Priorities for Public Sector Research on Food Security and Nutrition

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Chapter 1. Introduction

Good nutrition is the foundation for human health and well-being, physical and cognitive development, and economic productivity. Nutritional status is a critical indicator of overall human and economic development, as well as an essential social benefit in its own right. As an input to social and economic development, good nutrition is the key to breaking intergenerational cycles of poverty, because good maternal nutrition produces healthier children, who grow into healthier adults. Good nutrition reduces disease and raises labor productivity and incomes, including of those working in agriculture.

Agricultural policy makers now understand that addressing malnutrition requires more than simply making food abundant and affordable; interventions in health, sanitation, education and other sectors also play a role, and the food system itself must give higher priority to improving nutrition. Similarly, nutritionists now recognize that malnutrition is not just a health problem to be treated with supplements and medical interventions but is influenced by conditions across many sectors, including agriculture. Both groups agree that integrated actions are needed across health, education, and agricultural sectors, yet both tend to view agriculture as static, rather than as part of dynamic food systems that can be shaped to promote better nutrition.

Agriculture and food systems will always provide most of the nutrients and compounds that humans require to sustain healthy and productive lives. It is clear that, in the face of rapidly growing populations and land, environmental, human capacity, and institutional constraints, agriculture has not performed this function well in developing countries. The evidence on widespread under-nutrition (and over-nutrition) will be presented in Chapter 2 of this paper.

The nature of food systems, including structural characteristics and the decisions of actors involved in those systems, is central to determining how those systems interact with other causal factors and influence nutritional outcomes. Conceptual frameworks for analysis are discussed in Chapter 3.

Interventions that improve the general economic, social, or political environment may not be designed to improve nutrition but will almost certainly have a positive effect. Among these “nutrition-sensitive actions” are, for example, policies that increase agricultural productivity (and so raise producer incomes, lower the cost of food for consumers, and allow both producers and consumers to increase expenditures on more adequate, diverse diets, and can lead to increased expenditures on health, education and food, all key inputs into better nutrition), discussed in Chapter 4.

Many interventions discussed in this paper are nutrition-specific, undertaken with the primary purpose of producing good nutritional outcomes. For example, the principal impetus in development of biofortified crops is to improve nutrition. At the same time, these crops may also be more disease-resistant and better at growing in micronutrient-deficient soils. They may improve nutrition but also give higher crop yield and increase producer incomes, a win for both consumers and producers (HarvestPlus, 2013). Many additional approaches may increase the nutrient density of specific foods (Chapter 5).

Agricultural products reach consumers through food supply chains, and each link in a food supply chain affects the availability, affordability, diversity, and nutritional quality of the food, as well as price and ease of access. This in turn shapes consumer choices, dietary patterns, and nutritional outcomes. Opportunities exist at each link in the chain to deliver more diverse and nutritious foods (Chapter 6).

In poor countries, diseases associated with agriculture have important health impacts. Food that nourishes can also sicken and kill. Managing the health risks associated with food safety, zoonotic (diseases that are transmissible between man and animals), and emerging diseases, and diseases associated with agricultural intensification, are important for improving and maintaining good nutrition (Chapter 7).

Although many interventions are specific to a particular part of the food system, gender must be addressed in all types of interventions. Men and women will be affected differently by any interventions aimed at making food systems more nutrition sensitive (Chapter 8).

The integration of program and policy efforts across the agriculture, nutrition, and health sectors can lead to much more positive nutrition and health impacts. This includes policies to reduce obesity. Changes in activity and dietary patterns in developing countries are part of a "nutrition transition," where countries simultaneously face not only the emerging challenge of rising levels of overweight and obesity and related non-communicable diseases but also continue to deal with the problems of undernutrition and micronutrient deficiencies (Chapter 9).

Conclusions for research priorities are drawn in Chapter 10.

Chapter 2: The Prevalence and Costs of Malnutrition

Undernourishment and undernutrition

Undernourishment refers to food *intake* that is insufficient to meet dietary energy requirements for an active and healthy life. Undernourishment, or hunger, is estimated by FAO as the prevalence and number of people whose food intake is insufficient to meet their requirements on a continuous basis; dietary energy supply is used as a proxy for food intake. Since 1990-92, the estimated number of undernourished people in developing countries has declined from 980 million to 852 million and the prevalence of undernourishment has declined from 23 percent to 15 percent (FAO, 2012a).

Undernutrition is defined as an *outcome* of undernourishment, poor absorption or poor biological use of nutrients consumed (SCN 2004). Undernutrition or underweight in adults is measured by the Body Mass Index (BMI), with individuals having a BMI of 18.5 or less considered underweight.[1] Such data are relatively scarce for adults. Measures of undernutrition are more widely available for children: underweight (being too thin for one's age), wasting (being too thin for one's height) and stunting (being too short for one's age).

Stunting in children under 5 years of age is often used as the primary indicator of undernutrition because stunting captures the effects of long-term deprivation and disease and is a powerful predictor of the life-long burden of undernutrition (Victora et al., 2008). Stunting is caused by maternal undernutrition, which leads to poor fetal growth and low birth-weight, and by poor growth due to inadequate dietary intake and continuing bouts of infection and disease. Stunting causes permanent impairments to cognitive and physical development that lower educational attainment and reduce adult income. Between 1990 and 2011, prevalence of stunting declined by an estimated 16.6 percentage points, from 44.6 percent to 28 percent, in developing countries. Today there are 160 million stunted children in developing countries, compared to 284 million in 1990.

Micronutrient deficiencies

Micronutrient malnutrition is defined as being deficient in one or more vitamins and minerals of importance for human health. It is an *outcome* of inappropriate dietary composition and disease. It is technically a form of undernutrition, but it is often referred to separately because it can co-exist with adequate or excessive consumption of macronutrients and carries health consequences distinct from those associated with stunting.

Several micronutrients have been identified as being important for human health, but most of these are not widely measured. Vitamin A, iron, and iodine deficiencies are the most commonly measured micronutrient deficiencies because they are well known and have long been associated with specific health consequences (Figure 1). Other micronutrients, such as zinc, selenium, and Vitamin B12 are also important for human health, but

