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Food System Innovations for Healthier Diets in Low and Middle-Income Countries

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ABSTRACT

Malnutrition in all its forms is a major challenge everywhere in the world, and particularly in low and middle income countries. To reduce malnutrition, innovations in food systems are needed to both provide sufficient options for consumers to obtain diets with adequate nutritional value, and to help consumers make conscious and unconscious choices to choose healthier diets. A potential solution to this challenge is food systems innovations designed to lead to healthier diets. In this paper, we lay out a multidisciplinary framework for both identifying and analyzing innovations in food systems that can lead to improvements in the choices available to consumers and their diets from a health perspective. The framework identifies entry points for the design of potential food systems innovations, highlighting potential synergies, feedback, and tradeoffs within the food system. The paper concludes by providing examples of potential innovations and describes future research that can be developed to support the role of food systems in providing healthier diets.

Keywords: food systems; healthier diets; research framework; innovations

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ACRONYMS

ANH	Agriculture, Nutrition, and Health
FAO	Food and Agriculture Organization of the United Nations
GLOPAN	Global Panel on Agriculture and Food Systems in Nutrition
HLPE	High Level Panel of Experts on Food Security and Nutrition
ICT	Information and Communication Technologies
IFPRI	International Food Policy Research Institute
IOM	Institute of Medicine
LMIC	Low and Middle Income Countries
NRC	National Research Council
UNEP	United Nations Environment Programme

1 RATIONALE

Malnutrition in all its forms presents a major challenge everywhere in the world (IFPRI, 2016). According to FAO (2018b) nearly 30% of world population suffers from some form of malnutrition. While undernutrition, defined as insufficient food intake, has become somewhat less common in recent years, two other types of malnutrition are becoming more prominent, even in low and middle income countries (LMICs). Awareness has grown that hundreds of millions suffer from micronutrient deficiencies, and the number of people suffering from overweight and obesity are rapidly increasing almost everywhere. Adding to their burden of undernutrition and micronutrient deficiencies, LMICs are quickly joining the ranks of countries dealing with health problems related to overweight and obesity (e.g. Abarca-Gómez et al., 2017). The latter increase coincides with the transition from a traditional to a modern diet and the rapid increase in consumption of ultra-processed food, as well as more sedentary lifestyles in urban areas (Monteiro et al., 2018).

The triple burden of malnutrition suggests food systems are not providing consumers with options to choose diets with adequate nutritional value. From the perspective of economics, a market failure is occurring; prices for foods may reflect relative scarcity, but do not absorb the private or societal costs of people consuming unhealthy diets. From the consumer perspective, the healthy choice is not always easiest or preferred. To overcome this market failure and provide for healthier diets from a nutritional perspective, changes in food systems are necessary that simultaneously support supply-side opportunities and demand-side motives for healthier food choices at prices that make healthier food available at all wealth levels (Ruben et al., 2019).

A wide variety of potential approaches can be considered to systematically address problems with insufficient food availability or unbalanced diets. However, some alternatives focus solely on improving the availability of or access to specific types of nutritious food through single value chains (e.g. Gelli et al., 2015). Moreover, some perspectives on the shortcomings of food systems will not necessarily lead to dietary improvements (e.g. Bene et al., 2019). For example, improving the food system from an

agroecological perspective could worsen nutritional outcomes. Resource constraints, lack of information, customs or cultural beliefs, and poor availability of more nutritious foods can also constrain consumer options.

Meanwhile, recently a great deal of attention has been placed on optimizing diets both for nutrition and for environmental concerns (Willett et al., 2019). Although the EAT-Lancet proposed diet has introduced controversy, how food systems can induce people to choose healthier diets remains an open question. Here, we argue that a potential solution is to use food systems focused research to identify innovations for healthier diets. Such research focuses on interactions between the demand and supply of quality food, nutrition-sensitive distribution networks and value chains, consumer preferences and barriers, and the legal and institutional food environment that enables people and households to shape their dietary choices (Ruben et al., 2019). To properly target changes in food systems, an initial appraisal of dietary imbalances—meaning between the actual diet and a healthy diet—is required to identify key entry points for food systems innovations, from the perspective of improving dietary quality. Diets are individual specific, so this type of research must incorporate both systems analysis and an understanding of the role of factors such as an individual's gender, age, culture, and place of residence in determining how to make the diet healthier.

From a dietary perspective, we define a food systems innovation as a policy or regulation, an institutional process, a change in knowledge, a technology, or combination thereof that is either not used or not widely used within a food system, but has the potential to change diets on a wider scale (e.g. Hekkert et al., 2007). Interventions, then, are a subset of innovations that take place largely through public investment rather than by the private sector alone, or through public-private partnerships. Based on an analytical understanding of interactions within a food system, different types of innovations or interventions can be designed that should be assessed for effectiveness and impact in supporting healthier diets among individuals. Rather than only considering how to increase supply of healthier foods either overall or within specific food environments, this approach incorporates the potential for complementary or standalone behavioral change campaigns among consumers or other actors within the food system.

The main aim of this paper/article is to identify and describe how a food systems framework can be used to develop innovations that have the potential to transform food systems performance towards providing healthier diets for people in LMICs. The paper is organized as follows. The following section further develops the argument that a food systems perspective is appropriate for developing innovations that could lead to healthier diets. The next section introduces a multi-disciplinary theoretical framework to contextualize innovations, followed by a discussion of suitable entry points for dietary improvements. After discussing examples of food systems innovations, we discuss potential avenues for future research on food systems innovations. The final section concludes.

