A meat market in China. Rising demand for animal-source foods poses challenges for ensuring nutrition security, as well as environmental sustainability. (Andrew Hitchcock)

2

Agriculture for Nutrition: Direct and Indirect Effects

Derek Headey^{1*} and William A. Masters²

¹*International Food Policy Research Institute (IFPRI), Washington, DC, USA;*

²*Tufts University, Boston, Massachusetts, USA*

* Corresponding author: d.headey@cgiar.org

Introduction

For most of human history, agricultural development has focused on addressing food insecurity by providing sufficient dietary energy for survival and work each day. Population growth called for increased yields of staple foods to meet daily energy requirements, particularly the cereal grains and root crops that were selected over centuries to ensure human survival and then scaled up for use in modern food systems. Rising expectations for health and longevity, as well as higher incomes, now call for more diverse food supplies, producing a wider range of plant products and animal-sourced foods that reduce disease risks and make it easier for people to pursue healthier lives. The costs of malnutrition have also made improving the ways in which food systems and agriculture function a global imperative. Undernutrition is most widespread and pronounced around pregnancy and among children less than 2 years of age (Victora *et al.*, 2010), imposing lifelong costs in terms of health, cognitive function and productivity. Undernutrition also has intergenerational dimensions, affecting the children and grandchildren of its victims through each cycle of malnutrition during pregnancy and then infancy.

The scientific literature on mechanisms linking agriculture to nutrition is rapidly expanding, especially within the last decade. This chapter begins that analysis by describing three main channels through which changing agriculture can affect nutrition:

- the level and stability of real **income** and purchasing power among poor people;
- the relative **cost** and difficulty of acquiring more nutritious foods relative to other things; and
- exposure to **health** hazards associated with agricultural production, including various pathogens but also other harmful agricultural practices.

Within each channel, we highlight recent research findings that have strong implications for the way in which agriculture can be redesigned to improve nutrition.

A Simplified Conceptual Framework for Agriculture's Effects on Nutrition

Later chapters of this book and many previous studies have sought to conceptualize the complex relationship between agriculture and nutrition (Hoddinott, 2011; Headey *et al.*, 2012). Here we focus on the three basic linkages that encompass a number of specific interconnections, as illustrated in [Table 2.1](#).

A first lever for agriculture to improve nutrition is through household income and productivity. In low-income countries there are far more workers than there are non-farm jobs, and many of the poorest people have no choice but to do at least some farming to meet daily needs. It is the children of these farm families who are at greatest risk of undernutrition, as their household's total income determines whether they can afford to use a wide range of nutritionally relevant goods and services, including food, health care and education as well as water, sanitation, and hygiene (WASH). Public investment targeting staple foods remains key to raising poor people's real income, purchasing power, and time availability, by freeing their labor and resources for other things.

A second linkage between agriculture and nutrition is through the relative cost of more nutritious foods. After households meet daily energy needs, increasing access and reducing prices for nutrient-dense and healthier foods helps people improve their diet quality. In coastal cities that trade freely with the rest of the world, easily shipped food commodities can originate anywhere, so prices are set by demand and supply among all trading partners. In the poorest rural areas, local agriculture plays a larger role, until market infrastructure and institutions are able to provide similar access to lower-cost, higher-quality foods around the year. Spatial and seasonal variation in prices tends to be greatest in the places where malnutrition is most widespread, especially for perishable products such as eggs, fresh dairy produce, and many fruits and vegetables. For these items, transport and storage costs are so high that prices even in coastal cities will be determined by national agricultural systems (Headey *et al.*, 2017a). In these situations, farm output depends on local demand, so agriculture–nutrition linkages work

Table 2.1. Conceptualizing basic and specific linkages between agriculture and nutrition.

Basic linkages	Specific linkages	Comments
Income and resources per person	(a) Farm profits increase household incomes	Majority of the poor still work in agriculture
	(b) Off-farm income (off-farm and non-farm wage incomes and profits) contribute to household incomes	Substantial numbers of poor people work in off-farm or non-farm occupations
Relative costs of more nutritious foods	(a) Changes in production affect relative prices of different foods	Many nutritious foods, such as dairy produce, are imperfectly tradable, implying prices are heavily influenced by local supply and demand
	(b) Changes in trade policies affect relative prices of different foods	Many food sectors are still highly protected
	(c) Changes in transport and storage affect relative prices of different foods	Many foods are highly perishable and not traded long distances
Livelihood effects on health	(a) Farming practices affect time use of parents and children	Women's time use may be associated with less care towards young children
	(b) Farming practices can directly affect health through diseases, exposure to chemicals, and level of physical activity	Zoonotic diseases, including enteric and pulmonary infections Exposure to pesticides, herbicides Physically arduous tasks during pregnancy
	(c) Agricultural livelihoods affect empowerment of women and children	Women's control of agricultural assets is highly variable
	(d) Agricultural livelihoods influence access to nutrition-relevant goods and services	Remoteness and low population density reduce access to health, education, family planning and WASH ^a services