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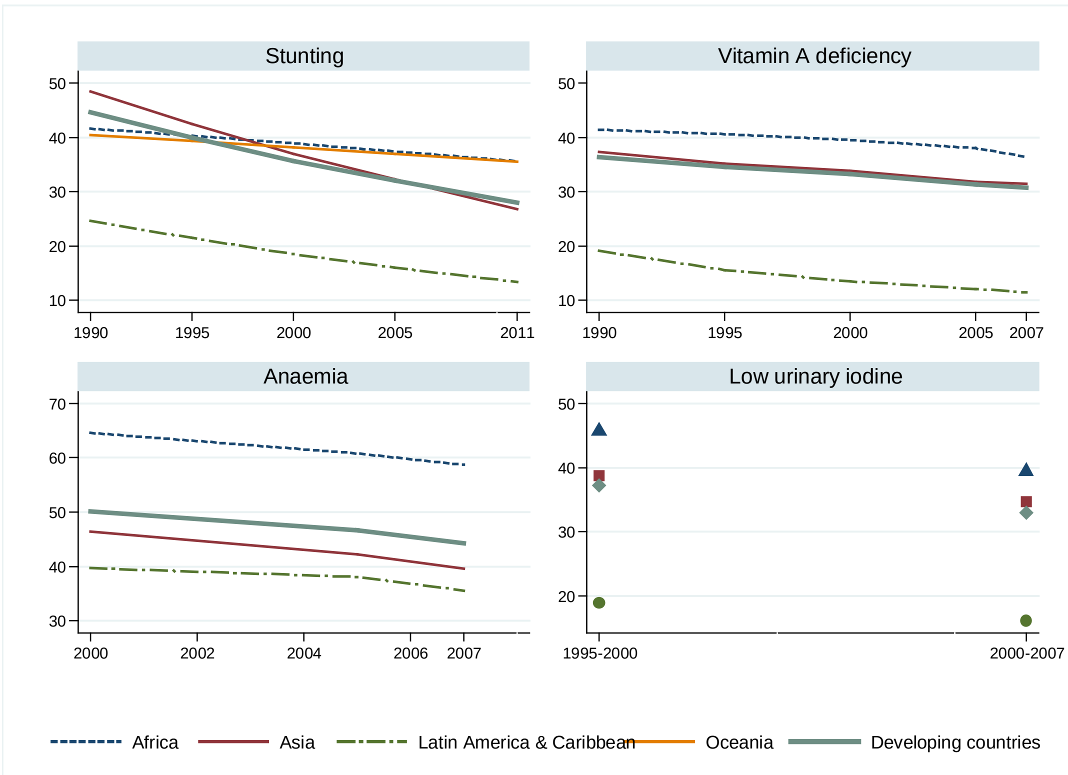
[1] The BMI equals the body weight in kilograms divided by height in meters squared (kg/m2) and is commonly measured in adults to assess underweight, overweight and obesity. The international references are as follows: underweight = BMI < 18.5; overweight = BMI ≥ 25; obese = BMI ≥ 30. Obesity is thus a subset of the overweight category.

comprehensive data do not exist to provide global estimates of deficiencies of these micronutrients. This report also tends to report micronutrient deficiencies among children, again because data are more consistently available across countries than for adults.

Figure 1.Prevalence of Stunting and Micronutrient Deficiencies in Children under 5 years of age



Source: SCN, 2010

Note: Due to limited data availability for urinary iodine, regional averages are reported for only two time periods.

Deficiency in vitamin A impairs normal functioning of the visual system, and maintenance of cell function for growth, red blood cell production, immunity and reproduction (WHO, 2009). Vitamin A deficiency (VAD) is the leading cause of blindness in children; 136 million children under five in developing countries were estimated to be vitamin A deficient with a prevalence of about 31 percent, in 2007, down from approximately 36 percent in 1990 (SCN, 2010).

Iron is important for red blood cell production and a deficiency in iron intake leads to anemia (other factors also contribute to anemia, but iron deficiency is the main cause). Iron-deficiency anemia (IDA) negatively affects the cognitive development of children, pregnancy outcomes, maternal mortality and work capacity for adults. Estimates indicate modest progress overall in reducing IDA among children under five, pregnant and non-pregnant women (SCN, 2010).

Iodine deficiencies impair mental function in 18 million children born each year. Overall, iodine deficiency – as measured by both total goiter rate and low urinary iodine – is falling. Estimates indicate that goiter prevalence (indicative of an extended period of deprivation, assessed in adults and/or children) in developing countries fell from about 16 to 13 percent between 1995-2000 and 2001-2007 (regional averages are only shown for these two time periods due to data limitations). Low urinary iodine (indicative of a current iodine deficiency) fell from about 37 to 33 percent (SCN, 2010).[2]

A number of regional trends and patterns in stunting and micronutrient deficiencies are discernible. In general sub-Saharan Africa has high levels of stunting, and micronutrient deficiencies, with relatively modest improvements over the last two decades. Prevalence rates for stunting and micronutrient deficiencies are relatively low in Latin America and the Caribbean. In terms of numbers, most of the severely affected population lives in Asia, but with wide sub-regional variation.

Overweight and obesity

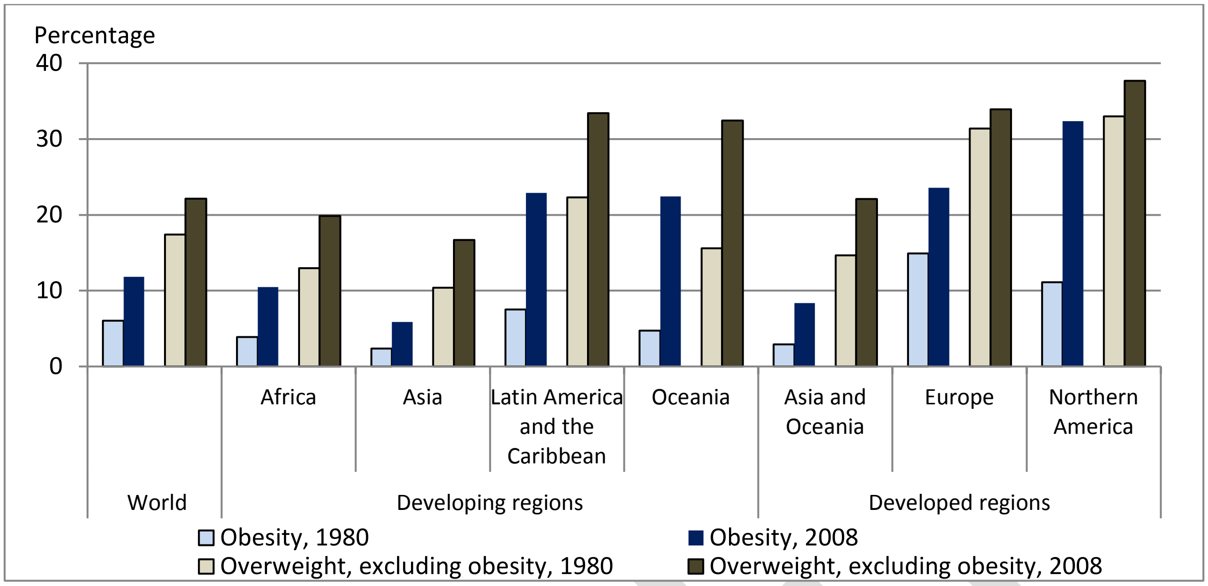
Measure of overnutrition - overweight and obesity - are defined as abnormal or excessive fat accumulation that may impair health (WHO 2012) and most commonly measured using the BMI. A high BMI is recognized as increasing the likelihood of incurring various non-communicable diseases (NCDs) and health problems, including cardiovascular disease (CVD), diabetes, various cancers and osteoarthritis (WHO, 2011). The health risks associated with overweight and obesity increase with the degree of excess body fat.

The global prevalence of combined overweight and obesity in adults increased to 34 percent in 2008. The prevalence of obesity has increased even faster, doubling from 6 to 12 percent. The prevalence of overweight and obesity has increased rapidly in all regions, with obesity rates rising faster than those for more moderate levels of overweight (Figure 2) (Stevens et al. 2012).

Obesity rates tend to be higher in developed regions, especially North America and Europe where 32 and 24 percent of adults are obese, although Latin America and the Caribbean and Oceania have obesity rates approaching those in Europe. The prevalence of overweight and obesity is increasing in nearly all countries throughout the world, even in low-income countries where it coexists with high rates of undernutrition (Stevens et al, 2012).

[2] Both sets of estimates are based on multi-variate models applied to all countries for those time periods. The estimates are not very different from those obtained by simply averaging over the available surveys (SCN 2010).

Figure 2.*The Prevalence of overweight and obesity among adults, by region*



Source: Authors' calculations using data that appears in Stevens et al, 2012.

