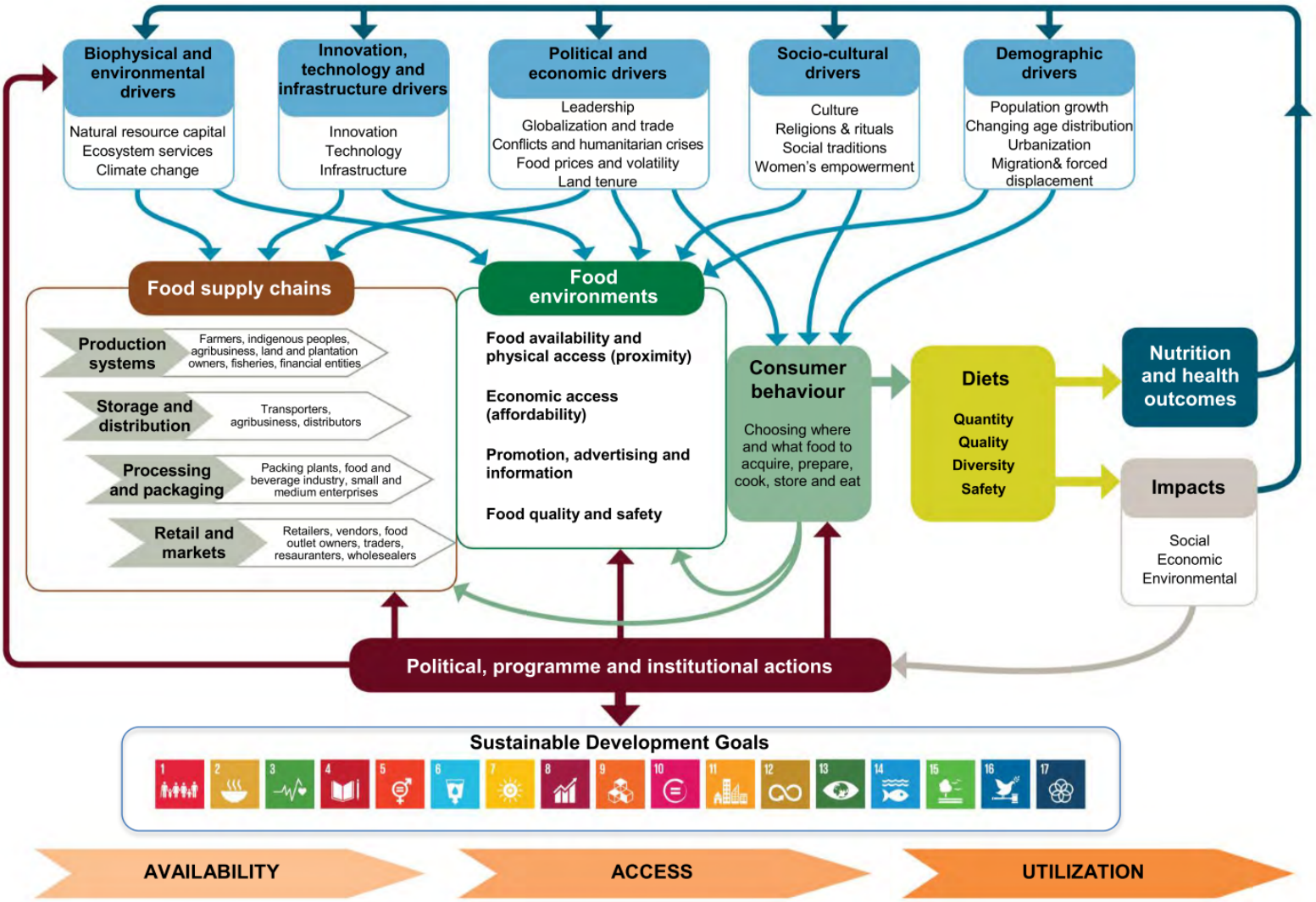

Figure 2. Conceptual framework of food systems linking agriculture to nutrition and health
Source: High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017.

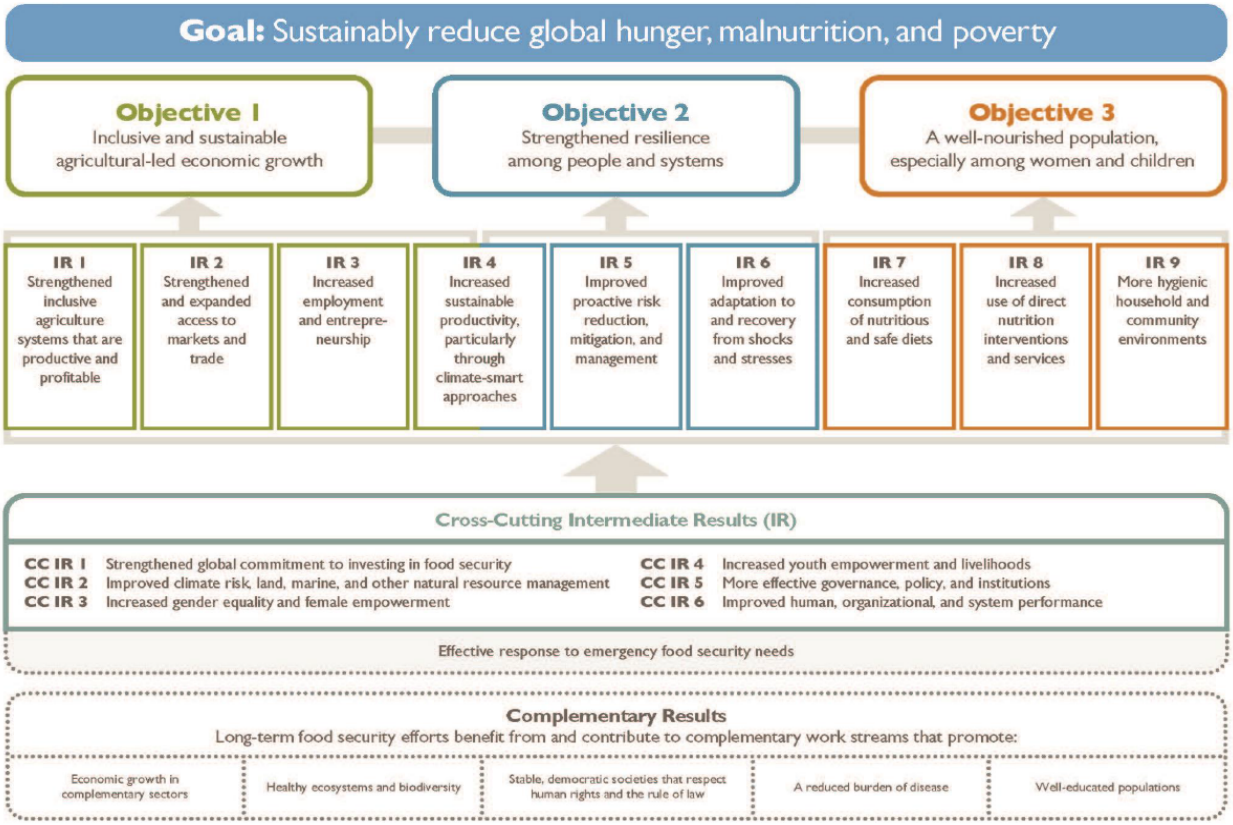

Figure 3. Results Framework for the U.S. Government Global Food Security Strategy (Feed the Future, 2017)