^aWASH: water, sanitation, and hygiene

through prices as well as income. For example, fresh milk is highly perishable and expensive to transport, so farm families with a lactating cow have much lower-cost access to milk each day and are more likely than others to feed milk to their children (Hoddinott *et al.*, 2015). More generally, the imperfect tradability of many fresh foods means that we should expect to see strong associations between local production patterns and local consumption patterns, and even between household production and household consumption.

A third basic linkage involves the broader non-market dimensions of agricultural livelihoods. These encompass the effect of farming practices on time use and exposure to health hazards, cultural norms and institutions such as women's control over assets, and access to nutrition-relevant goods and services. Some modern agricultural practices may be beneficial to health

and nutrition (e.g. more modernized livestock management, labor-saving technologies, improved storage facilities), and some may not be, especially if improperly used (e.g. pesticide use). Examples are provided below.

Agricultural Growth as a Driver of Incomes

A substantial body of literature explores linkages from agricultural growth to the total amount of available resources for improved nutrition (Bershteyn *et al.*, 2014; Masters *et al.*, 2018). Agricultural growth can impact nutrition directly through households' own income or wealth, and indirectly through government investments in such areas as rural market infrastructure, rural education (especially for girls),

and sanitation, as well as service provision, particularly for maternal and child health.

Figure 2.1 uses data from the multi-country Demographic and Health Surveys (DHS), pioneered by the US Agency for International Development (USAID), to illustrate the linkages between agricultural income and nutrition outcomes by examining stunting prevalence in sub-Saharan Africa and South Asia. The data are disaggregated by locality (rural/urban), father's primary occupation (farmers, manual workers, services, professional), household wealth (the average number of six assets owned), and the number of people in each occupational category. Several striking findings are noticeable in Fig. 2.1.

1. In Africa the largest share of children live in households where the father primarily relies on farming for a living, while the rural and urban manual and services occupation clusters all have broadly similar population sizes. In Asia, more children live in rural non-farm households (manual plus services), and more of the population is urbanized.

2. There are very strong associations between locality–occupation categories and household wealth. In Africa, the poorest rely on farming and all rural households are substantially poorer than urban households. In South Asia, where landlessness is more common, the wealth differences between farm and non-farm occupation is not marked, and rural–urban differences in wealth are evident but not as pronounced as they are in Africa.

3. In Africa, children of farming households have by far the highest rate of undernutrition, with almost 50% stunted in the 24–59-month age range. Stunting rates are lower in rural non-farm occupations and substantially lower for more urbanized livelihoods. The association between stunting and wealth is much more pronounced in Africa than in Asia, where stunting is still high in urban services and urban professional households.

Overall these findings suggest that agriculture growth is likely to have more impact on stunting in Africa than in Asia, because stunting there is more closely associated with poverty, with farming as a livelihood, and with rural living in general. In the more structurally advanced economies of South Asia, the income role of agricultural growth is somewhat more limited.

Agricultural Change and Food Prices

Food affordability has long been viewed as an important linkage between agricultural productivity, poverty, and food security. Most analyses compare food prices with non-food prices, wages or incomes. Many analyses also focus on the price of staple foods. Given the importance of protein-rich and micronutrient-rich non-staple foods for nutrition, however, a more important question is how affordable these non-staple foods are relative to staples. In other words, how costly is it to diversify away from staples?

A recent study by Headey *et al.* (2017a) addressed the affordability of different sources of calories in 177 countries. They used national price data for 200 specific standardized food products and converted the prices of all foods into a price per calorie. They then took the ratio of each food's caloric price to the price of the cheapest staple cereal in each country (since cereals are consumed everywhere and are highly tradable). These 'calorie price ratios' revealed the costliness of diversifying away from the cheapest staple in any given country. Their results showed that prices of different foods were highly variable across countries and across different income levels, particularly for less tradable products such as eggs, fresh milk, and some (but not all) fresh fruits and vegetables. Figures 2.2 and 2.3 show scatter plots of these calorie price ratios for seven food groups and for fortified infant cereals (which are a potential alternative means of diversifying the diet with a complete range of essential nutrients) against the gross domestic product (GDP) per capita of a sample of countries. In this large sample of countries, per capita income varies from just US\$617 per capita in the Democratic Republic of Congo to approximately US\$50,000 per capita in the USA. The results reveal important findings.