Social and economic costs of malnutrition

The social and economic costs of malnutrition can be quantified in a number of ways, although any methodology has limitations. Disability Adjusted Life Years (DALYs) measure the social burden of disease, or the health gap between current health status and an ideal situation where everyone lives into old age, free of disease and disability (WHO, 2008). One DALY represents the loss of the equivalent of one full year of "healthy" life.

The available evidence suggests that child and maternal undernutrition imposes by far the largest nutrition-related health burden globally, with more than 166 million DALYs lost per year in 2010 compared with 94 DALYs lost due to adult overweight and obesity (Tables 1 and 2).[3] Countries in Asia and Africa bear by far the largest burden of maternal and child undernutrition. The number of DALYs lost due to child and maternal undernutrition has declined almost by half during the last two decades, while DALYs lost due to overweight and obesity have almost doubled. Great progress has been made in reducing DALYs associated with individual nutritional deficiencies among children, notably underweight, suboptimal breastfeeding and some micronutrient deficiencies.

[3] The most recent work on the global burden of disease (published at the time of writing) shows that worldwide DALYs attributed to high body-mass index (overweight and obesity) and related risk factors (such as diabetes and high blood pressure) have increased dramatically, while those attributed to child and maternal malnutrition have decreased. However, in most of sub-Saharan Africa child underweight remains the leading risk factor underlying the disease burden (Lim et al, 2012).

Table 1. Total DALYS for children under 5, by risk factor, population group and region

	Children under 5											
Region	**Child and maternal undernutrition**		**Underweight**		**Iron deficiency**		**Vitamin A deficiency**		**Zinc deficiency**		**Suboptimal breastfeeding**	
	1990	**2010**	**1990**	**2010**	**1990**	**2010**	**1990**	**2010**	**1990**	**2010**	**1990**	**20**
World	**339,951**	**166,147**	**197,774**	**77,346**	**15,671**	**15,389**	**30,300**	**10,775**	**24,375**	**9,139**	**110,226**	**47,5**
Developed regions	**2,243**	**1,731**	**160**	**51**	**417**	**292**	**38**	**13**	**132**	**59**		
Developing regions	**337,708**	**164,416**	**197,614**	**77,294**	**15,254**	**15,097**	**30,262**	**10,762**	**24,244**	**9,080**	**110,226**	**47,5**
Africa	**121,492**	**78,017**	**76,983**	**43,990**	**4,309**	**5,107**	**14,902**	**7,015**	**8,701**	**4,682**	**34,882**	**21,4**
Eastern Africa	42,123	21,485	27,702	11,148	1,007	1,557	5,526	1,909	3,482	1,349	11,766	6,2
Middle Africa	18,445	17,870	12,402	11,152	549	730	2,108	1,777	1,556	1,511	4,550	4,9
Northern Africa	10,839	4,740	4,860	1,612	487	542	596	237	477	136	4,819	1,5
Southern Africa	2,680	1,814	930	382	208	164	277	140	138	69	1,365	1,0
Western Africa	47,405	32,108	31,089	19,696	2,057	2,115	6,396	2,952	3,047	1,617	12,383	7,6
Asia	**197,888**	**80,070**	**115,049**	**32,210**	**9,236**	**8,843**	**14,331**	**3,610**	**14,214**	**4,010**	**64,691**	**24,0**
Central Asia	3,182	1,264	**967**	**169**	**153**	**125**	**134**	**28**	**346**	**111**	**1,768**	**5**
Eastern Asia	21,498	4,645	6,715	347	2,334	1,647	653	54	1,452	189	11,369	1,3
Southern Asia	138,946	60,582	89,609	27,325	5,274	5,581	11,664	2,961	9,507	2,864	39,019	17,4
South-Eastern Asia	27,971	9,736	15,490	3,318	1,085	1,031	1,706	487	2,631	733	9,139	3,1
Western Asia	6,291	3,843	2,269	1,051	390	457	174	81	278	113	3,397	1,5
Latin America & the Caribbean	**17,821**	**6,043**	**5,292**	**979**	**1,693**	**1,124**	**997**	**124**	**1,295**	**373**	**10,480**	**1,8**
Caribbean	2,559	1,073	849	252	487	187	134	26	229	64	958	2
Central America	5,437	1,491	2,124	366	333	297	405	36	461	137	3,167	6
South America	9,826	3,479	2,319	361	873	640	459	62	605	172	6,355	9
Oceania	**507**	**286**	**290**	**115**	**17**	**23**	**31**	**13**	**33**	**15**	**174**	**1**

Note: DALYs estimates presented for Child and maternal malnutrition include childhood underweight for children aged 1 week to 5 years, iron deficiency for children under 5, vitamin A deficiency for children aged 6 months to 5 years, zinc deficiency for children aged 1-4 and suboptimal breastfeeding for children aged 1 week to 2 years.

Source: Global Burden of Disease Study 2010. Global Burden of Disease Study 2010 (GBD 2010) Results by Risk Factor 1990-2010. Institute for Health Metrics and Evaluation (IHME), 2012

Table 2. Total DALYS for adults, by risk factor, population group and region

	Adults							
Region	**Iron deficiency - men**		**Iron deficiency - women**		**Overweight and obesity - men**		**Overweight and obesity - women**	
	1990	**2010**	**1990**	**2010**	**1990**	**2010**	**1990**	**2010**
World	**6,352**	**5,820**	**17,004**	**15,868**	**25,410**	**48,442**	**26,203**	**45,398**
Developed regions	**283**	**269**	**691**	**688**	**15,047**	**20,251**	**14,909**	**17,708**
Developing regions	**6,069**	**5,551**	**16,313**	**15,179**	**10,363**	**28,191**	**11,295**	**27,690**
Africa	**1,336**	**1,802**	**3,339**	**4,216**	**1,514**	**4,248**	**2,057**	**5,357**
Eastern Africa	393	594	977	1,191	165	542	188	689
Middle Africa	233	338	448	647	85	224	72	348
Northern Africa	183	228	530	557	895	2,220	1,135	2,554
Southern Africa	59	58	121	143	225	625	395	817
Western Africa	468	584	1,263	1,680	143	638	268	950
Asia	**4,149**	**3,184**	**12,222**	**10,289**	**6,414**	**18,175**	**6,541**	**16,376**
Central Asia	**32**	**32**	148	180	470	944	483	765
Eastern Asia	108	73	1,449	849	2,631	7,439	2,797	5,892
Southern Asia	3,054	2,366	8,660	7,569	1,629	4,792	1,324	4,489
South-Eastern Asia	833	540	1,586	1,178	447	2,314	598	2,718
Western Asia	122	173	378	514	1,237	2,686	1,340	2,512
Latin America & the Caribbean	**577**	**559**	**727**	**644**	**2,398**	**5,640**	**2,665**	**5,809**
Caribbean	97	75	200	187	179	387	222	468
Central America	131	86	84	50	561	1,599	667	1,710
South America	349	398	443	406	1,658	3,654	1,776	3,632
Oceania	**6**	**7**	**26**	**30**	**37**	**128**	**32**	**148**

Note: DALYs estimates presented for iron deficiency adults aged 15 and older. Those for OWOB include adults aged 25 and older. Source: Global Burden of Disease Study 2010. Global Burden of Disease Study 2010 (GBD 2010) Results by Risk Factor 1990-2010. Institute for Health Metrics and Evaluation (IHME), 2012.