2 WHY DO WE NEED A FOOD SYSTEMS PERSPECTIVE FOR HEALTHIER DIETS?

To be able to understand the types of food systems innovations that can potentially improve diets, it is important to present definitions of both healthier diets and food systems. We first define a healthy diet as involving aspects of nutrient adequacy, dietary balance and moderation. The World Health Organization defines a healthy diet as being one that has energy intakes in balance with energy expenditures. Fat intakes should be no more than 30 percent of total energy intake, with saturated fats making up one third or less of total fat intakes. Added sugar should also be a low percentage of total calorie intakes (less than 10 percent of total calories, but better is lower than 5 percent), and salt consumption should also be low (below 5 grams). A basic tenet of a healthy diet is that it must contain a variety of items from several different food groups (i.e. a mix of fruits, vegetables, legumes, nuts, and whole grains). Fruits and vegetables should be made abundant enough to ensure adequate consumption of micronutrients (World Health Organization, 2018)[1]. A healthy diet should be low in ultra processed foods. Finally, a healthy diet depends upon one's age and gender; at specific points during the life cycle, individuals may require more of specific nutrients; for example, adolescent girls require more iron in their diets during menarche.

For any given individual, then we can define a healthier diet as relative to the individual's present diet. To be precise, we define a healthier diet as a diet that is better than the individual's current diet on at least one of the measures listed above, without becoming unhealthier along one or more of the other measures. One cannot define a diet as over a day, but over a longer time period (e.g. a month, a quarter, or a year). An example of a healthier diet, then, would be a diet that becomes lower in added sugar without other changes over a specific period of time.

Next, we follow the HLPE (2017) in defining a food system. A food system "gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of

[1] Some micronutrients become detrimental to health at extremely high levels of consumption (Renwick, 2006). For example, excessive intake of vitamin A may cause liver damage, and consumption of iodine beyond tolerable levels may result in thyroid hyperactivity (Verkaik-Kloosterman et al., 2012). Modest increases from current intake levels in LMICs will not approach these levels, but innovation design should be aware of such constraints.

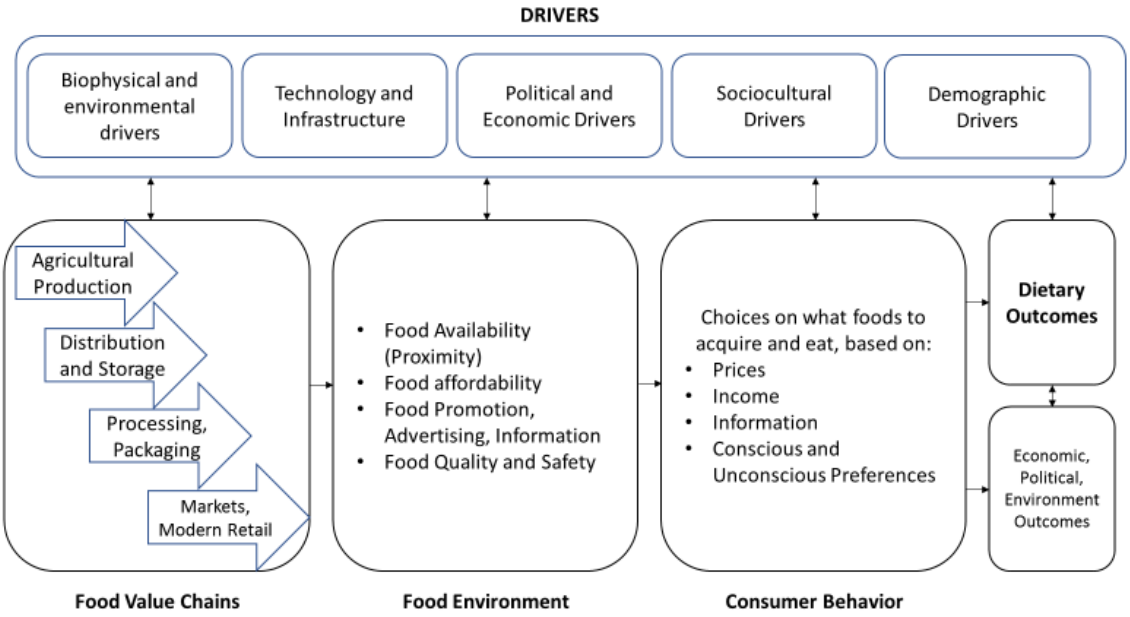
these activities, including socio-economic and environmental outcomes." Geographical boundaries must be defined for the food system in question, whether they be local, subnational, national, regional, or global, to make possible analysis of specific outcomes. By definition, food systems are complex adaptive systems, so taking a food systems approach to improving diets must necessarily include analysis of dynamics related to dietary outcomes, and their interactions with other elements of food systems (e.g. IOM and NRC, 2015).

We identify three fundamental elements of food systems that potentially determine an individual's diet: consumer behaviour, the food environment, and food value chains (Figure 1). Consumer behaviour depends on their individual characteristics in addition to and in interaction with the characteristics of their food environment. At the individual level, a range of biological, demographic, psychological and situational determinants ranging from taste preferences to habits and cultural issues related to food choice (Symmank et al., 2017). At the food environment level, the quality (taste, smell, nutritional value, appearance), safety, and price of food items play a role but also the environment in a broader sense. The food environment, for example, includes the convenience of obtaining specific foods, as well as the information about foods offered to consumers, and consumers' perceptions of the palatability of these foods. Through food supply chains, food products are transferred from primary production of farmers through storage, processing, trade, and retail to consumers.