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

FEED THE FUTURE INNOVATION LABS HELP FIGHT GLOBAL HUNGER

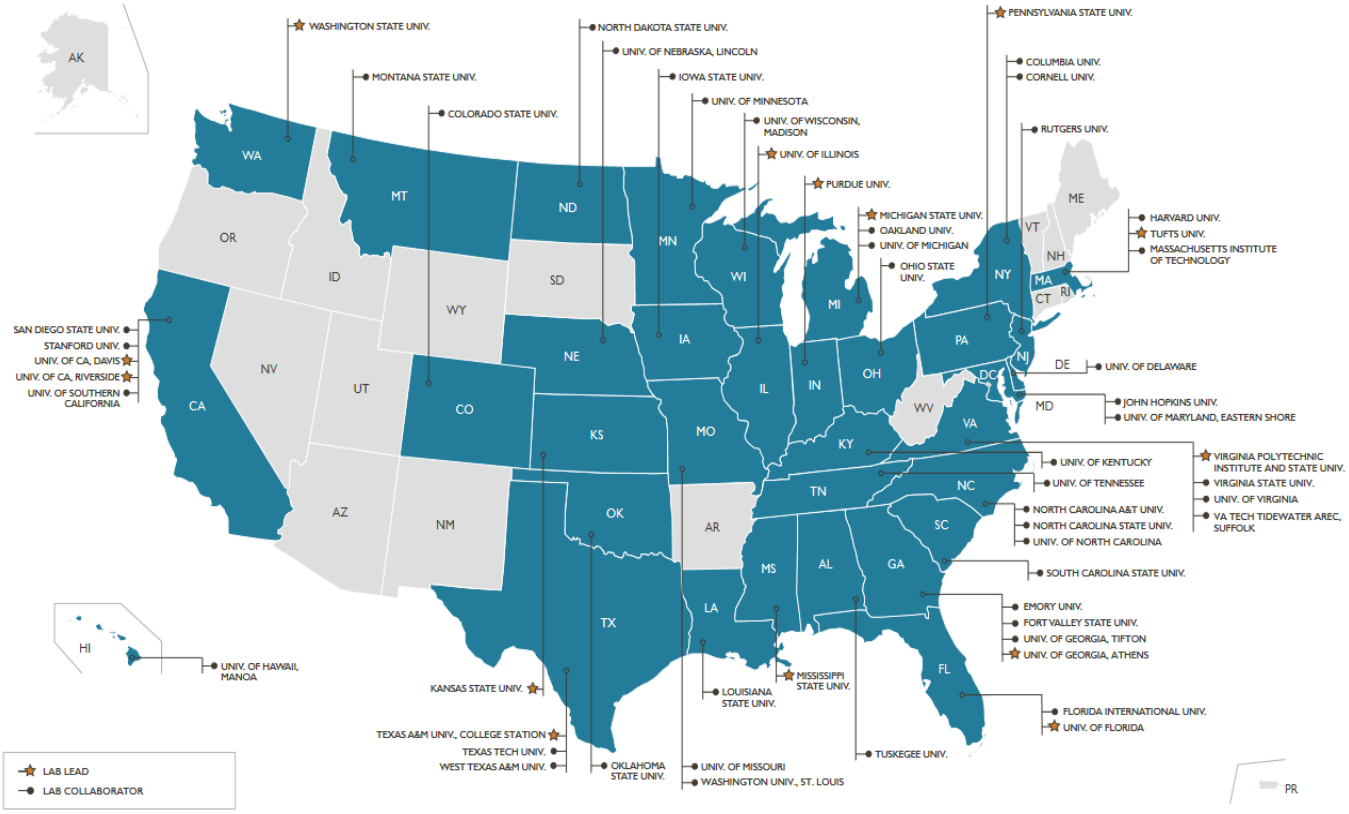

Figure 4. Feed the Future Innovation Lab locations in the United States
Source: Feed the Future, 2019a.


Tool
Method
Metric
Technology: Geospatial application
Technology: Instruments, devices, visual aid
Technology: Mobile, tablet-based or web-based
Surevey and interview tools: Quantitative
Surevy and interview tools: Qualitative
Research design
Analysis
Measures: continuous including scales
Indices: dichotomous or polytomous
Value chains and food transformation
Food Safety
Economy
Water, Sanitation and Hygiene
Markets
Food environments
Ecology, sustainability and environment

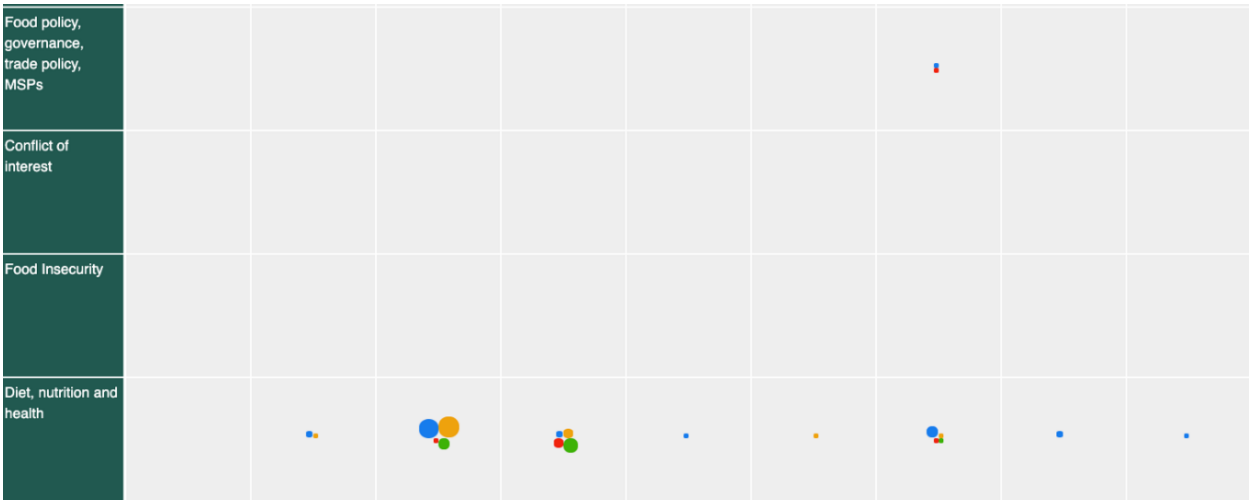

Figure 5. Evidence and gap map on innovative metrics, tools and methods in agriculture-nutrition research, including 318 studies.
Source: DFID, Understanding pathways between agriculture and nutrition (Sparling et al., 2019).