In Tables 1 and 2, Total DALYs show the overall magnitude of the burden of different types of malnutrition for each region. Also relevant is the size of this burden, in DALYs, relative to the pertinent population group. For example, total DALYs for child underweight are higher in Asia than in Africa, but on a per-child basis the burden is three times higher in Africa than in Asia. Measured in this way, the burden in Oceania is as large as in Asia. Per-capita DALYs also show that while iron deficiency is relatively low in Latin America and the Caribbean as a whole, it is higher in the Caribbean than in any other region. And with the exception of Northern Africa, vitamin A deficiency and suboptimal breastfeeding impose significantly higher burdens in Africa than anywhere else. Finally, per-capita DALYs for overweight and obesity are higher in Oceania than even in developed regions. The wide regional differences bring out the importance of an adequate assessment of the nutrition situation at the country and sub-national level.

Beyond the social costs of malnutrition reflected in DALYs, malnutrition also imposes economic costs on society. The economic costs of undernutrition, which arise through its negative effects on human capital formation (physical and cognitive development), productivity, poverty reduction and economic growth, may reach as high as 2 to 3 percent of global GDP (World Bank, 2006b).

The economic costs of undernutrition are cumulative through an inter-generational life-cycle of deprivation. An estimated 30 million low birth-weight babies are born each year (WHO 2008). Low birth-weight, childhood undernutrition, exposure to poor sanitary conditions and inadequate health care are reflected in poor physical growth and mental development, resulting in lower adult productivity.[4] Empirical evidence clearly shows that childhood stunting reduces adult productivity (Strauss and Thomas, 1998; Hunt, 2005) but, more insidiously, maternal stunting is one of the strongest predictors for giving birth to a low birth-weight infant. Maternal and child malnutrition thus perpetuate the cycle of poverty.

Micronutrient deficiencies, as distinct from undernutrition, impose significant costs on society. Iron deficiency anemia among adult wage earners is estimated to lead to productivity losses of up to 20 percent (Levin et al, 1994). The median total economic loss due to physical and cognitive impairment resulting from anemia was estimated at 4

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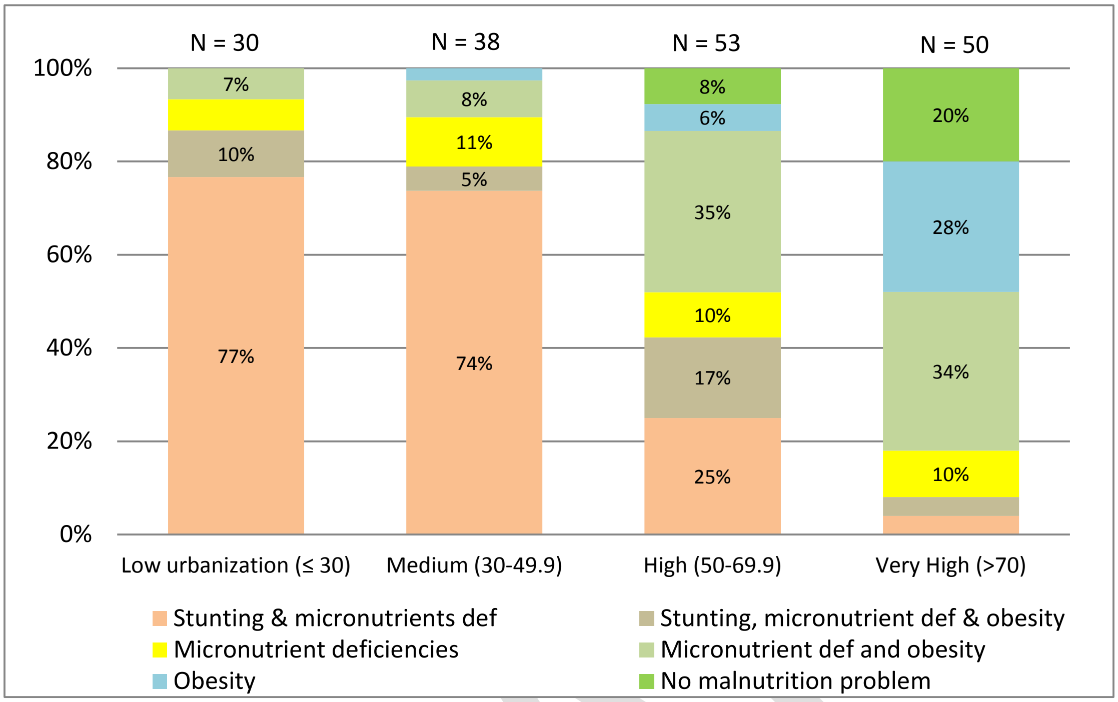
[4] Alderman and Behrman (2004) calculate that the economic benefits from preventing one child from being born with a low birthweight is about US$ 580.

percent of GDP for 10 developing countries, ranging from 2 percent in Honduras to 8 percent in Bangladesh (Horton and Ross, 2003). This study also suggested that while the productivity losses associated with anemia are higher for individuals who must perform heavy manual work (17 percent), they are also serious for those doing light manual work (5 percent) and cognitive tasks (4 percent). Further evidence shows that treating anemia can increase productivity even among individuals involved in work that is not physically demanding (Schaetzel and Sankar, 2002).

Overweight and obesity also impose economic costs on society directly through increased health care spending and indirectly through reduced economic productivity. A recent study by Bloom et al (2011) estimates a cumulative output loss of US$ 47 trillion over the next two decades, equivalent to 75 percent of global GDP in 2010. Most of the losses occur in high-income countries. In the United States, about 10 percent of total healthcare spending is obesity-related, of which about half is financed by the government and half by private insurance companies and individuals (Finkelstein et al, 2009).

Figure 3 depicts the nutrition transition from undernourishment to overnourishment as it accompanies greater urbanization. Stunting falls and obesity rises almost in tandem. At the same time, micronutrient deficiencies fall very slowly as the rates of urbanization rise, and they remain remarkably prevalent even in higher income, highly urbanized countries.

Figure 3. ***Urbanization and the changing burden of malnutrition***



Data: Micronutrients: WHO, CDC, IZiNCG, compiled by the Micronutrient Initiative, 2009; stunting: WHO and UNICEF; overweight: WHO; urbanization: FAOSTAT.

Conclusions

The nature of the malnutrition burden facing the world is increasingly complex. Significant progress has been made in reducing food insecurity, undernourishment and undernutrition; however, prevalence rates remain high in some regions, most notably Africa and South and Southeast Asia. At the same time, micronutrient deficiencies remain stubbornly high and obesity rates are rising rapidly in many regions, even in countries where undernutrition persists.

The social and economic costs of undernutrition, micronutrient deficiencies and obesity are high. While costs associated with obesity are rising rapidly, those associated with undernutrition and micronutrient deficiencies are still much higher both in absolute terms of "disability adjusted life years" and relative to the affected populations. The economic cost of undernutrition may reach as high as 2-3 percent of GDP in developing countries. Food system transformation and the nutrition transition go hand in hand. Addressing the nutritional challenges in a given context requires understanding the nature of the food system and identifying key entry-points throughout the system.

Chapter 3. Conceptual Frameworks

Nutritional outcomes depend on many factors, but food systems and the policies and institutions that shape them are a fundamental part of the equation. A common denominator across all types of malnutrition is the appropriateness of the foods consumed. At the most basic level, food systems determine the quantity, quality, diversity, and nutritional content of the foods available for consumption.