The concept of food environments as a central dimension of food systems has received increasing attention in the international policy arena (HLPE, 2017; FAO, 2016b). In the research community, several models have been developed to describe the food environment, largely focusing on the relatively stable food environments of high-income countries. For example, the Agriculture, Nutrition and Health (ANH) Academy Technical Working Group provide a framework in which opportunities and constraints that influence food choice are structured in the external and personal food environment domains (Turner et al., 2018). The external domain includes vendor characteristics, product characteristics, availability, prices, marketing, information, and policies. The personal food environment on the other hand consists of affordability, accessibility, desirability in terms of taste, knowledge, preferences, etc., and convenience.

An alternative is the Food Environment Framework (Herforth and Ahmed, 2015). In their framework, the food environment is positioned between income and consumption since it influences how consumers react to changes in income and prices. The food environment is described in terms of food availability, affordability, desirability and convenience.

Figure 1: Conceptual framework of food systems for diets and nutrition



Source: Adapted from HLPE (2017)

The food environment is in turn shaped by food supply, or food value chains within the food system in question. A food value chain consists of the actors necessary to the production, distribution, and retailing of a specific food product. Putting a food systems lens on problems, then, requires going beyond a simple description of single food value chains. It necessitates accounting for multiple food value chains and the food environment with consumer preferences and constraining factors such as income, and interactions between all these elements (e.g. Ericksen, 2008).

o be able to develop food systems innovations, it is important to consider how food systems change dynamically, as different variables change at different speeds. For example, increased dairy production

could decrease malnutrition in the short run if dairy is consumed by population groups who lack vitamin A, iron, zinc, or calcium in their diets. However, in many countries an expansion of the dairy industry at scale could influence the production environment in both the short and long run. In the short run, the land and water intensity of dairy production is typically higher than that for many crops, and in the long run the total production environment may change through its contribution to climate change.

A key feature of food systems analysis is the presence of drivers, or variables that drive changes to one of the three key elements of the food system from a dietary perspective (World Economic Forum, 2017; HLPE, 2017; GLOPAN, 2016). There are several types of potential drivers, including technological, environmental, political, economic, cultural, and demographic drivers. Technological drivers include technology and potentially infrastructure that can facilitate food trade. Environmental drivers include natural resource capital endowments and how they are affected by climate change. The remaining set of drivers can all be thought of as institutional. Political and economic drivers include anything from international trade to food prices to conflict that can threaten food production or distribution, as well as changes in income that can lead to dietary shifts[2]. Cultural drivers include food traditions and women's empowerment, and demographic drivers include population growth, comprising the gender composition of population, and movement, encompassing urbanization and migration. All the drivers can affect value chains, the food environment, as well as food demand, but these three elements can also feed back into the system and affect drivers.

We therefore argue that innovations should be designed to attempt to influence food systems dynamics to move them towards healthier diets. Considering a food system as a complex adaptive system, an important challenge in designing innovations to improve diets is the inherent uncertainty about how outcomes may feedback and change other outcomes or drivers, then affecting the way the innovation influences diets. Innovations could potentially have synergies with other ongoing food system changes, leading to improved outcomes, but they might also feed back into drivers and dampen any desired effects

[2] A rich economics literature studies how demand for different food types, and therefore nutritional status, responds to changes in income and economic growth (e.g. Bouis and Haddad, 1992; Fogel, 1993).

from innovations[3]. Therefore, food system actors who design and implement innovations to improve diets must have the capacity to learn and adapt to changes in the system that might threaten or enhance dietary outcomes. When multiple stakeholders are involved (e.g. the public and private sectors), the availability of information about outcomes and drivers may be important to attaining positive outcomes.

There are several advantages to identifying innovations that can lead to healthier diets from a food systems perspective. First, a food systems approach to identifying innovations for healthier diets allows the analyst to fully consider the dynamic interactions between the food system elements and its drivers (UNEP, 2016). From a dietary perspective, this point is a substantial advantage, as food systems influence both the lack of nutrients in diets of those suffering from undernutrition, as well as diets with too many calories, leading to overweight and obesity.

Further, the food systems approach can help illuminate the various tradeoffs that might occur as innovations are planned. To use an example described above, if a development intervention attempts to stimulate the consumption of animal source foods, there are potentially important environmental concerns if the project goes to scale. Such tradeoffs, in fact, may become obvious even as diets shift with income growth or aggregate price changes. For example, animal source food consumption has grown rapidly with increasing wealth levels in East Asia; this growth has had substantial implications both for land use and international trade, both of animals and feed (e.g. He et al., 2018). There is also the ability to potentially think through how food systems changes affect heterogeneous groups of actors within the food system—for example, innovations driven by the private sector may have important socioeconomic consequences. We develop these ideas further in the following section.

In fact, the use of food systems innovations to promote healthier diets may also involve several important higher level tradeoffs, as policy makers and/or other decision makers might need to consider dietary goals against other important goals (e.g. Willett et al., 2019). First, there may be tradeoffs with environmental goals; growing healthier foods such as fruits and vegetables is water intensive relative to

[3] Further, such changes need not be gradual nor predictable, as there may be tipping points that change the system from one stable state to another.

grains, and animal source foods are in general more resource intensive. More intensive animal source food production in some countries could come at the expense of climatic goals (e.g. Vermeulen et al., 2012). Second, there may be food safety issues related to healthier foods, as they usually spoil relatively quickly, and fruits and vegetables are often grown with more chemicals than grains and legumes. A third consideration relates to migration. As people move from rural to urban areas or across international borders, their diets likely change with them, with implications for food systems. However, there is little systematic research on the effect of migration on diets. An exception is Cockx et al. (2018), who show that in Tanzania individuals who move to urban areas consume more processed foods and with less micronutrient density than they did prior to migration. Fourth, the role of international trade in the food system varies substantially across countries; nudging a food system towards healthier diets along some dimensions might lead to changes in the trade balance, with potential further macroeconomic implications.