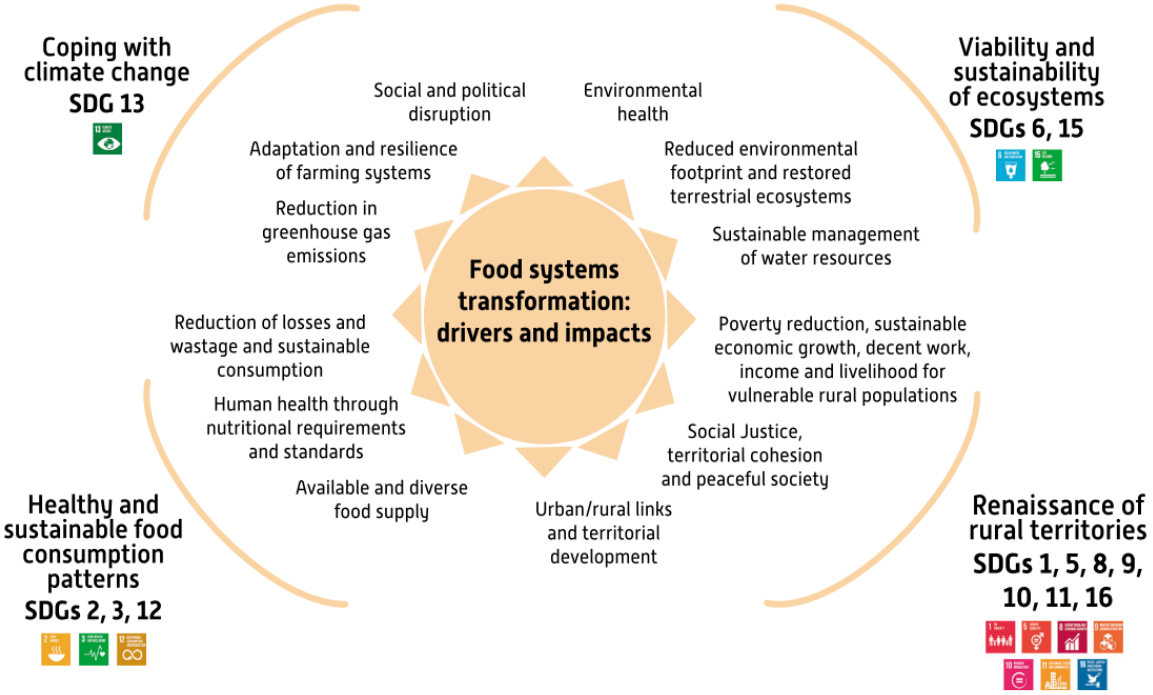

Figure 6. Framework for drivers and impacts of food systems transformation
Source: Caron et al., 2018.

References

Adjaye-Gbewonyo, K., Vollmer, S., Avendano, M., & Harttgen, K. (2019). Agricultural trade policies and child nutrition in low- and middle-income countries: A cross-national analysis. *Globalization and Health*. https://doi.org/10.1186/s12992-019-0463-0

Affognon, H., Mutungi, C., Sanginga, P., & Borgemeister, C. (2015). Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-Analysis. *World Development*, *66*, 49–68. https://doi.org/10.1016/J.WORLDDEV.2014.08.002

Allen, S., & de Brauw, A. (2018). Nutrition sensitive value chains: Theory, progress, and open questions. *Global Food Security*, *16*(July 2017), 22–28. https://doi.org/10.1016/j.gfs.2017.07.002

Alonso, S., Muunda, E., Ahlberg, S., Blackmore, E., & Grace, D. (2018). Beyond food safety: Socio-economic effects of training informal dairy vendors in Kenya. *Global Food Security*. https://doi.org/10.1016/j.gfs.2018.08.006

Andrews-Trevino, J. Y., Webb, P., Shively, G., Rogers, B. L., Baral, K., Davis, D., … Ghosh, S. (2019). Relatively Low Maternal Aflatoxin Exposure Is Associated with Small-for-Gestational-Age but Not with Other Birth Outcomes in a Prospective Birth Cohort Study of Nepalese Infants. *The Journal of Nutrition*, 1–8. https://doi.org/10.1093/jn/nxz122

Antwi-Agyei, P., Cairncross, S., Peasey, A., Price, V., Bruce, J., Baker, K., … Ensink, J. (2015). A farm to fork risk assessment for the use of wastewater in agriculture in Accra, Ghana. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0142346

Augustin, M. A., Riley, M., Stockmann, R., Bennett, L., Kahl, A., Lockett, T., … Cobiac, L. (2016). Role of food processing in food and nutrition security. *Trends in Food Science and Technology*, *56*, 115–125. https://doi.org/10.1016/j.tifs.2016.08.005

Barrett, D. M. (2007). Maximizing the nutritional value of fruits & vegetables. *Food Technology*.

Bhutta, Z. A., Ahmed, T., Black, R. E., Cousens, S., Dewey, K., Giugliani, E., … Maternal and Child Undernutrition Study Group. (2008). *No Title*. *371*(9610). https://doi.org/10.1016/S0140-6736(07)61693-6

Bhutta, Z. A., Das, J. K., Rizvi, A., Gaffey, M. F., Walker, N., Horton, S., … Lancet Nutrition Interventions Review Group, the Maternal and Child Nutrition Study Group. (2013). Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? *Lancet (London, England)*, *382*(9890), 452–477. https://doi.org/10.1016/S0140-6736(13)60996-4

Bill and Melinda Gates Foundation, & UKAID. (2019). *Agriculture for Improved Nutrition: A Future Research Agenda*.

Bird, F. A., Pradhan, A., Bhavani, R. V, & Dangour, A. D. (2019). Interventions in agriculture for nutrition outcomes: A systematic review focused on South Asia. *FOOD POLICY*, *82*(SI), 39–49. https://doi.org/10.1016/j.foodpol.2018.10.015

Black, R. E., Allen, L. H., Bhutta, Z. A., Caulfield, L. E., de Onis, M., Ezzati, M., … Rivera, J. (2008). Maternal and child undernutrition: global and regional exposures and health consequences. *The Lancet*. https://doi.org/10.1016/S0140-6736(07)61690-0

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., Onis, M. de, … Uauy, R. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet*, *382*(9890), 427–451. https://doi.org/10.1016/S0140-

6736(13)60937-X
Bouis, H. E., & Saltzman, A. (2017). Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. *Global Food Security*, *12*(January), 49–58. https://doi.org/10.1016/j.gfs.2017.01.009
Campbell, D. I., Elia, M., & Lunn, P. G. (2018). Growth Faltering in Rural Gambian Infants Is Associated with Impaired Small Intestinal Barrier Function, Leading to Endotoxemia and Systemic Inflammation. *The Journal of Nutrition*, *133*(5), 1332–1338. https://doi.org/10.1093/jn/133.5.1332
Caron, P., y de Loma-Osorio, G., Nabarro, D., Hainzelin, E., Guillou, M., Andersen, I., … Verburg, G. (2018). Food systems for sustainable development: proposals for a profound four-part transformation. *AGRONOMY FOR SUSTAINABLE DEVELOPMENT*, *38*(4). https://doi.org/10.1007/s13593-018-0519-1
Chaccour, C. J., Ngha'bi, K., Abizanda, G., Irigoyen Barrio, A., Aldaz, A., Okumu, F., … Killeen, G. (2018). Targeting cattle for malaria elimination: marked reduction of Anopheles arabiensis survival for over six months using a slow-release ivermectin implant formulation. *Parasites & Vectors*, *11*(1), 287. https://doi.org/10.1186/s13071-018-2872-y
Choi, J. H., Yates, Z., Veysey, M., Heo, Y. R., & Lucock, M. (2014). Contemporary issues surrounding folic acid fortification initiatives. *Preventive Nutrition and Food Science*, *19*(4), 247–260. https://doi.org/10.3746/pnf.2014.19.4.247
Chopera, P., Chagwena, D. T., Mushonga, N. G. T., & Chagwena, D. T. (2014). Food label reading and understanding in parts of rural and urban Zimbabwe. *African Health Sciences*. https://doi.org/10.4314/ahs.v14i3.12
Colchero, M. A., Guerrero-López, C. M., Molina, M., & Rivera, J. A. (2016). Beverages sales in Mexico before and after implementation of a sugar sweetened beverage tax. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0163463
Cunningham, K., Ferguson, E., Ruel, M., Uauy, R., Kadiyala, S., Menon, P., & Ploubidis, G. (2019). Water, sanitation, and hygiene practices mediate the association between women's empowerment and child length-for-age z-scores in Nepal. *Maternal and Child Nutrition*, *15*(1), 1–9. https://doi.org/10.1111/mcn.12638
de Brauw, A., Eozenou, P., Gilligan, D., Hotz, C., Kumar, N., & Meenakshi, J. V. (2018). *Biofortification, crop adoption and health information: Impact pathways in Mozambique and Uganda*. *100*(3), 906–930. https://doi.org/10.1093/ajae/aay005
Delia, G., & Roesel, K. (2014). Food Safety and Informal Markets: Animal products in sub-Saharan Africa. In *Routledge*.
Development Initiatives 2018. (n.d.). *2018 Global Nutrition Report: Shining a light to spur action on nutrition.* Bristol, UK.
Division for Sustainable Development Goals. (n.d.). Sustainable Development Goals. Retrieved July 16, 2019, from https://sustainabledevelopment.un.org/?menu=1300
Dror, D. K., & Allen, L. H. (2011). The importance of milk and other animal-source foods for children in low-income countries. *Food and Nutrition Bulletin*, *32*(3), 227–243. https://doi.org/10.1177/156482651103200307
El Sabry, M. I., McMillin, K. W., & Sabliov, C. M. (2018). Nanotechnology Considerations for Poultry and Livestock Production Systems – A Review. *Annals of Animal Science*, *18*(2), 319–334. https://doi.org/10.1515/aoas-2017-0047