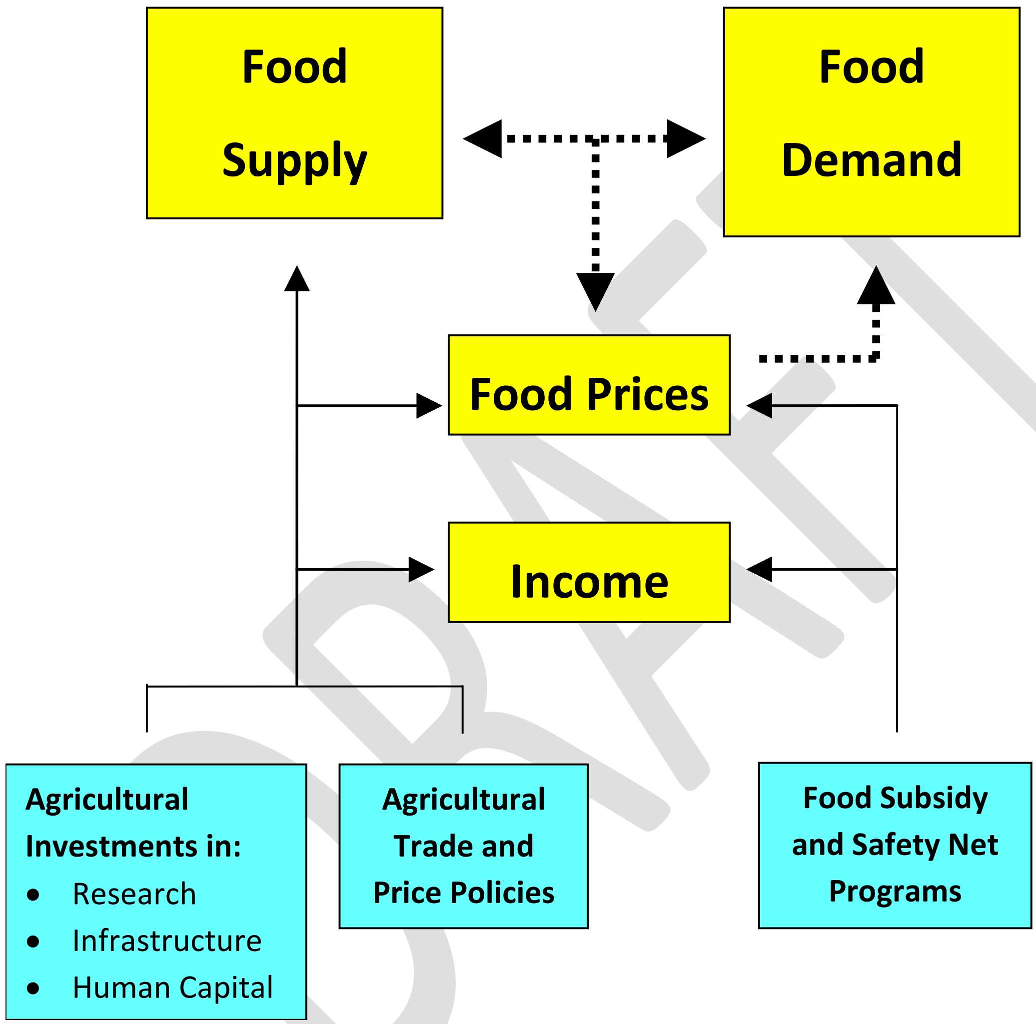
Creating a strong nutrition-sensitive food and agricultural system is arguably the most practical, convenient, and sustainable way to address malnutrition, as food choices and consumption patterns ultimately become integrated into the lifestyle of the individual. Taking a systems approach to food and nutrition provides a frame of action in which to determine, design, and implement food-based interventions to improve nutrition. There is no single food system, or even unique typology, but rather a multiplicity of systems with characteristics that vary by, for instance, geography or livelihood or need. Below we present three frameworks for analysis of how food and nutrition policies may impact nutrition outcomes

3.1. Macro-Economic Perspective

As shown in Figure 4, at the level of agricultural sector, supply and demand for various foods determine food prices. Supplies of various foods are driven by agriculture investment, trade, and price policies. Demand is determined primarily by income and food prices. It is the interplay of supply, demand, income, and food prices that to a very significant extent determine the diets that people can afford, and so nutrition outcomes.

If there is rapid technological change in agriculture and food productivity increases, food prices may fall at the same time as rural incomes improve, to the benefit of better diets for all, in both rural and urban areas. If, on the other hand, food prices increase, this may benefit some rural producers, but food price increases represent in effect a decline in income for net buyers of food. These issues are discussed in Chapter 4.

Figure 4. Food Supply, Food Demand, Food Prices, Income, and Agriculture Sector Policies.

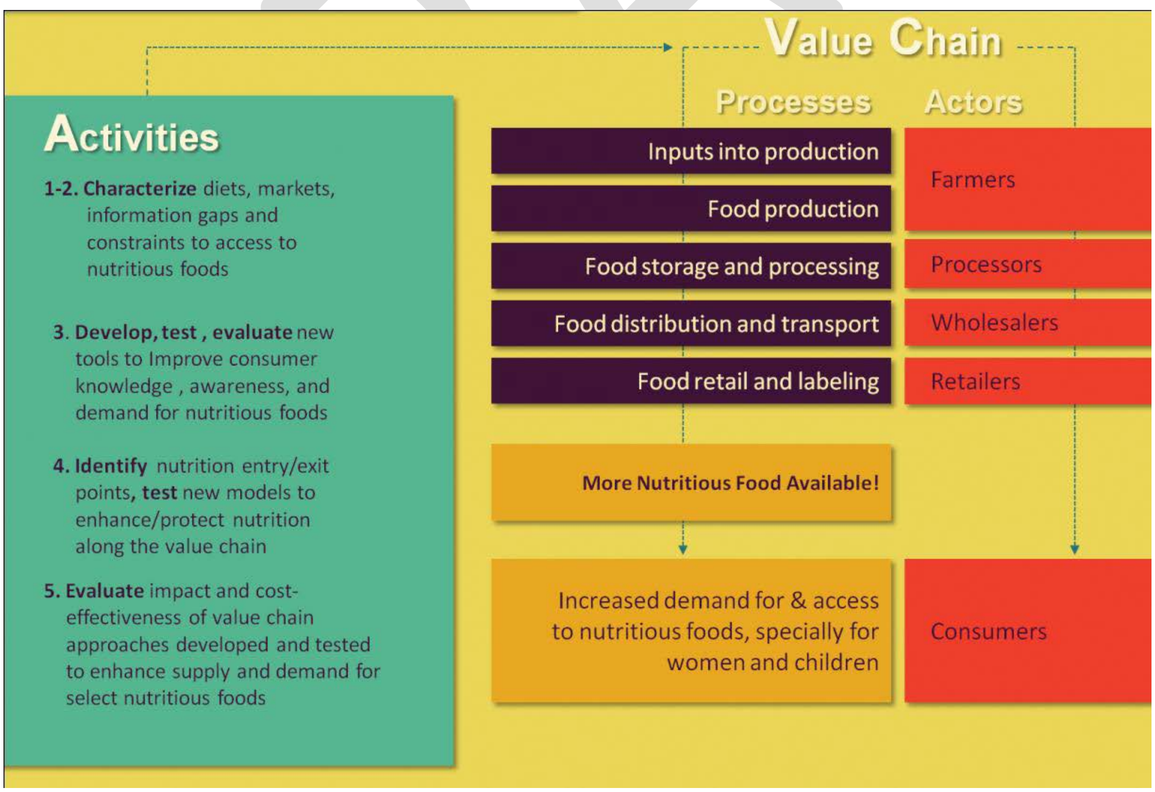


3.2. Market-Level Perspective

Food production is just one factor in the consumption and availability of nutrients. Food is stored, distributed, processed, retailed, prepared, and consumed in a range of ways that affect the access, acceptability, and nutritional quality of foods for the consumer. Producing for consumption in the home or for local markets remains important, but the market-oriented nature of agricultural policies means that increasingly farmers are net-food buyers and are thus affected by commercial markets.