1. The prices of roots/tubers, vitamin A-rich fruits and vegetables, and other fruit/vegetables have no significant relationships with per capita income, and these foods are often relatively cheap sources of calories. Root/tuber calories are often as inexpensive as cereal calories, if not cheaper, and in many countries the cheapest fruits and vegetables are only 2–5 times as expensive as cereals (bananas being a particularly cheap source of fruit-based calories).

Fig. 2.1. Stunting rates for children aged 24–59 months, by location, father’s occupation, and assets owned: (A) 22 countries in sub-Saharan Africa; (B) four countries in South Asia. Data are estimated from the Demographic and Health Surveys (DHS). Rural/urban classifications follow the DHS (national) definitions, except that all farming households are classified as rural. Circle sizes reflect the size of the sample of children in each locality–occupation class. Ideally this measure should use sample weights, since the DHS over-samples urban areas, but since many surveys are several years old we do not apply weights, in order to allow for recent urbanization trends. The six assets in question are a TV, motorbike, car, refrigerator, electrification, and an improved floor material. The four countries in South Asia are India, Pakistan, Bangladesh and Nepal.

Fig. 2.2. Calorie price ratios (relative to the cheapest cereal) for various vegetal-based foods: (A) cheapest root/tuber; (B) cheapest legume; (C) cheapest vitamin A-rich fruit/vegetable; (D) cheapest other fruit/vegetable. Data are extracted from Headey *et al.* (2017b). Red lines show LOWESS curves to allow for non-linear functional forms. Individual observations are marked by the following regional groupings: sub-Saharan Africa (SSA); Latin America and Caribbean (LAC); South Asia and East Asia (ASIA); Middle East and North Africa (MENA); all other countries in Europe, North America, and Australasia (Other).

2. Higher prices of protein-rich legumes, animal-sourced foods and fortified infant cereals have strong negative associations with per capita income, though there is a large price variation at low income levels. For example, in the poorest countries legumes are 4 times as expensive as the cheapest cereal on average, but in some poor countries legumes are equally cheap as cereals and in others they are 7–8 times as expensive. Amongst milk products, both fresh milk and powdered milk are included, but only the latter is highly tradable. Despite this, milk prices vary markedly even within low-income countries and milk is often 4–6 times more expensive than the cheapest cereal. Flesh foods (meat, fish) show a similar relationship, but eggs are a far more expensive source of calories in low-income countries where they vary between being 4 to 15 times as expensive as cereals. Eggs are an extreme case of a food product that is difficult to trade long distances (especially in countries with

underdeveloped value chains), so the prices of eggs are largely determined by productivity levels in the domestic poultry sector, which is generally low in poorer countries. In contrast to eggs, fortified infant cereals are highly tradable products, but still extremely expensive in lower-income countries, often 10–30 times as expensive as conventional unfortified cereals. This potentially surprising result likely stems from a basic information asymmetry problem: parents have little trust in locally produced infant cereals, and instead opt for very expensive multinational brands if they can afford them (Masters *et al.*, 2017).

The results above suggest that the relative price of nutrient-rich foods, particularly protein- and micronutrient-rich animal-sourced foods, is very high in low-income countries, but declines as a country becomes wealthier. Moreover, Headey *et al.* (2017b) showed that the high prices

Fig. 2.3. Calorie price ratios (relative to the cheapest cereal) for various animal-sourced foods and fortified infant cereals: (A) cheapest milk; (B) cheapest flesh food; (C) cheapest egg; (D) fortified infant cereal. Data are extracted from Headey *et al.* (2017b). Red lines show LOWESS curves to allow for non-linear functional forms. Individual observations are marked by the following regional groupings: sub-Saharan Africa (SSA); Latin America and Caribbean (LAC); South Asia and East Asia (ASIA); Middle East and North Africa (MENA); all other countries in Europe, North America, and Australasia (Other).

of animal-sourced foods (ASFs) significantly explained the low consumption of ASFs in lower-income countries, as well as specific ASF consumption patterns with lower-income regions. For example, fresh milk and eggs are extremely expensive in sub-Saharan Africa, and their consumption is low, whereas fish is relatively cheap in most of Africa and its consumption is high. The high prices of ASFs, as well as some vegetal foods, clearly provides an opportunity for policies to greatly improve the affordability of these foods, as discussed in the concluding section.