Ensink, J. H. J., Mahmood, T., & Dalsgaard, A. (2007). Wastewater-irrigated vegetables: Market handling versus irrigation water quality. *Tropical Medicine and International Health*. https://doi.org/10.1111/j.1365-3156.2007.01935.x

FAO. (2011). The state of food and agriculture: Women in agriculture. In *FAO report*. Rome.

FAO. (2014). *Strengthening the links between resilience and nutrition in food and agriculture: a discussion paper*. Rome.

FAO. (2015). *The state of agricultural commodity markets: Nutrition in the trade and food security nexus*. Rome.

Feed the Future. (2017). *The U.S. Government's Global Food Security Research Strategy | U.S. Agency for International Development*. Retrieved from https://www.usaid.gov/documents/1867/us-governments-global-food-security-research-strategy

Feed the Future. (2019). *U.S. Government Global Food Security Strategy Implementation Report of 2018*. Retrieved from https://www.feedthefuture.gov/resource/u-s-government-global-food-security-strategy-implementation-report-of-2018/

Feed the Future Innovation Lab for Horticulture. (2019). *New , low-cost indicator of food dryness : DryCard*. 17.

Finaret, A. B., & Masters, W. A. (2019). Beyond Calories: The New Economics of Nutrition. *Annual Review of Resource Economics*. https://doi.org/10.1146/annurev-resource-100518-094053

Food and Agriculture Organization. (2012). *Pesticide residues in food 2012, Joint FAO/WHO Meeting on Pesticide Residues*. Retrieved from https://www.who.int/foodsafety/areas_work/chemical-risks/Pesticide_Residues_in_Food_18-27_September_2018.pdf?ua=1%0Ahttp://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/JMPR/Report12/JMPR_2012_Report.pdf

Food and Agriculture Organization of the United Nations. (1996). *Rome Declaration on World Food Security and World Food Summit Plan of Action: World Food Summit 13-17 November 1996, Rome, Italy*.

Frongillo, E. A., Leroy, J. L., & Lapping, K. (2019). *Appropriate Use of Linear Growth Measures to Assess Impact of Interventions on Child Development and Catch-Up Growth*. 372–379.

Gillespie, S., Poole, N., van den Bold, M., Bhavani, R. V., Dangour, A. D., & Shetty, P. (2019). Leveraging agriculture for nutrition in South Asia: What do we know, and what have we learned? *Food Policy*, *82*(November 2018), 3–12. https://doi.org/10.1016/j.foodpol.2018.10.012

Global Panel on Agriculture and Food Systems for Nutrition. (2016). *Assuring safe food systems : Policy Options for a Healthier Food Supply How can Agriculture and Food System Policies improve Nutrition ?* (5).

Global Panel on Agriculture and Food Systems for Nutrition. (2017). *Policy Actions to support enhanced consumer behavior for high quality diets*. Retrieved from https://www.glopan.org/wp-content/uploads/2019/06/GlobalPanelConsumerBehaviourBrief.pdf

Gollin, D., Hansen, C. W., & Wingender, A. (2018). *Two Blades of Grass: The Impact of the Green Revolution*. https://doi.org/10.3386/w24744

Gómez, M. I., & Ricketts, K. D. (2013). Food value chain transformations in developing

countries: Selected hypotheses on nutritional implications. *Food Policy*, *42*, 139–150. https://doi.org/10.1016/j.foodpol.2013.06.010

Gough, E. K., Prendergast, A. J., Mutasa, K. E., Stoltzfus, R. J., & Manges, A. R. (2015). Assessing the intestinal microbiota in the SHINE Trial. *Clinical Infectious Diseases*. https://doi.org/10.1093/cid/civ850

Grace, D, Makita, K., Ethe, E. K. K., & Bonfoh, B. (2010). Safe Food, Fair Food: Participatory Risk Analysis for improving the safety of informally produced and marketed food in sub Saharan Africa. *Rev Africaine Sante Prod Anim.*, *8*(S), 3–11.

Grace, Delia. (2015a). Food safety in low and middle income countries. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph120910490

Grace, Delia. (2015b). Review of Evidence on Antimicrobial Resistance and Animal Agriculture in Developing Countries. *Availableat: Https://Cgspace.Cgiar.Org/Handle/10568/67092. Accessed 29 October 2015*. https://doi.org/10.12774/eod_cr.june2015.graced

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., & Meybeck, A. (2011). *Global food losses and food waste*. https://doi.org/10.1098/rstb.2010.0126

Haddad, L., Hawkes, C., Webb, P., Thomas, S., Beddington, J., Waage, J., & Flynn, D. (2016). A new global research agenda for food. *Nature*, *540*(7631), 30–32. https://doi.org/10.1038/540030a

Harvey, M., Dangour, A., Lambert, R., Alemu, M., Ashton-Griffiths, E., Green, T., … Sutherland, J. (2014). *Can agriculture interventions promote nutrition?* (March), 70.

Hasyim, H., Dhimal, M., Bauer, J., Montag, D., Groneberg, D. A., Kuch, U., & Müller, R. (2018). Does livestock protect from malaria or facilitate malaria prevalence? A cross-sectional study in endemic rural areas of Indonesia. *Malaria Journal*, *17*(1), 302. https://doi.org/10.1186/s12936-018-2447-6

Hawkes, C., & Ruel, M. (2011). *Value Chains for Nutrition. 2020 Conference: Leveraging Agriculture for Improving Nutrition and Health. 2020 Conference Paper #4. 4*(February 2011), 1–4. Retrieved from http://www.ifpri.org/sites/default/files/publications/2020anhconfpaper04.pdf

Headey, D., Nguyen, P., Kim, S., Rawat, R., Ruel, M., & Menon, P. (2017). Is exposure to animal feces harmful to child nutrition and health outcomes? A multicountry observational analysis. *American Journal of Tropical Medicine and Hygiene*, *96*(4), 961–969. https://doi.org/10.4269/ajtmh.16-0270

Herforth, A., & Ahmed, S. (2015). The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. *Food Security*, *7*(3), 505–520. https://doi.org/10.1007/s12571-015-0455-8

Herforth, A., & Ballard, T. J. (2016). Nutrition indicators in agriculture projects: Current measurement, priorities, and gaps. *Global Food Security*, *10*, 1–10. https://doi.org/10.1016/j.gfs.2016.07.004

Herforth, A., & Harris, J. (2014). Linking Agriculture and Nutrition: Understanding and Applying Primary Pathways and Principles. *Improving Nutrition through Agriculture Technical Brief Series*, (March).