Though thinking through innovations for healthier diets using a food systems approach has the benefits laid out above, as with any type of analysis, they come with a cost. Because of the dynamic feedback loops in the system, in the design stage it can be complex to determine innovation entry points, predict potential system level consequences, and empirically disentangle drivers and outcomes of innovations. Further, if several potential dynamic effects are identified through a food systems approach, one might have to develop simpler models to understand those that are most important. If any new information is needed to monitor innovations, there is a cost in ensuring that information is collected. Finally, any innovation takes place with an element of risk or uncertainty; due to the changing nature of food systems, the most important sources of risk may be difficult to ascertain ex ante. When planning or studying innovations that use a food systems approach, such costs must be kept in mind.

3 FOOD SYSTEMS INNOVATIONS

Within the context of food systems, a coherent set of theories is needed to understand how food systems innovations can lead to healthier diets. A relevant theoretical package attempts to unify understanding across disciplines while moving from a descriptive analysis to one that explores how specific outcomes might change as innovations are introduced. One particular challenge in developing such theory is that the food system is a macro-level concept, but the diet is inherently individual, comprised of individual choices about what and how much to eat, which necessarily differs by age, gender and other individual specific factors, as well as the context of the food environment. Actors within the food system, such as farmers, food processors, policy makers, and vendors, also make individual level decisions that affect the choice set facing consumers within the food environment.

The food environment clearly represents a critical component of the food system as it shapes choices available for individual diets. To afford everyone within a food system the opportunity for a healthy diet, the food environment must provide that opportunity. Yet at present food environments clearly do not; for example, in many contexts total fruit and vegetable availability is well below the aggregate required to provide all individuals with adequate micronutrients (e.g. Siegel et al., 2014). The overall availability of different types of foods within a food system will be reflected in relative prices; consumption of different types of food are then affected by those prices (e.g. Bouis et al., 2011). Particularly, when prices are high and/or incomes are low, people rely on inexpensive staple foods to meet their energy needs, such as cereals and tubers, but these foods tend to be poor sources of many micronutrients.

Moreover, it is not just the availability and accessibility of a healthy diet that matter. People must have the knowledge and motivation to be able to make healthy food choices. Thus, people must be made aware of the importance of eating healthy and diverse diets. Accordingly, food systems innovations need to be based on an assessment of on both the supply of and demand for of a healthy diet. From the demand side, providing information and educating people is only part of the solution. Consumers also have to be

willing and able to access and process the information and apply it to their personal situation. In addition or in combination, interventions can target on consumers' motives (such as taste) and barriers (such as shelf-life), influence behavior through changes in the food environment (nudges), or change availability (for example, regulations on vending machines at schools, or school meals themselves). Using our definition of healthier diets and the role of food systems in diets, we can consider how innovations can lead to healthier diets. Several theories about innovations might apply. Innovations can be considered as new ways of combining inputs into a production process that leads to a new outcome. By this definition, innovations can be physical—for example, a new food product—or not—for example, an organizational process. Schumpeter (1942) famously described the process of innovation as being that of creative destruction, in which new ways of combining inputs make previous methods obsolete. One might question how such innovations take place in the first place; as an example, Hayami and Ruttan (1985) suggest that innovation can be induced by changing the relative scarcity of production factors (land, labor) within an (agricultural) economy. As one factor becomes more expensive relative to the other, it induces entrepreneurs to find ways to more cheaply produce intensifying use of the cheaper factor, bringing the system closer to equilibrium.

The discussion above highlights the need to reduce relative prices of healthier foods, which could lead to higher consumption of such foods; alternatively, one might need to increase relative prices of less healthy foods. Transaction cost theory suggests that increasing the relative efficiency of value chains can result in a reduction in consumer prices without negatively affecting producers and thus production (e.g. Williamson, 1981)[4]. Specific innovations that reduce transaction costs in food value chains that are not sufficiently consumed in current diets could lower their prices relative to foods that are consumed sufficiently or in excess. Examples are direct subsidies, the development of cold chains, or contract farming schemes around perishable crops. Conversely, prices of overconsumed unhealthy foods can be increased by imposing a tax on the unhealthy component, e.g. the introduction of a sugar tax. The

[4] Note that Williamson (1981) studies transaction costs within the firm, but a parallel can easily be drawn to food systems by considering transaction costs within a value chain or set of value chains.

outcomes of such interventions in different groups of consumers should be carefully considered to determine direct and indirect effects, such as substitutions and economic effects (Jensen and Smed, 2018). A combination of taxes and subsidies is perhaps more effective (Redondo et al., 2018)..

Expanding from the economic perspective and moving into marketing and psychology, it is important to consider how healthier food products are perceived from the consumer perspective. In other words, there is a need to carefully consider how to market healthier products, as processed foods are often heavily marketed by their manufacturers. Attributes of products that can influence their consumption include not just taste and smell, but the attractiveness or texture of any packaging and even how that packaging can make potential consumers feel; consumers who feel affinity for a product are more likely to both purchase and consume it. Attributes of such products can play an important role in stimulating demand for food products. It is also important to consider habit formation in any plan to market healthier foods; if consumers' habits around eating healthier foods are much more likely to affect health than sporadically trying to attain a healthier diet. Finally, all this demand creation must be properly contextualized for a specific audience. Younger consumers may perceive food products as very different from older consumers; moreover, the components of a healthy diet change over the life course.