Value-chain concepts and approaches have been widely used in international development with the objective of enhancing the livelihoods of food producers. Although they often address food safety issues, value-chain analyses rarely incorporate nutritional and other health considerations (Hawkes and Ruel 2011). The food supply chain is most often discussed from the perspective of value-chain actors—the *supply* side**.** Little emphasis is placed on how informed consumers can play a role in influencing the value chains, and how changes in the *demand* for specific foods can influence the processes and outputs of value chains.

Figure 5. Value Chain Processes and Actors



3.3. Household and Individual Level Perspective

Food and nutrient intakes are not the only factors that drive nutrition and health outcomes. Additional important factors include:

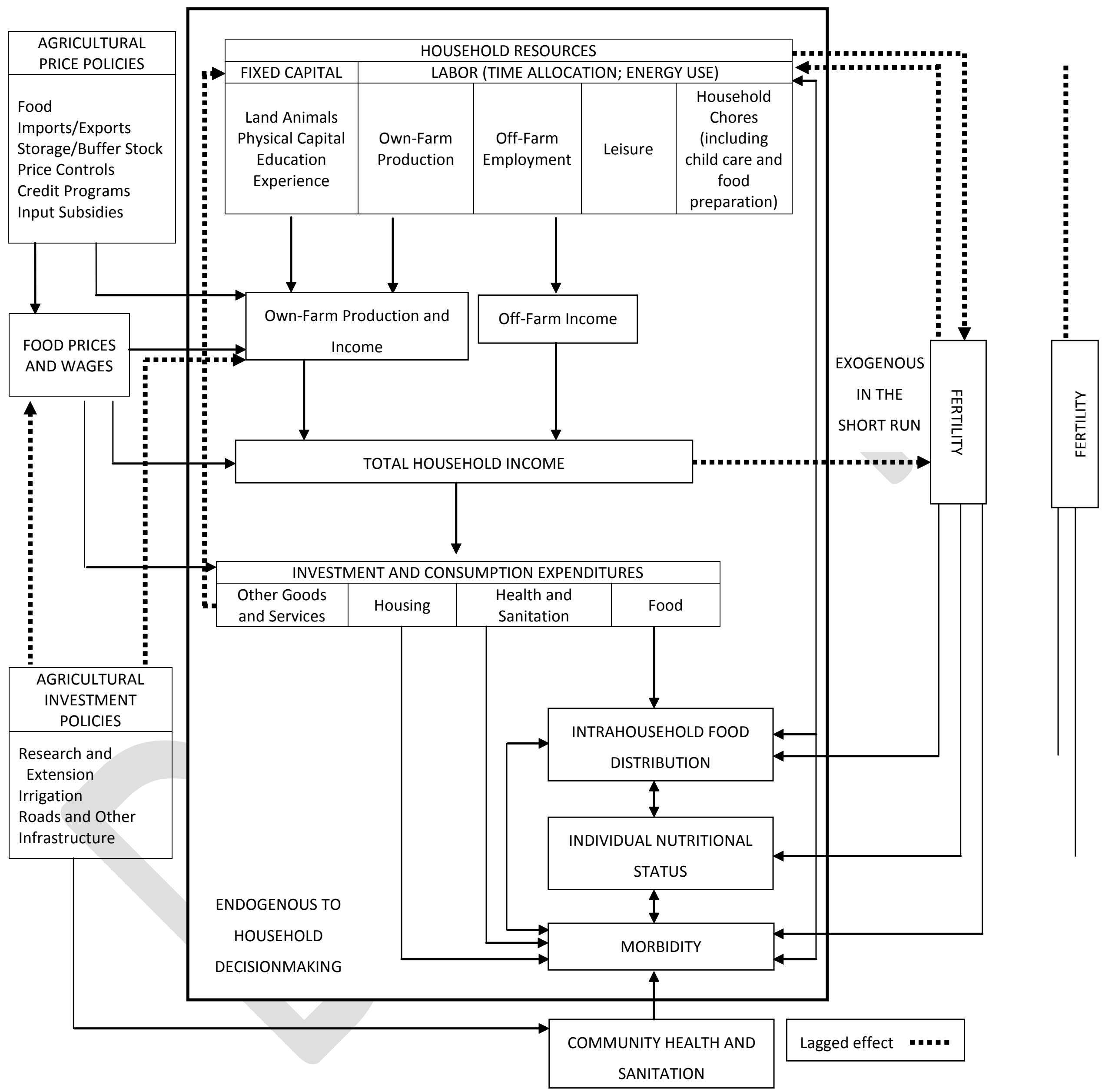
- Demands on women's time to earn income (e.g. work in farm fields) may take time away from child care, which is particularly crucial for infants.
- Poor ***community-level*** sanitation and access to health remains an obstacle even as household-level income, sanitation, and medical care improve.
- Women's education and knowledge about child care and sanitation practices can be expected to increase with income.
- Cultural diversity with respect to attitudes toward food and women's roles

These issues can be discussed in the context of the Figure 6 below. The household has a fixed amount of time and capital that it must decide to allocate among various income-generating activities with the objective of maximizing the well-being of household members through consumption expenditures, leisure time, and better nutrition and health.

Depending on how those resources are allocated to own-farm production activities and off-farm employment, a certain amount of cash and in-kind income is generated that can then be spent on various consumption items. One of the primary linkages is food expenditures: how they increase with higher incomes, the extent to which nutrient availability is enhanced by these extra food expenditures at the household level, and how these nutrients are distributed among various household members. As shown at the bottom of Figure 3, nutrient intakes are an important determinant of nutritional status.

Nutrient intakes are not the only link through which household allocation decisions affect nutritional status. The household that earns less income because it allocates more time to food preparation and child care may enjoy better nutrition than if it had earned extra income and spent more for food. Reviews by Basu and Basu [1] and Desai and Jain [2], for example, conclude that maternal employment is associated with higher infant or child mortality and undernutrition because working women cannot make time available to care of children. The extra income earned does not make up for the decline in time for child care. However, studies by the World Bank [3] and the World Health Organization [4] show a strong positive relationship between income and health care utilization.

Figure 6. Agricultural policies, household resource allocation, and nutrition



Note: This figure is taken from Kennedy E and Bouis H. Linkages Between Agriculture and Nutrition: Implications for Policy and Research. Washington, D.C.: International Food Policy Research Institute, 1993. Figure 1.

Chapter 4: Effects of Incomes and Food Prices on Diets

4.1. Dietary Quality and Household Income

Food prices and income levels have a strongly determinative effect on dietary quality. Table 3 shows per capita energy intake and share of food expenditures by broad food groups by income group for three countries, Bangladesh, Kenya, and the PHilippines. At low incomes the poor give priority to purchasing food staples, the most inexpensive source of energy, to keep from going hungry. As income increases, they buy non-staple plant foods (e.g. lentils, fruits, vegetables) and animal products (including fish) because of a strong underlying preference for the tastes of these non-staple foods.