High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. (2017). *Nutrition and Food Systems: A Call for ocherence, action and accountability*. (September). Retrieved from http://www.fao.org/3/a-i7846e.pdf

Hoffmann, V., Jones, K., & Leroy, J. L. (2018). The impact of reducing dietary aflatoxin exposure

on child linear growth: A cluster randomised controlled trial in Kenya. *BMJ Global Health*, *3*(6), 1–8. https://doi.org/10.1136/bmjgh-2018-000983

Hoffmann, V., & Moser, C. (2017). You get what you pay for: the link between price and food safety in Kenya. *Agricultural Economics (United Kingdom)*, *48*(4), 449–458. https://doi.org/10.1111/agec.12346

Horticulture Innovation Lab World Food Center & Program in International and Community Nutrition. (2018). *Aligning the Food System to Meet Dietary Needs: Fruits and Vegetables.* Davis, CA.

Humphrey, J. H., Mbuya, M. N. N., Ntozini, R., Moulton, L. H., Stoltzfus, R. J., Tavengwa, N. V, … Makoni, T. (2018). Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on child stunting and anaemia in rural Zimbabwe: a cluster-randomised trial. *The Lancet Global Health*, *7*(1), e132–e147. https://doi.org/10.1016/s2214-109x(18)30374-7

Iannotti, L. L., Lutter, C. K., Stewart, C. P., Gallegos Riofrío, C. A., Malo, C., Reinhart, G., … Waters, W. F. (2017). Eggs in Early Complementary Feeding and Child Growth: A Randomized Controlled Trial. *Pediatrics*, *140*(1), e20163459. https://doi.org/10.1542/peds.2016-3459

Ickowitz, A., Powell, B., Rowland, D., Jones, A., & Sunderland, T. (2019). Agricultural intensification, dietary diversity, and markets in the global food security narrative. *Global Food Security*, *20*(February 2018), 9–16. https://doi.org/10.1016/j.gfs.2018.11.002

Imbahale, S. S., Montaña Lopez, J., Brew, J., Paaijmans, K., Rist, C., & Chaccour, C. (n.d.). *Mapping the potential use of endectocide-treated cattle to reduce malaria transmission*. https://doi.org/10.1038/s41598-019-42356-x

Jaffee, S., Henson, S., Unnevehr, L., Grace, D., & Cassou, E. (2018). The Safe Food Imperative: Accelerating Progress in Low- and Middle-Income Countries. In *The Safe Food Imperative: Accelerating Progress in Low- and Middle-Income Countries*. https://doi.org/10.1596/978-1-4648-1345-0

Jones, A. D. (2017). Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low- and middle-income countries. *Nutrition Reviews*, *75*(10), 769–782. https://doi.org/10.1093/nutrit/nux040

Jumrani, J., & Birthal, P. S. (2016). Livestock, Women, and Child Nutrition in Rural India. *Agricultural Economics Research Review*, *28*(2), 223. https://doi.org/10.5958/0974-0279.2016.00003.3

Kadiyala, S., Harris, J., Headey, D., Yosef, S., & Gillespie, S. (2014). Agriculture and nutrition in India: mapping evidence to pathways. *Annals of the New York Academy of Sciences*, *1331*(1), 43–56. https://doi.org/10.1111/nyas.12477

Kennedy, E., Kershaw, M., & Coates, J. (2018). Food Systems: Pathways for Improved Diets and Nutrition. *Current Developments in Nutrition*, *2*(9), 1–3. https://doi.org/10.1093/cdn/nzy027

Keusch, G. T., Denno, D. M., Black, R. E., Duggan, C., Guerrant, R. L., Lavery, J. V., … Brewer, T. (2014). Environmental enteric dysfunction: Pathogenesis, diagnosis, and clinical consequences. *Clinical Infectious Diseases*, *59*(Suppl 4), S207–S212. https://doi.org/10.1093/cid/ciu485

Keusch, G. T., Rosenberg, I. H., Denno, D. M., Duggan, C., Guerrant, R. L., Lavery, J. V., … Brewer, T. (2013). Implications of acquired environmental enteric dysfunction for growth

and stunting in infants and children living in low-and middle-income countries. *Food and Nutrition Bulletin*, *34*(3), 357–364. https://doi.org/10.1177/156482651303400308
Kitinoja, L. (2013). *Use of cold chains for reducing food losses in developing countries*. Oregon, USA.
Kjeldsberg, C., Shrestha, N., Patel, M., Davis, D., Mundy, G., & Cunningham, K. (2018). Nutrition-sensitive agricultural interventions and gender dynamics: A qualitative study in Nepal. *Maternal and Child Nutrition*, *14*(3), 1–9. https://doi.org/10.1111/mcn.12593
Kosek, M., Haque, R., Lima, A., Babji, S., Shrestha, S., Qureshi, S., … Gottlieb, M. (2013). Fecal markers of intestinal inflammation and permeability associated with the subsequent acquisition of linear growth deficits in infants. *American Journal of Tropical Medicine and Hygiene*, *88*(2), 390–396. https://doi.org/10.4269/ajtmh.2012.12-0549
Kumar, D., & Kalita, P. (2017). Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. *Foods*, *6*(1), 8. https://doi.org/10.3390/foods6010008
Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., & Ward, P. J. (2012). Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of the Total Environment*, *438*, 477–489. https://doi.org/10.1016/j.scitotenv.2012.08.092
L'Aquila Joint Statement on Global Food Security: L'Aquila Food Security Initiative. (n.d.). Retrieved July 14, 2019, from https://www.globalpolicy.org/images/pdfs/SocEcon/LAquila_Joint_Statement_on_Global_Food_Security10.pdf
Lagerkvist, C. J., Amuakwa-Mensah, F., & Tei Mensah, J. (2018). How consumer confidence in food safety practices along the food supply chain determines food handling practices: Evidence from Ghana. *Food Control*, *93*(June), 265–273. https://doi.org/10.1016/j.foodcont.2018.06.019
Lauer, J. M., Duggan, C. P., Ausman, L. M., Griffiths, J. K., Webb, P., Agaba, E., … Ghosh, S. (2018). Biomarkers of maternal environmental enteric dysfunction are associated with shorter gestation and reduced length in newborn infants in Uganda. *American Journal of Clinical Nutrition*, *108*(4), 889–896. https://doi.org/10.1093/ajcn/nqy176
Lauer, J. M., Duggan, C. P., Ausman, L. M., Griffiths, J. K., Webb, P., Bashaasha, B., … Ghosh, S. (2018). Unsafe drinking water is associated with environmental enteric dysfunction and poor growth outcomes in young children in rural southwestern Uganda. *American Journal of Tropical Medicine and Hygiene*. https://doi.org/10.4269/ajtmh.18-0143
Lauer, J. M., Duggan, C. P., Ausman, L. M., Griffiths, J. K., Webb, P., Wang, J. S., … Ghosh, S. (2019). Maternal aflatoxin exposure during pregnancy and adverse birth outcomes in Uganda. *Maternal and Child Nutrition*, *15*(2), 1–7. https://doi.org/10.1111/mcn.12701
Lee, R., Singh, L., van Liefde, D., Callaghan-Gillespie, M., Steiner-Asiedu, M., Saalia, K., … Manary, M. J. (2018). Milk Powder Added to a School Meal Increases Cognitive Test Scores in Ghanaian Children. *The Journal of Nutrition*. https://doi.org/10.1093/jn/nxy083
Leroy, J. L., & Frongillo, E. A. (2019). Perspective: What Does Stunting Really Mean? A Critical Review of the Evidence. *Advances in Nutrition (Bethesda, Md.)*. https://doi.org/10.1093/advances/nmy101
Lin, A., Arnold, B. F., Afreen, S., Goto, R., Huda, T. M. N., Haque, R., … Luby, S. P. (2013). Household environmental conditions are associated with enteropathy and impaired growth