Our theoretical discussion above suggests that an appraisal of dietary imbalance between actual and healthier diets is an initial requirement to improve dietary quality. These imbalances can imply that more consumption of specific types of food or micronutrients are necessary, or that less consumption of unhealthy foods is warranted. Note that it is important not to just understand the imbalances in the aggregate, but for specific population groups as well; specifically, it is important to understand diets among those who are particularly vulnerable (young children, women of child bearing age) or those with attributes making them more likely to be undernourished (e.g. low income groups).

Clear entry points for food system innovations are consumers, value chain actors in the private sector who shape the food environment, and policy makers. Consumers can broadly be targeted either through behavior change approaches, or through nudges such as incentives that either directly change the relative cost of healthier food choices relative to unhealthy foods. From the consumer perspective,

understanding habit formation may also play an important role in improving diets[5]. For example, social practice theory could be used to understand how socially-built meanings, norms and power structures reproduce and reinforce improved routines of food consumption choices (Delormier et al., 2009).

Among value chain actors, it is important to understand the incentive structure faced; somewhat hidden constraints along the value chain, such as trust between actors, may hinder the potential a food system would have in moving towards providing healthier food. Along those lines, public policies can be designed to provide appropriate incentives for positive innovations and disincentives for negative, less healthy (or unhealthy) innovations. These policies could also address key elements of the food environment with a strong influence on social practices around food consumption. For example, they can limit billboard advertising of unhealthy food, making it less desirable, and shaping social norms towards healthy food, making it more aspirational (Chandon and Wansink, 2012). Of course, any such policies require enforcement to change producer or consumer behavior. Ideally, public and private actors can be convinced to work in concert to achieve healthier diets.

[5] Habit formation has been modeled in disciplines as varied as economics, psychology, and neuroscience (e.g. Pollak, 1970; Yin and Knowlton, 2006, Lally et al., 2010).

4 EXAMPLES OF POTENTIAL FOOD SYSTEMS INNOVATIONS

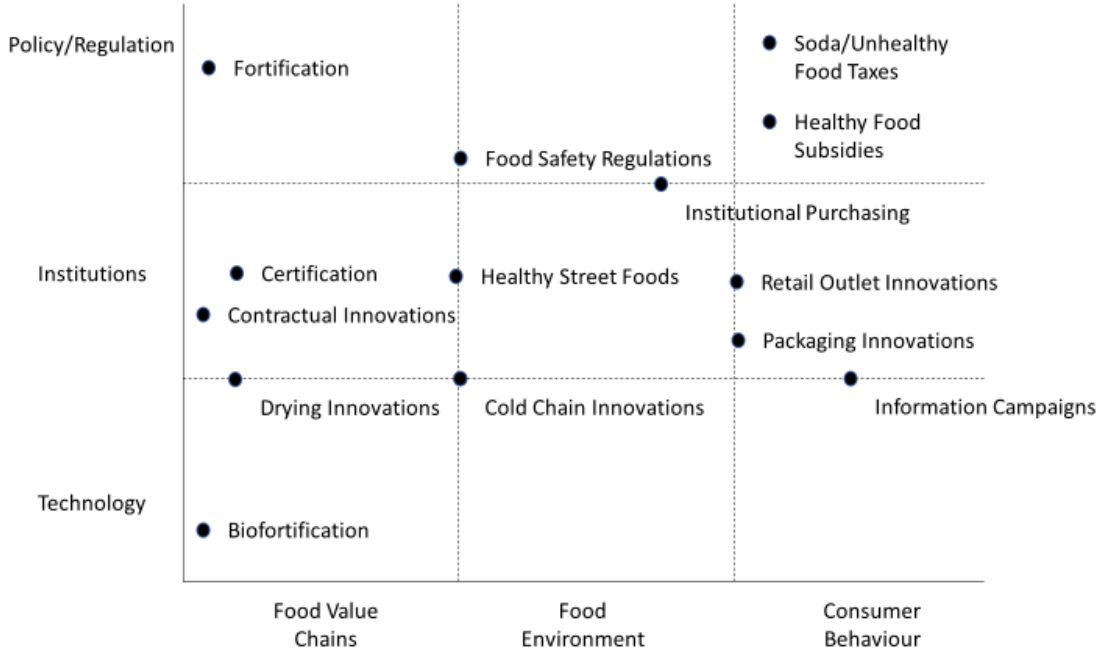
Based on the discussion above, innovations can be designed once dietary imbalances are identified. It is important to identify gaps in either access or availability of products that could correct those dietary imbalances, or perceptions of such constraints among consumers. Further, it is important to understand whether the policy and regulatory context is supportive of or constrains potential innovations. When these points are known, solutions to reduce dietary imbalances can be designed and implemented.

Innovations can occur at the macro, meso or micro levels. Macro level innovations include policy or regulatory changes that can lead directly or indirectly towards the consumption of healthier diets. Meso level innovations emerge when consumers, producers and value chain actors collaborate to create an innovation that changes institutions, or the general "rules of the game." These innovations include public and private policies with broad implications for the overall food system (i.e. food safety regulations, labelling, private standards, traceability, etc.); they can be combined with policy or regulatory changes as well. Alternatively, innovations can either take place within one of the three primary elements of the food system, or in a coordinated fashion across several nodes. These innovations also take a systems approach both in the design and implementation phases, and can include anything from processes to technologies within production systems that increase efficiencies or respond to specific demands around food safety, quality or traceability; changes in trading or distribution systems to reduce loss and waste, maintain quality, reduce contamination or incentivize change in production; and changes in retail to enhance visibility, maintain or improve quality, reduce prices, and/or increase sales.