This section has described cross-country variation in prices, but there is also an extensive literature on variation in opportunity costs or 'shadow' prices within countries. Shadow prices are the value of labor or other things needed to acquire each food even when explicit prices do not exist because of missing or incomplete markets. Markets might fail to provide an adequate supply of all foods because of the perishability

of certain foods – particularly eggs, fresh milk and many fruits and vegetables – and because local demand for these products is quite limited in low-income and low-density rural populations. Faced with imperfect supply from markets, households make production decisions that are designed to satisfy their consumption demands. For example, in Ethiopia over 90% of the milk produced by a rural household is consumed by that household (Hoddinott *et al.*, 2015). In this situation there are, unsurprisingly, strong associations between cattle ownership and children's milk consumption, but also between cattle ownership and child growth outcomes. Many other studies have linked livestock ownership to increased consumption of ASFs (Kabunga *et al.*, 2017), and local crop diversity to dietary diversity (Dillon *et al.*, 2015; Jones, 2017). Overall, these results strongly suggest that there are high degrees of market failure in developing countries, leading to a high degree

of dependence on local agricultural systems and vulnerability to local shocks.

Agriculture, Rural Livelihoods and Nutrition

As shown above in Fig. 2.1, stunting rates and absolute numbers of stunted children are significantly higher in rural areas of sub-Saharan Africa than in urban areas. Figure 2.1 also provides at least one explanation of this phenomenon: rural people are simply poorer than urban people, as measured by household assets. However, wealth differences provide only one likely explanation of the nutritional disadvantages of rural populations, since there are many other dimensions of rural living that might also contribute to under-nutrition. Earlier research concluded that this rural–urban inequality in nutritional status stemmed from differences in ‘endowments’ – such as wealth, education and access to services – rather than from the nutritional returns to these endowments (Smith *et al.*, 2004). Headey *et al.* (2017d) extended this research for a broader range of sub-Saharan African countries to examine both rural–urban differences, and differences across different degrees of remoteness (as measured by proximity to small cities). Strikingly, the results implied that proximity to cities is not important independent of its associations with wealth, education and access to services. Instead, remote villages – and rural villages in general – are simply characterized by poverty, low levels of human capital, and poor access to services. Indeed, these authors extended the rural–urban decompositions of earlier work to find that differences in endowments such as wealth, education, and access to services explained 77% of the observed difference in stunting rates across rural and urban areas. Differences in socio-economic status (wealth and non-farm employment) accounted for almost 40% of this difference, followed by parental education (19%) and health/infrastructural services (11%). They found similar results for rural–urban differences in child dietary diversity. An implication of these results is that physical remoteness seems to primarily influence nutrition through its harmful impacts on multidimensional poverty, including vulnerability to shocks (Mulmi *et al.*, 2016).

Beyond problems with remoteness and poor access to services, most rural populations still primarily work in agriculture, which presents its own potential health and nutritional hazards. A mostly qualitative literature, particularly in South Asia, has explored associations between women’s employment in agriculture and maternal nutrition, including substantial workloads during and soon after pregnancy (see Headey *et al.* (2012) for a review of earlier studies on this subject). One important concern is that physical exertion – especially in conditions of high temperatures – may be harmful for women’s nutrition, including weight loss. This literature also expresses concerns about the impacts of women’s workloads on their ability to care for children, including breastfeeding and dietary diversity. Headey *et al.* (2012) examined whether agricultural mothers in India were more likely to leave younger children in the care of others. They found that while this practice was common for agricultural women, it was also common for women in other unskilled occupations. Overall, though, there is little solid empirical evidence on whether agricultural employment is harmful to maternal or child nutrition beyond the obvious associations between employment in agriculture and general socio-economic poverty.

Other research has examined specific biological mechanisms linking agricultural livelihoods to health. For example, Brainerd and Menon (2014) looked at the longstanding concern that excessive and inappropriate use of chemical inputs, particularly pesticides and herbicides, has harmful effects on health and nutrition. They found significant evidence of adverse impacts on maternal and child health, including birthweight. More recently, Sheahan *et al.* (2017) examined pesticide use in five sub-Saharan African countries and found that pesticide use was associated with greater health expenditures and more sick days, though they did not test associations with child nutrition outcomes.