in rural Bangladesh. *American Journal of Tropical Medicine and Hygiene*, *89*(1), 130–137. https://doi.org/10.4269/ajtmh.12-0629

Lin, B. B. (2011). Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change. *BioScience*. https://doi.org/10.1525/bio.2011.61.3.4

Lombard, M. J. (2014). Mycotoxin exposure and infant and young child growth in Africa: what do we know? *Annals of Nutrition & Metabolism*, *64*, 42–52. https://doi.org/10.1159/000365126

Lunn, P. G. (2000). The impact of infection and nutrition on gut function and growth in childhood. *Proceedings of the Nutrition Society*, *59*(1), 147–154. https://doi.org/10.1017/s0029665100000173

Macours, K. (2019). Farmers' Demand and the Traits and Diffusion of Agricultural Innovations in Developing Countries. *Annual Review of Resource Economics*, *11*(1), annurev-resource-100518-094045. https://doi.org/10.1146/annurev-resource-100518-094045

Maestre, M., Poole, N., & Henson, S. (2017). Assessing food value chain pathways, linkages and impacts for better nutrition of vulnerable groups. *Food Policy*, *68*, 31–39. https://doi.org/10.1016/j.foodpol.2016.12.007

Malapit, H. J., Sproule, K., Kovarik, C., Meinzen-Dick, R. S., Quisumbing, A. R., Ramzan, F., … Alkire, S. (2014). Measuring progress toward empowerment: Women's empowerment in agriculture index: Baseline report. *IFPRI Books*. Retrieved from https://ideas.repec.org/b/fpr/ifprib/oclc884924765.html

Manyema, M., Veerman, L. J., Chola, L., Tugendhaft, A., Sartorius, B., Labadarios, D., & Hofman, K. J. (2014). The potential impact of a 20% tax on sugar-sweetened beverages on obesity in South African adults: A mathematical model. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0105287

Martin, W. (2017). *Win-Win: How international trade can help meet the sustainable development goals - Chapter 5 - Agricultral trade and hunger* (M. Helble & B. Shepherd, Eds.). Tokyo: Asian Development Bank Institute.

Martin, W. (2018). *Food trade policy and the dietary transition*. Washington D.C.

Martin, W., & Laborde, D. (2018). Trade: The free flow of goods and food security and nutrition, Chapter 3. In International Food Policy Research Institute (Ed.), *Global Food Policy Report*. https://doi.org/10.2499/9780896292970_03

Masset, E., Haddad, L., Cornelius, A., & Isaza-Castro, J. (2012). Effectiveness of agricultural interventions that aim to improve nutritional status of children: systematic review. *BMJ (Clinical Research Ed.)*, *344*, d8222. https://doi.org/10.1136/bmj.d8222

Masters, W. A., Bai, Y., Herforth, A., Sarpong, D. B., Mishili, F., Kinabo, J., & Coates, J. C. (2018). Measuring the affordability of nutritious diets in Africa: Price indexes for diet diversity and the cost of nutrient adequacy. *American Journal of Agricultural Economics*, *100*(5), 1285–1301. https://doi.org/10.1093/ajae/aay059

Masters, W. A., Rosenblum, N. Z., & Alemu, R. G. (2018). Agricultural Transformation, Nutrition Transition and Food Policy in Africa: Preston Curves Reveal New Stylised Facts. *Journal of Development Studies*, *54*(5), 788–802. https://doi.org/10.1080/00220388.2018.1430768

Micha, R., Coates, J., Leclercq, C., Charrondiere, U. R., & Mozaffarian, D. (2018). Global Dietary Surveillance: Data Gaps and Challenges. *Food and Nutrition Bulletin*.

https://doi.org/10.1177/0379572117752986
Monteiro, C., Cannon, G., Levy, R., Moubarac, J.-C., Jaime, P., Martins, A. P., … Parra, D. (2016). The Food System: Food classification. Public health. NOVA. The star shines bright. *World Nutrition*, *7*(1–3), 28–38. Retrieved from https://worldnutritionjournal.org/index.php/wn/article/view/5
Mosites, E., Thumbi, S. M., Otiang, E., McElwain, T. F., Njenga, M., Rabinowitz, P. M., … Walson, J. L. (2016). Relations between Household Livestock Ownership, Livestock Disease, and Young Child Growth. *The Journal of Nutrition*, *146*(5), 1118–1124. https://doi.org/10.3945/jn.115.225961
Muhammad, A., D'Souza, A., Meade, B., Micha, R., & Mozaffarian, D. (2017). How income and food prices influence global dietary intakes by age and sex: Evidence from 164 countries. *BMJ Global Health*. https://doi.org/10.1136/bmjgh-2016-000184
Mulmi, P., Masters, W. A., Ghosh, S., Namirembe, G., Rajbhandary, R., Manohar, S., … Webb, P. (2017). Household food production is positively associated with dietary diversity and intake of nutrient-dense foods for older preschool children in poorer families: Results from a nationally-representative survey in Nepal. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0186765
Murcott, S. (2012). Arsenic Contamination in the World: An International Sourcebook 2012. *Water Intelligence Online*. https://doi.org/10.2166/9781780400396
National Treasury, R. of S. A. (2016). *Taxation of sugar sweetened beverages*. (July), 1–30. Retrieved from http://www.treasury.gov.za/public comments/Sugar sweetened beverages/POLICY PAPER AND PROPOSALS ON THE TAXATION OF SUGAR SWEETENED BEVERAGES-8 JULY 2016.pdf
Neff, R. A., Hartle, J. C., Laestadius, L. I., Dolan, K., Rosenthal, A. C., & Nachman, K. E. (2012). A comparative study of allowable pesticide residue levels on produce in the United States. *Globalization and Health*. https://doi.org/10.1186/1744-8603-8-2
Neumann, C. G., Murphy, S. P., Gewa, C., Grillenberger, M., & Bwibo, N. O. (2007). Meat Supplementation Improves Growth, Cognitive, and Behavioral Outcomes in Kenyan Children. *The Journal of Nutrition*, *137*(4), 1119–1123. https://doi.org/10.1093/jn/137.4.1119
Ngenoh, E., Kurgat, B. K., Bett, H. K., Kebede, S. W., & Bokelmann, W. (2019). Determinants of the competitiveness of smallholder African indigenous vegetable farmers in high-value agro-food chains in Kenya: A multivariate probit regression analysis. *Agricultural and Food Economics*, *7*(1). https://doi.org/10.1186/s40100-019-0122-z
Niebylski, M. L., Redburn, K. A., Duhaney, T., & Campbell, N. R. (2015a). Healthy food subsidies and unhealthy food taxation: A systematic review of the evidence. *Nutrition*, *31*(6), 787–795. https://doi.org/10.1016/j.nut.2014.12.010
Niebylski, M. L., Redburn, K. A., Duhaney, T., & Campbell, N. R. (2015b). Healthy food subsidies and unhealthy food taxation: A systematic review of the evidence. *Nutrition*, *31*(6), 787–795. https://doi.org/10.1016/j.nut.2014.12.010
Nitya, R., & Raju, S. (2017). Gendered Time, Seasonality and Nutrition: Insights from Two Indian Districts. *Lansa*, *2017*(22).
Null, C., Stewart, C. P., Pickering, A. J., Dentz, H. N., Arnold, B. F., Arnold, C. D., … Colford, J. M. (2018). Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. *The*