To help organize our thinking around placing innovations within a typology, we develop the framework (Figure 2). On the x-axis, we consider the target element within the food system for each innovation, whether that be within food value chains, the food environment, or consumer behavior. It is possible for innovations to take place between elements as well; for example, innovations could affect both value chains and the food environment. On the y-axis, we consider whether innovations are largely policy or regulation related, institutional, or technological. Again, innovations could share more than one

of these characteristics, so the placement on the figure reflects whether innovations have, for example, aspects in both policy and institutions.

Figure 2. Typology of Food System Innovations



There are some clear examples of both older and more recent examples of innovations that can be considered from a food systems perspective to achieve specific outcomes related to healthier diets. We can categorize these innovations as relating to types of fortification, taxation and other public interventions, information campaigns, and innovations within food value chains. We describe these innovations and evidence around them below.

4.1 Food fortification

Perhaps the most widespread food systems innovation is food fortification. Fortification attempts to address micronutrient deficiencies by adding micronutrients directly to regularly consumed foods. Neufield et al. (2017) state that 140 countries have mandated the iodization of salt, 86 countries have mandated the fortification of at least one cereal grain, and 49 countries have mandated the fortification of

edible oils. While laudable, they find that many national fortification programs lack quality control and enforcement, which may reduce the amount of fortification taking place, and the consumption of foods that are to be fortified is not always high enough among target populations to reduce inadequate micronutrient intakes. Moreover, it is important to periodically review the foods to be fortified, as demand for the foods being fortified can also change. Within our typology (Figure 2), fortification takes place within the food value chain, and it is largely a regulatory innovation, though it requires technology transfer.

Similarly, biofortification attempts to combat micronutrient malnutrition by breeding additional micronutrients into staple crops (Pfieffer and McClafferty, 2007). If they are grown and consumed they can lead to higher micronutrient intakes among vulnerable groups (Hotz et al., 2012a; Hotz et al., 2012b). Now that millions of smallholder farmers are growing or have grown biofortified crops (Bouis, 2018), a challenge is getting biofortified crops anchored into both national agricultural research systems and value chains; the latter would ensure that farmers demand seeds and consumers demand foods derived from biofortified crops (Uchitelle-Pierce and Ubomba-Jaswa, 2017). Within our typology of interventions, biofortification is a technological innovation taking place at the beginning of the food value chain.

4.2 Taxes and subsidies

Government can intervene in the food system either by changing prices through taxes or subsidies for specific products or through regulations. For example, a recent policy innovation in several countries and sub-national areas is to implement new taxes on sugary beverages. The goal of such taxes is to both reduce demand for these products, as they have no obvious nutritional benefits, and generate revenue. Underlying the former goal is a hope that reduced consumption will lead to lower rates of overweight and obesity, or slowing the rate of increase of overweight and obesity status. Evidence suggests that such taxes reduce demand, but health impacts are unclear. For example, Colchero et al. (2016) show that sales of taxed sugar sweetened beverages fall by 6 percent in 2014 relative to 2012-3 in Mexico, while sales of non-taxed beverages increase by 4 percent. However, there may also be a health cost, at least in the short

term. Gutierrez and Rubli (2018) show that gastrointestinal disease incidence increases in areas of Mexico with low access to tap water and bad groundwater quality, though that incidence declines after the tax is in place for a year.

4.3 Regulations

Food safety regulations are an example of regulations, though they can be either public or private through third parties. Many more nutritious foods are perishable, and consumers are more likely to purchase and eat them if they are confident they are safe. The perception of food safety is particularly important in this context, rather than the guarantee of safety. Food safety standards are common throughout the developing world, despite differences in policy and compliance costs (Unnevehr and Ronchi, 2014). However, the public sector in many LMICs has little capacity to enforce food safety regulations (Unnevehr and Hoffmann, 2015). An alternative is co-regulation, in which firms help determine how they will meet standards, which has been effective in some developed countries (Fairman and Yapp, 2005) but has not been rigorously evaluated in LMICs. Within the typology, food safety regulations affect both the value chain and potentially the food environment.

4.4 Public food acquisition programs

Another example of the use of the public sector is to use large public institutions to purchase foods in an attempt to improve nutrition[6]. The most common of such interventions are school feeding programs. For example, in Brazil the government used a public acquisition program to both link into its school feeding program and to push local farmers to grow more nutritious foods under its Zero Hunger initiative (e.g. Sidaner, Balaban, and Burlandy, 2013). Similarly, though typically on a more localized scale, the World Food Programme has promoted a set of home grown school feeding interventions, often incorporating nutrition as a goal (e.g. Ruel and Alderman, 2013; Masset and Gelli, 2013). However, there is no real evidence that such programs affect food systems on any scale; primary effects of such programs are on

[6] Other examples of large public institutions with need to purchase large amounts of food include hospitals, prisons, and military bases, though there is no literature on ways they can affect the food system.

beneficiaries or members of households in which beneficiaries live (Alderman and Bundy, 2011). Institutional purchasing changes the food environment within targeted institutions, and is also related to policy.

4.5 Information Campaigns

A type of intervention that can be directed at consumers are information campaigns directed at increasing consumption of healthier foods. A large literature studying generic commodity advertising programs in developed countries shows that it is possible to affect demand for specific food products through information provision (e.g. Alston, Freebairn and James, 2003). However, such campaigns may or may not target increased consumption of healthier foods. In LMICs, behavior change communication programs have been tested largely as part of integrated programs to increase consumption of healthier foods (e.g. Ruel, Quisumbing, and Balagamwala, 2018). New technologies may make delivery of such messages more cost effective. For example, Gilligan and Hidrobo (2018) are testing whether nutrition messages delivered by mobile phone can improve diets. Video messages could also be effective (e.g. Abate et al., 2019); in particular, if deemed effective on a micro scale it is quite easy to scale them up through television. While such interventions are not necessarily food systems innovations, they can be if as they scale up they are can catalyze feedback loops into the system. The goal in information campaigns is to change the relationship between the consumer and their food environment either through institutions, technologies, or the combination of the two.