Although diets are expressed in Table 3 only in terms of energy (and not minerals and vitamins), because non-staple plant foods and animal products are denser than food staples in bioavailable minerals and vitamins, percentage increases in mineral and vitamin intakes rise much more sharply with income than do energy intakes. Animal products are the most expensive source of energy, but the richest sources of bioavailable minerals and vitamins.

There is a natural underlying tendency, then, for dietary quality to improve as economic development proceeds. As household income rises and demand for non-staple plant foods and animal products rises, prices for these better quality foods will tend to rise, all things being equal. These price signals, in turn, will give rise to supply responses from agricultural producers. The essence of agricultural development is that technological improvements will be stimulated (e.g. development of higher yielding varieties either through public or private investments in agricultural research), which in turn will lead to more efficient production, faster supply growth rates, and eventually lower non-staple food prices.

It is the role of public food policies to influence this long-run process so that aggregate growth is rapid and so that all socio-economic groups (importantly the malnourished poor) share in the benefits of this growth.

Table 3.Per capita energy intakes (calories/day) and food budget shares by broad food group by income group for three countries

	Bangladesh				Kenya					Philippines				
Food Group	Income Tercile			All House-holds	Income Quartile				All House-holds	Income Quartile				All House-holds
	1	2	3		1	2	3	4		1	2	3	4	
Per Capita Energy Intake														
Staples	1805	1903	1924	1879	1283	1371	1388	1394	1360	1361	1431	1454	1381	1406
Non-Staple Plant	281	347	394	340	256	348	363	464	357	197	229	304	395	281
All Animal	44	61	89	64	112	120	161	187	145	67	102	118	207	124
Total	2130	2311	2407	2283	1651	1839	1912	2045	1862	1625	1762	1876	1983	1811
Food Budget Share (Percent)														
Staples	46	41	36	40	Data Not Available					43	36	28	24	33
Non-Staple Plant	32	35	36	34						30	36	39	37	35
All Animal	22	24	28	26						27	28	33	39	32
Total	100	100	100	100						100	100	100	100	100

Note: This table appears in [14], Table XV.

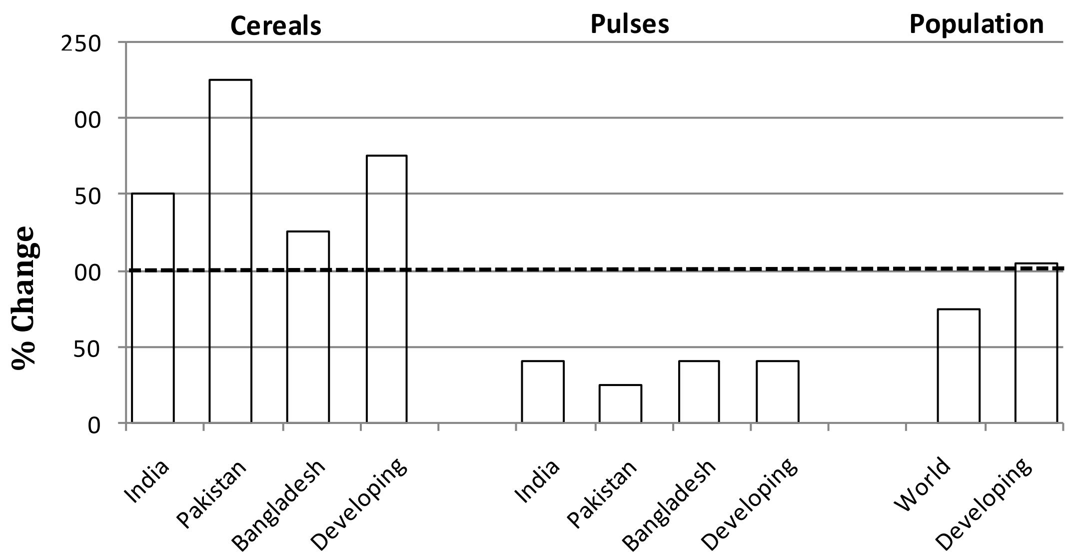
4.2 Dietary diversity and nutrition outcomes

Healthy diets contain a balanced and adequate combination of macronutrients (carbohydrates, fats, and protein) and essential micronutrients (vitamins and minerals). Nutrition guidelines generally maintain that diverse diets will provide adequate nutrition for most people to meet energy and nutrient requirements, although supplements may be required for certain populations (FAO/WHO, 1992). Nutritionists consider dietary diversity, or dietary variety – defined as the number of different foods or food groups consumed over a given reference period – as a key indicator of a high quality diet (Ruel, 2003). Evidence indicates that dietary diversity is strongly and positively associated with child nutritional status and growth, even after socioeconomic factors have been controlled for (Arimond and Ruel, 2004; Arimond et al., 2010). Some questions remain controversial, such as whether animal-source foods are an essential part of the diet and whether all people, especially young children, can acquire adequate nutrients from food without supplementation.

4. 3. Dietary Quality, Food Prices, and the Green Revolution

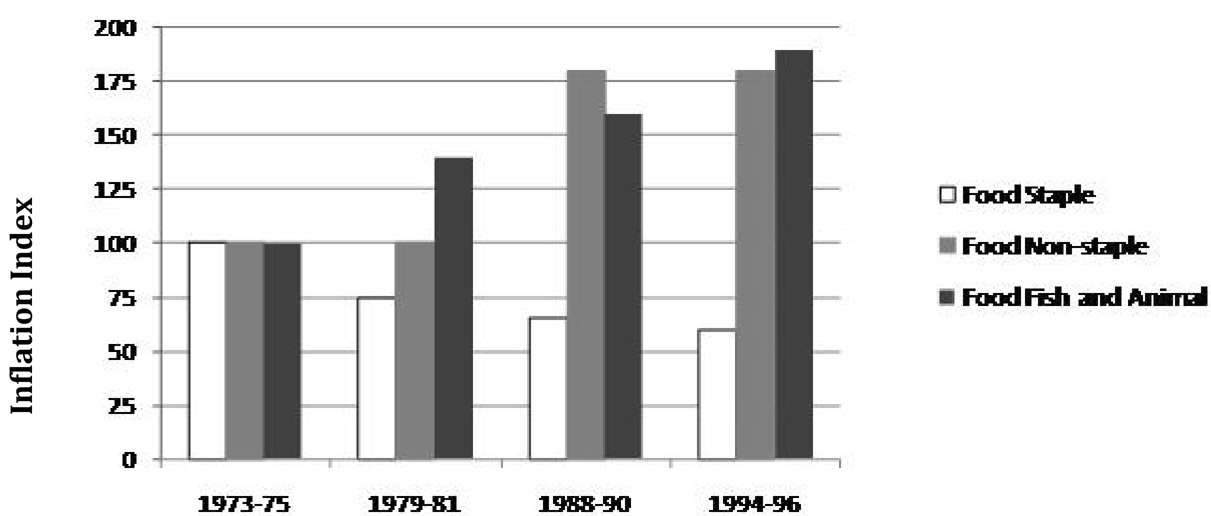
Figure 7 shows the percentage increases in developing country population, in cereal production, and in pulse production between 1965 and 1999. Developing country population doubled during this period. It is the great achievement of the Green Revolution that cereal production more than doubled due to rapid technological change. After adjusting for inflation, real cereal prices have fallen over time despite the doubling of developing country population. As suggested in Table 3, the poor spend a high percentage of their income on food staples, and lower cereal prices free up income that eases their burden and can be spent on a range of necessities, including better quality food.