Lancet Global Health, *6*(3), e316–e329. https://doi.org/10.1016/S2214-109X(18)30005-6
Oberoi, S., Barchowsky, A., & Wu, F. (2014). The global burden of disease for skin, lung, and bladder cancer caused by arsenic in food. *Cancer Epidemiology Biomarkers and Prevention*. https://doi.org/10.1158/1055-9965.EPI-13-1317
Omotayo, O. P., Omotayo, A. O., Mwanza, M., & Babalola, O. O. (2019). Prevalence of mycotoxins and their consequences on human health. *Toxicological Research*. https://doi.org/10.5487/TR.2019.35.1.001
Ordiz, M. I., Shaikh, N., Trehan, I., Maleta, K., Stauber, J., Shulman, R., … Manary, M. J. (2016). Environmental enteric dysfunction is associated with poor linear growth and can be identified by host fecal mRNAs. *Journal of Pediatric Gastroenterology and Nutrition*, *63*(5), 453–459. https://doi.org/10.1097/MPG.0000000000001315
Osendarp, S. J. M., Martinez, H., Garrett, G. S., Neufeld, L. M., De-Regil, L. M., Vossenaar, M., & Darnton-Hill, I. (2018). Large-Scale Food Fortification and Biofortification in Low- and Middle-Income Countries: A Review of Programs, Trends, Challenges, and Evidence Gaps. *Food and Nutrition Bulletin*, *39*(2), 315–331. https://doi.org/10.1177/0379572118774229
Pachepsky, Y., Shelton, D. R., McLain, J. E. T., Patel, J., & Mandrell, R. E. (2011). Irrigation Waters as a Source of Pathogenic Microorganisms in Produce. A Review. In *Advances in Agronomy*. https://doi.org/10.1016/B978-0-12-386473-4.00007-5
Pangaribowo, E. H., Gerber, N., & Torero, M. (2013). *Food and nutrition security indicators: A review*. (February), 63. https://doi.org/ISSN 1864-6638
Parfitt, J., Barthel, M., & MacNaughton, S. (2010). Food waste within food supply chains: Quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 3065–3081. https://doi.org/10.1098/rstb.2010.0126
Passarelli, S., Mekonnen, D., Bryan, E., & Ringler, C. (2018). Evaluating the pathways from small-scale irrigation to dietary diversity: evidence from Ethiopia and Tanzania. *Food Security*, *10*(4), 981–997. https://doi.org/10.1007/s12571-018-0812-5
Pingali, P. (2015). Agricultural policy and nutrition outcomes – getting beyond the preoccupation with staple grains. *Food Security*. https://doi.org/10.1007/s12571-015-0461-x
Popkin, B. M. (2014a). Nutrition, agriculture and the global food system in low and middle income countries. *Food Policy*, *47*, 91–96. https://doi.org/10.1016/j.foodpol.2014.05.001
Popkin, B. M. (2014b). Nutrition, agriculture and the global food system in low and middle income countries. *Food Policy*, *47*, 91–96. https://doi.org/10.1016/j.foodpol.2014.05.001
Prendergast, A. J., Rukobo, S., Chasekwa, B., Mutasa, K., Ntozini, R., Mbuya, M. N. N., … Humphrey, J. H. (2014). Stunting is characterized by chronic inflammation in zimbabwean infants. *PLoS ONE*, *9*(2). https://doi.org/10.1371/journal.pone.0086928
Rios, A. R., Shively, G. E., & Masters, W. A. (2009). Farm Productivity and Household Market Participation: Evidence from LSMS Data by Ana R. Rios * , Gerald E. Shively ** , and William A. Masters **. *Development*.
Ruel, M. T., & Alderman, H. (2013a). Maternal and Child Nutrition 3 Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? *www.Thelancet.Com*, *382*. https://doi.org/10.1016/S0140-6736(13)60843-0
Ruel, M. T., & Alderman, H. (2013b). Nutrition-sensitive interventions and programmes: How can they help to accelerate progress in improving maternal and child nutrition? *The Lancet*,

382(9891), 536–551. https://doi.org/10.1016/S0140-6736(13)60843-0
Ruel, M. T., Quisumbing, A. R., & Balagamwala, M. (2018). Nutrition-sensitive agriculture: What have we learned so far? *Global Food Security*. https://doi.org/10.1016/j.gfs.2018.01.002
Santoso, M. V, Kerr, R. B., Hoddinott, J., Garigipati, P., Olmos, S., & Young, S. L. (2019). *Role of Women ' s Empowerment in Child Nutrition Outcomes : A Systematic Review*. 1–14.
Shankar, B., Poole, N., & Bird, F. A. (2019). Agricultural inputs and nutrition in South Asia. *Food Policy*, *82*(October 2018), 28–38. https://doi.org/10.1016/j.foodpol.2018.10.011
Shapiro, M. J., Downs, S. M., Swartz, H. J., Parker, M., Quelhas, D., Kreis, K., … Fanzo, J. (2019). A Systematic Review Investigating the Relation Between Animal-Source Food Consumption and Stunting in Children Aged 6–60 Months in Low and Middle-Income Countries. *Advances in Nutrition*. https://doi.org/10.1093/advances/nmz018
Sibhatu, K. T., & Qaim, M. (2017). Rural food security, subsistence agriculture, and seasonality. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0186406
Sibhatu, K. T., & Qaim, M. (2018). Review: The association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy*, *77*(October 2017), 1–18. https://doi.org/10.1016/j.foodpol.2018.04.013
Smith, L. E., Prendergast, A. J., Turner, P. C., Mbuya, M. N. N., Mutasa, K., Kembo, G., & Stoltzfus, R. J. (2015). The potential role of mycotoxins as a contributor to stunting in the SHINE Trial. *Clinical Infectious Diseases*, *61*(Suppl 7), S733–S737. https://doi.org/10.1093/cid/civ849
Smith, L. E., Stoltzfus, R. J., & Prendergast, A. (2012). Food Chain Mycotoxin Exposure, Gut Health, and Impaired Growth: A Conceptual Framework. *Advances in Nutrition*, *3*(4), 526–531. https://doi.org/10.3945/an.112.002188
Smith, V. H. (2016). Producer insurance and risk management options for smallholder farmers. *World Bank Research Observer*. https://doi.org/10.1093/wbro/lkw002
Sparling, T., White, H., John, D., Saran, A., Boakye, S., & Kadiyala, S. (2019). *Understanding pathways between agriculture and nutrition: A gap map of tools, metrics and methods developed and applied in the last ten years*.
Syed, S., & Duggan, C. P. (2016). Risk Factors for Malnutrition and Environmental Enteric Dysfunction—You Really Are What You Eat. *Journal of Pediatrics*. https://doi.org/10.1016/j.jpeds.2016.08.005
Talsma, E. F., Melse-Boonstra, A., & Brouwer, I. D. (2017). Acceptance and adoption of biofortified crops in low- and middle-income countries: A systematic review. *Nutrition Reviews*, *75*(10), 798–829. https://doi.org/10.1093/nutrit/nux037
Thapa, G., & Shively, G. (2018). A dose-response model of road development and child nutrition in Nepal. *Research in Transportation Economics*, *70*, 112–124. https://doi.org/10.1016/J.RETREC.2018.11.002
Thumbi, S. M., Njenga, M. K., Marsh, T. L., Noh, S., Otiang, E., Munyua, P., … McElwain, T. F. (2015). Linking Human Health and Livestock Health: A "One-Health" Platform for Integrated Analysis of Human Health, Livestock Health, and Economic Welfare in Livestock Dependent Communities. *PLOS ONE*, *10*(3), e0120761. https://doi.org/10.1371/journal.pone.0120761
Torjesen, I. (2019). WHO pulls support from initiative promoting global move to plant based foods. *BMJ (Clinical Research Ed.)*. https://doi.org/10.1136/bmj.l1700