An alternative outlet for information campaigns is to producers or vendors of street foods, which also has potential to become a food systems innovation for healthier diets, particularly in urban areas. Urban street foods have emerged as an important portion of the diet in many developing economies (e.g. Bromley, 2000). Such foods might be purchased either as fruits and/or vegetables in informal markets along the roadside, or as prepared food for a meal; as such foods are often more convenient than foods purchased at more modern markets, they are often targeted for interventions to improve nutrition or availability. For example, in Odisha state of India eKutir built an ICT platform to match vegetable

availability from poor farmers (supply) with customers in urban areas using carts (Jha, Pinsonneault, and Dube, 2016). The idea of improving nutritional content of prepared street foods is an older one (e.g. Tinker, 1997), but there is little empirical evidence of effective methods of making street foods more nutritious, let alone changing food systems through street foods. Such interventions are more institutional and link food value chains to the food environment to affect consumption.

A more unconscious method of providing information is through product placement on shelves within convenience stores and supermarkets. The idea is to provide the consumer with visually pleasing products closer to eye level, reducing implicit search costs and potentially increasing demand for healthy foods. A systematic review of such innovations aimed at increasing sales of nutritious foods, largely in the United States, show that there is promise for positive outcomes based on high or moderate quality studies (Cameron et al., 2016). Product placement is also institutional and takes place in the food environment to attempt to affect consumer behaviour.

4.6 Value Chain Relationships

Similar to innovations with prepared foods, new technologies may help overcome contractual barriers to the spread of healthier diets. Micronutrient rich foods are typically perishable, adding risk to actors from producers through end markets that the product will spoil. The presence of these risks implies that contracting—whether explicit or implicit—is even more important between value chain actors, so that risk can be spread among actors. Whereas trust-based alternatives to long chains can help promote positive outcomes, particularly for perishables (e.g. Moustier, 2017), technology is providing a potential alternative through distributed ledger technology (Lin et al., 2017). However, the latter requires all nodes on the value chain to have access to technology, so its growth appears more rapid in more developed countries at present.

A major concern at present is that of food loss and waste either as food moves from production through value chains or among consumers after purchase (e.g. FAO, 2018a). Although many reports have been written claiming that as much as one-third of food is lost or wasted, the actual amount of food loss

and waste is not well known (HLPE, 2014). In LMICs, new research shows losses are much lower than previous claims (Ambler et al., 2018; Delgado et al. 2017). Moreover, they are highest on-farm, and efforts to effectively reduce post-harvest losses can be cost effective (Omotilewa et al., 2018). More careful research is necessary to understand the extent of food loss and waste, particularly for perishable products, and the implications of its reduction for food systems.

Cold chains and drying technologies are both potential solutions to reduce food loss and waste among perishables and to increase their reach to additional consumers. Cold chains conserve quality and increase shelf-life, as keeping perishables cold maintains sensory and nutritional properties and to slow down biological and physical degradation processes (IRR, 2009; Kitinoja, 2013). Similarly, drying perishables retains nutritional content and increases the shelf life of agricultural products. Implementing cold chain innovations involves considerable fixed investments in equipment and requires a minimum scale of operations for profitability. Cold chain innovations also depend on a stable energy infrastructure (electricity or solar power) and a suitable business climate for long-term private investments (FAO, 2016a). Therefore, institutional conditions must be aligned with investment and aggregate benefits over time must outweigh the fixed costs of investment. Cold chain or drying innovations take place both within value chains and the food environment, and as the technology exists they must overcome institutional barriers.

Certification of growing standards for healthier crops can be considered a potential food systems intervention for healthier diets. Most certification programs are based on the application of defined management principles and/or good agricultural practices (GAP) by smallholder organizations to guarantee sustainable livelihoods and minimum living wages (Nelson & Martin, 2013). Such programs focus on the value chain, and often refer to specific issues, such as safe working conditions for laborers, eliminating child labor, or relate to the environmental impact.

At scale, certification could plausibly benefit diets by adding healthy foods to the food system and feedback into either the food environment or agricultural production through improved livelihoods; however, evidence of impacts on either producers or consumers is mixed. Oya et al (2018) find minor

price effects and limited income effects for smallholder producers and workers, while Shumeta and D'Haese (2018) could not confirm positive impact on food security and nutrition. In a similar vein, commodity labels are more effective for signaling intrinsic quality and safety characteristics, and price premiums for organic are quite effective, but willingness to pay for fairness attributes appears limited (Janssen & Hamm, 2014). Certification standards are mainly an institutional innovation within value chains though they can involve technology.

5 KNOWLEDGE GAPS AND RESEARCH CHALLENGES

A key insight from the previous sections is that the food systems approach goes beyond just thinking about how innovations affect one specific outcome—in this context the diet—to consider how those innovations can either positively or negatively affect other parts of the system. So researchers and practitioners considering entry points to the food system from the dietary perspective must consider the way that desired outcomes will affect other system outcomes or even drivers. For example, system dynamics including feedback, trade-offs, synergies and spillovers can link interventions targeting improved diets to issues such as biodiversity conservation (Johns and Eyzaguirre, 2006) or greenhouse gas emissions (Popp et al., 2010). A key component of future research on food system innovations targeting healthier diets should be to provide information on the dynamic consequences of innovations on such secondary outcomes, as well as the potential for food system transformation through engagement of other actors in the system.