Another strand of research has looked at health problems associated with livestock ownership. Formative research in a rural Zimbabwean village monitored children for 12-hour periods (Ngure *et al.*, 2013). The study found that a large proportion of children directly consumed chicken feces, and dirt that may have been contaminated with chicken feces. They also showed that the bacterial loads of chicken

feces were some 10,000 times higher than dirt and other surfaces in the household. They argued that ingestion of such high loads of bacteria might contribute to environmental enteropathy, a chronic but latent infection of the gut that has been strongly linked to child stunting. Subsequent research in Ethiopia (Headey and Hirvonen, 2016) and Bangladesh (George *et al.*, 2015) found that children living under the same roof as poultry were more likely to be stunted, and a three-country study by Headey *et al.* (2017c) found that homesteads in Bangladesh and Ethiopia with observable animal feces in the compound had shorter children. A systematic review of diarrheal studies also found significant associations with livestock ownership in a majority of studies (Zambrano *et al.*, 2014). Hence, despite the importance of animal-sourced food intake for child nutrition, and the clear associations between livestock ownership and ASF consumption, there are also negative pathways between livestock ownership and child growth. These pathways presumably operate mainly through fecal contamination and enteric infections, though pulmonary infections associated with poultry ownership are a potential concern (Gomaa *et al.*, 2015), as is the connection between cattle ownership and malaria (Donnelly *et al.*, 2015).

Conclusions

Historical and comparative evidence discussed in this chapter suggests that agriculture's impact on nutrition can be seen to operate through three main levers, with a wide variety of other dimensions explored in later chapters of this book.

A first lever for agricultural change to improve nutrition is via real incomes and poverty reduction. Agricultural growth – including growth in staple food production – has been shown to be a historically important driver of poverty reduction because so many poor people directly and indirectly depend on agriculture for a living (Diao *et al.*, 2010). Evidence reported above suggests that agricultural growth is still likely to be an important driver of poverty reduction in South Asia and especially in sub-Saharan Africa, in ways that are heavily influenced by the local context (Dercon and Gollin, 2014).

The second lever explored in this chapter is through altering the relative price of nutritious foods. Headey *et al.* (2017a) showed that critically important animal-sourced foods are a very expensive source of calories in sub-Saharan Africa and much of Asia. Moreover, higher prices of ASFs are strongly and negatively associated with children's consumption of ASFs, suggesting high prices are a major constraint to ASF consumption, and perhaps to other nutrient-rich foods. Micro-econometric evidence also sheds light on the importance of incomplete markets; there are strong associations between agricultural assets/agroecological characteristics and consumption patterns, including consumption among infants. This suggests that in many localities certain nutrient-rich foods are either not affordable or not accessible in the market, forcing farmers into potentially inefficient self-reliance. The costliness of highly nutritious foods in lower income countries perhaps provides the strongest mandate for nutrition-focused agricultural development; other economic sectors may well drive income growth, but only food policies can influence the affordability of nutritious foods. These roadblocks highlight an opportunity for policy to improve the affordability of nutritious foods by, for example, setting quality standards for locally produced food products or improving market and transportation infrastructure in order to enable access to highly perishable, healthy foods.

A third agricultural lever for nutrition is through the transformation of agricultural livelihoods. These livelihoods consist of farming as an occupation, but also rural living, and all that it entails for maternal nutrition and empowerment, child care practices, and access to nutritionally relevant goods, services and infrastructure. In developing countries rural populations pervasively have nutrition outcomes that are significantly worse than urban populations, and there is no mystery as to why this is so: rural populations are much poorer and have substantially less access to essential goods and services. Yet they also face specific hazards associated with agricultural living, including exposure to potentially harmful chemical inputs, physically arduous work (including mothers), and highly unhygienic environments due to excessively close proximity to livestock. Continued research on the impact of these hazards on nutrition and

health can help policies and programs minimize them in the future.

There are many opportunities for productive research to guide policy choices regarding how agriculture affects nutrition. In recent years our understanding of agriculture–nutrition linkages has vastly improved, but many knowledge

and policy gaps remain. Much more emphasis is needed on how policies influence diets through income and price changes, what tradeoffs may exist between poverty and nutrition targets, and on how multisectoral rural development efforts can improve access to basic services and reduce farming's hidden health risks.

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