Tschirley, D., Reardon, T., Dolislager, M., & Snyder, J. (2015). The rise of a middle class in east and southern Africa: Implications for food system transformation. *Journal of International Development*. https://doi.org/10.1002/jid.3107

Turner, R., Hawkes, C., Waage, J., Ferguson, E., Haseen, F., Homans, H., … Shankar, B. (2013). Agriculture for Improved Nutrition: The Current Research Landscape. *Food and Nutrition Bulletin*, *34*(4), 369–377. https://doi.org/10.1177/156482651303400401

Tyczewska, A., Woźniak, E., Gracz, J., Kuczyński, J., Twardowski, T., Wozniak, E., … Twardowski, T. (2018). Towards Food Security: Current State and Future Prospects of Agrobiotechnology. *Trends in Biotechnology*, *36*(12), 1219–1229. https://doi.org/10.1016/j.tibtech.2018.07.008

United States Agency for International Development. (2016). *U.S. Government Global Food Security Strategy FY 2017-2021*. Retrieved from https://www.usaid.gov/what-we-do/agriculture-and-food-security/us-government-global-food-security-strategy

Unnevehr, L., Grace, D., BANDYOPADHYAY, R., COTTY, P. J., WALKER, S., DAVIES, B., … Grace, D. (2013). Aflatoxins Finding Solutions for Improved Food Safety. In *2020 Vision Focus*. https://doi.org/http://dx.doi.org/10.2499/9780896296763

USAID. (2012). Building Resilience to Recurrent Crisis - USAID Policy and Program Guidance. In *USAID Report*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:No+Title#0

USAID. (2014). *USAID Multi-Sectoral Nutrition Strategy 2014-2025*. Retrieved from https://www.usaid.gov/nutrition-strategy

USAID, & Tufts University. (2019). Feed the Future Innovation Lab for Nutrition. Retrieved from https://www.nutritioninnovationlab.org/what-we-do/research-themes/nutrition-agriculture-linkages

USDA. (2019). United States Department of Agriculture. Retrieved August 31, 2019, from https://www.usda.gov/

Verger, E. O., Ballard, T. J., Dop, M. C., & Martin-Prevel, Y. (2019). Systematic review of use and interpretation of dietary diversity indicators in nutrition-sensitive agriculture literature. *Global Food Security*, *20*, 156–169. https://doi.org/10.1016/J.GFS.2019.02.004

Vipham, J. L., Chaves, B. D., & Trinetta, V. (2018). Mind the gaps: How can food safety gaps be addressed in developing nations? *Animal Frontiers*, *8*(4), 16–25. https://doi.org/10.1093/af/vfy020

Wang, P., Afriyie-gyawu, E., Tang, Y., Johnson, N. M., Xu, L., Tang, L., … Phillips, T. D. (2008). NovaSil clay intervention in Ghanaians at high risk for aflatoxicosis: II. Reduction in biomarkers of aflatoxin exposure in blood and urine. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*. https://doi.org/10.1080/02652030701598694

Watson, S., Moore, S. E., Darboe, M. K., Chen, G., Tu, Y.-K., Huang, Y.-T., … Gong, Y. Y. (2018). Impaired growth in rural Gambian infants exposed to aflatoxin: a prospective cohort study. *BMC Public Health*, *18*(1), 1–10. https://doi.org/10.1186/s12889-018-6164-4

Webb, P., & Kennedy, E. (2014). Impacts of Agriculture on Nutrition: Nature of the Evidence and Research Gaps. *Food and Nutrition Bulletin*, *35*(1), 126–132. https://doi.org/10.1177/1564826514035001 13

Weisz, A. J., Manary, M. J., Stephenson, K., Agapova, S., Manary, F. G., Thakwalakwa, C., …

Manary, M. J. (2012). Abnormal gut integrity is associated with reduced linear growth in rural Malawian children. *Journal of Pediatric Gastroenterology and Nutrition*, *55*(6), 747–750. https://doi.org/10.1097/MPG.0b013e3182650a4d

WHO. (2015). Estimates of the global burden of foodborne diseases. In *World Health Organization*.

Wild, Christopher P., & Gong, Y. Y. (2010). Mycotoxins and human disease: A largely ignored global health issue. *Carcinogenesis*, *31*(1), 71–82. https://doi.org/10.1093/carcin/bgp264

Wild, Christopher Paul. (2007). Aflatoxin exposure in developing countries: The critical interface of agriculture and health. *Food and Nutrition Bulletin*.

Wilde, P. E., Conrad, Z., Rehm, C. D., Pomeranz, J. L., Penalvo, J. L., Cudhea, F., … Mozaffarian, D. (2018). Reductions in national cardiometabolic mortality achievable by food price changes according to Supplemental Nutrition Assistance Program (SNAP) eligibility and participation. *Journal of Epidemiology and Community Health*, *72*(9), 817–824. https://doi.org/10.1136/jech-2017-210381

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., … Murray, C. J. L. (2019). Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet (London, England)*. https://doi.org/10.1016/S0140-6736(18)31788-4

Williams, S. B., Baributsa, D., & Woloshuk, C. (2014). Assessing Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and aflatoxin contamination. *Journal of Stored Products Research*, *59*, 190–196. https://doi.org/10.1016/j.jspr.2014.08.003

Wood, S. A., Smith, M. R., Fanzo, J., Remans, R., & Defries, R. S. (2018). Trade and the equitability of global food nutrient distribution. *Nature Sustainability*. https://doi.org/10.1038/s41893-017-0008-6

World Health Organization (WHO). (2015). Who estimates of the global burden of foodborne diseases. *Foodborne Disease Burden Epidemiology Reference Group*, 265.

Yadava, D. K., Hossain, F., & Mohapatra, T. (2018). Nutritional security through crop biofortification in India: Status & future prospects. *The Indian Journal of Medical Research*, *148*(5), 621–631. https://doi.org/10.4103/ijmr.IJMR_1893_18

Zuma, M. K., Kolanisi, U., & Modi, A. T. (2018). The potential of integrating provitamin A-biofortified maize in smallholder farming systems to reduce malnourishment in South Africa. *International Journal of Environmental Research and Public Health*, *15*(4). https://doi.org/10.3390/ijerph15040805