In the context of LMICs, future research should consider how food system innovations can promote individuals' access, affordability and desirability of healthier diets in dynamic food environments. Several trends are converging in many LMICs, including rapid urbanization and recently emerging food sources such as supermarkets and convenience stores that require longer value chains, and marketing influencing individuals' dietary habits from fresh to processed foods (Turner et al., 2018). System-focused research can help visualizing the potential environmental (e.g. reducing pollution) and social (increasing employment opportunities) benefits of increasing adoption of healthier diets as dimensions of food environments evolve. Research can help identify ways to scale-out innovations while either accentuating benefits from divers or at least minimizing their potential negative effects on the availability, accessibility, affordability, and/or desirability of healthier diets. Complementary research could provide insights on the design of institutions and governance arrangements that can promote scaling-out given external and personal dimensions of the food environment for example focusing on how regulations (e.g. on safety standards) can affect convenience and desirability of food products. At the

intersection between the supply side and the food environment, future research could focus on how interventions for healthier diets can promote sustainable production that increase healthy food availability while reducing product waste and losses.

From the consumer perspective, it is important to increase our understanding of the interaction between the food environment and dietary habits. To attain anything like the goals propounded by Willett et al. (2019), it is crucial to learn about which aspects of the food environment can be changed to induce healthier consumer choices. The food environment encompasses food availability, prices, vendor and product properties, and promotional information; and personal dimensions such as the accessibility, affordability, convenience and desirability of food sources and products; changing some of these dimensions must be more effective than others in catalysing habit-forming choices among consumers.

Moreover, it is important to understand how different groups of people respond to different innovations, particularly at the consumer level, as gender and age influence what constitutes a healthy diet. From the systems perspective, it is important to consider the demographic composition of a population in designing food systems innovations, because they could potentially have positive effects on one demographic group while having negative effects on another if not carefully designed. For example, a health information campaign will not be as effective for low education consumers, unless text and language is tailored to their literacy level. Also, taxes will affect those with varying income and expenditure patterns differently.

Another line of research to help us understand the feasibility of specific innovations is to better understand the type of decision making that must be done by stakeholders to make resource investments—thinking of resources as financial, institutional, time, or information—in up-taking a food systems innovation. Considering that these choices could be socially- sensitive and complex, this line of research should embrace a participatory approach to ensure that the right stakeholders' views are represented in the assessment of costs and benefits of a food system innovation. This research could design robust methods to engage stakeholders and promote debates on potential costs and benefits of including additional food system components in intervention design, assessment, and implementation.

Finally, for this research to inform the design of socially- and technically-robust solutions, research on food systems for healthier diets must explicitly recognize the multiple political constraints that might affect the type of food system change that is plausible. For example, public recommendations that consumers should eat less red meat in general will reflexively generate both public statements and lobbying from red meat producer groups. But politics also affect knowledge management and research agenda-setting (Scoones, 2015). Future research should therefore adopt methods to ensure that representatives of previously unheard social groups of food consumers are engaged along with representative of constituencies focusing on problems and solutions regarding the food system drivers and outcomes relevant to improve diets.

6 CONCLUSION

A substantial proportion of the population of LMICs suffers from some form of malnutrition. This paper discusses how a food systems approach is a potentially advantageous way to identify or design innovations to help individual diets become healthier. We develop theory about how such innovations can be both developed and categorized. The theory argues that food systems innovations must have the potential for feedback effects back within the system, both directly on targeted outcomes, but indirectly as well on outcomes in other system areas and feedback to system drivers. We provide examples of the types of innovations that could positively affect diets and describe research gaps in our understanding of how such innovations potentially affect diets. We note that there is clearly more emphasis on potential innovations that are institutional rather than technological, and more of the innovations take place closer to producers along the food flow.

As food systems innovations are designed to attempt to shift towards healthier diets, the paper illuminates that dynamics of food systems play an important role. Innovations should be designed to attempt to influence where the food system is headed, taking potential advantage of synergies and feedbacks inherent to the system, while minimizing any negative externalities or spillovers. Innovations should further account for the fact that individual diets are the result of conscious and unconscious choices made by consumers. Since there is inherent uncertainty in the choices that consumers make and the way that both food systems outcomes and drivers will evolve, it is important to both gather as much information about relationships between outcomes and drivers while designing innovations, and to understand the inherent uncertainty, in planning to adjust innovations if they do not initially evolve as expected.

It is further important to consider tradeoffs in planning food systems innovations for healthier diets. If food systems improve from a dietary perspective, there are potentially negative economic, political, and environmental tradeoffs, which could cause actors within the system to push back against the changes. For example, it is not necessarily profitable at present nor potentially even economically

feasible to provide populations with complete opportunities to obtain foods making up a healthy diet; therefore, it becomes important for innovations to influence and shape the structure of economic incentives. Given the potential health costs of poor diets, changing such incentives might be better for the whole economy in the long run (e.g. Jaacks et al., 2017). However, large changes in economic incentives require political will; without it, dietary improvements through food systems innovations are unlikely to take place.

Finally, the private sector clearly plays an important role in both the value chains that move food from farmers' fields to consumers, and through the food environment. To ensure that innovations that are positive for diets become anchored in the food system, public-private partnerships can help ensure that incentives are aligned for both sets of actors in developing innovations. These partnerships can help align individual incentives among food systems actors, ensuring that agreements between the public and private sectors become self-enforcing. Given the dominance of private information in these situations prior to agreements, such partnerships may be essential to ensuring that innovations for healthier diets become successful.

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