Figure 7. Percent changes in cereal and pulse production and in population, 1965-1999



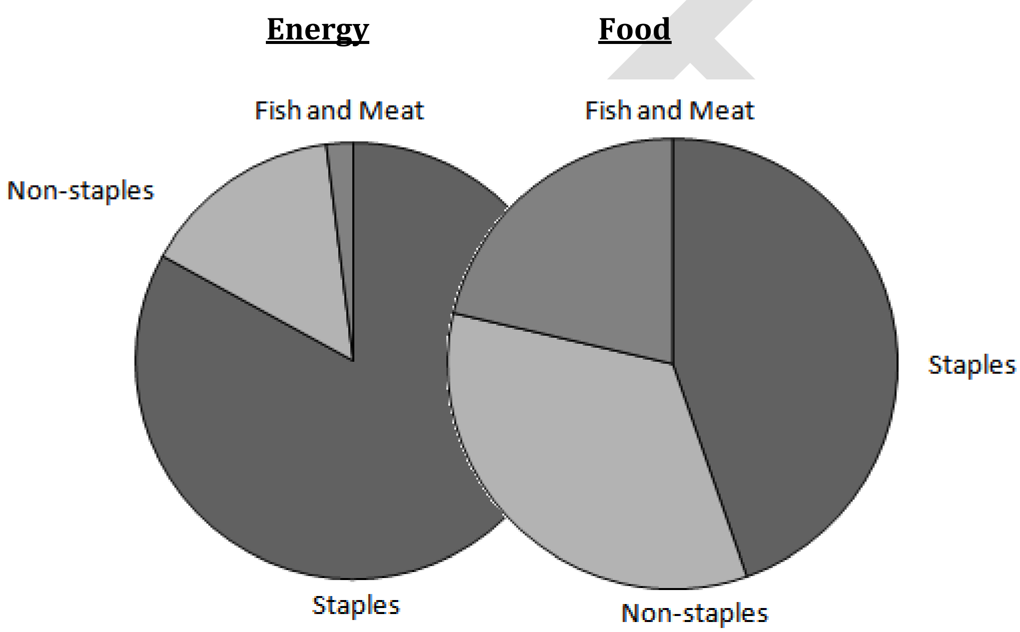
Pulse production in Figure 7 is representative of increases in production for any number of non-staple plant and animal foods. Production increased significantly, but did not keep pace with growth in demand -- due both to population growth and income increases as developing country economies have grown. There was no commensurate technological change in the non-staple food sector. Consequently, inflation-adjusted prices of many non-staple foods have increased over time, as shown in Figure 8.

Figure 8. Indices of inflation-adjusted prices for Bangladesh 1973-75 = 100



The data cited in Figure 9 were collected in the mid-1990s in rural Bangladesh after rice prices (adjusted for inflation) had fallen considerably from the early 1970s and non-staple food prices had risen significantly. Given these relative price changes over time, energy (rice in the case of Bangladesh) became more affordable, but dietary quality (non-staples) more expensive. As shown in Figure 9, expenditures for non-staple plant foods and fish and meat exceed those for rice [5].

Figure 9. Share of energy source and food budget in rural Bangladesh

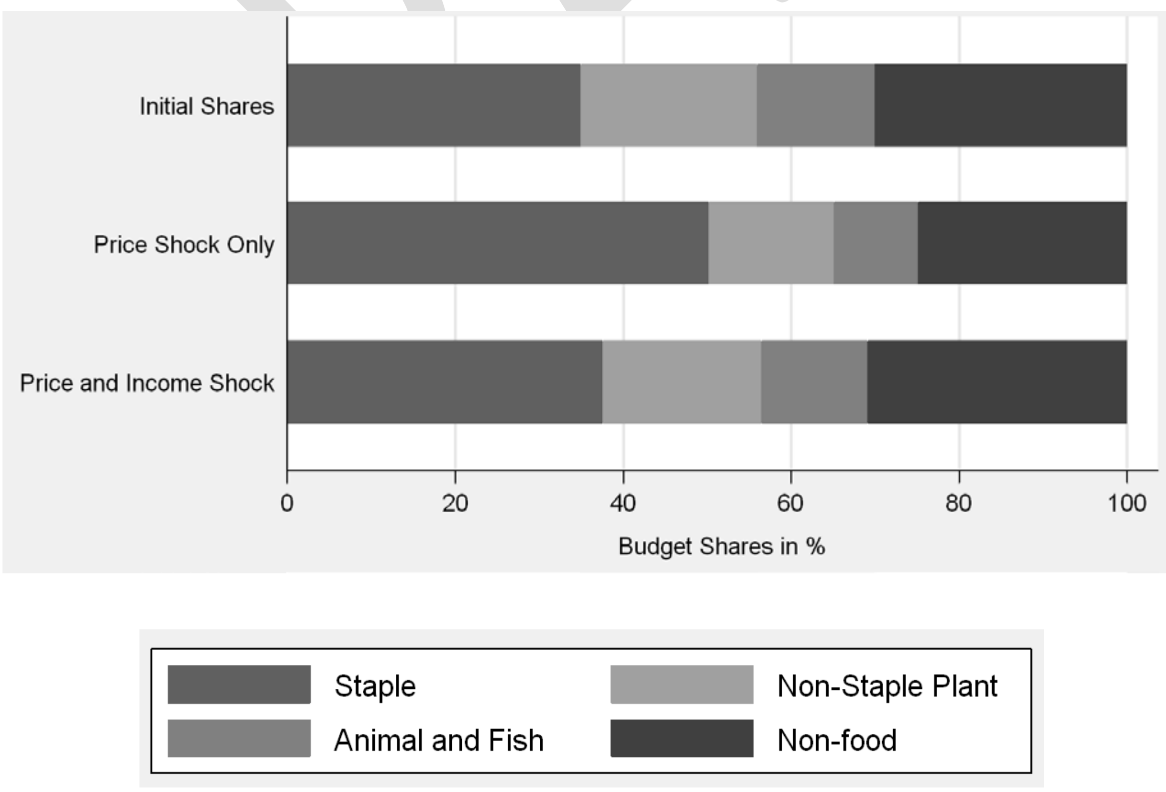


This change in relative prices has made it even more difficult for the poor to achieve mineral and vitamin adequacy in their diets. Certainly, for those poor whose incomes have remained constant, price incentives have shifted the diet toward reliance on food staples, particularly in the absence of knowledge about the importance of a nutritious diet and what minerals and vitamins relatively inexpensive non-staple foods can provide . This has led to a worsening of mineral and vitamin intakes for many segments of developing country populations, micronutrient malnutrition, and poor health.

4.4 Dietary Quality and the Recent Rises Staple Food Prices in the Post Green Revolution Period

Rapid increases in yields of rice, wheat, and maize led to the declining prices for food staples, as exemplified for Bangladesh in Figure 8. However, in part due to declining public investments in agricultural research over the past two decades, high growth rates in cereal yields in developing countries were not sustained, while population continued to grow. As incomes increased in China, India, and other developing countries, greater demand for animal products led to increased use of cereals for animal feed. These longer-run supply and demand factors put underlying pressures on food staple prices to begin to rise. Finally, short-term draw downs in global cereal food stocks and weather shocks caused by drought in major producing countries led to very rapid and substantial increases in food staple prices in the first half of 2008. What are the consequences of such prices for dietary quality of the poor? The poor must, at all costs, protect their consumption of food staples to keep from going hungry. Bangladeshis, for example, must now spend more for rice. This leaves less money to spend on non-staple foods and non-foods as illustrated in Figure 10.

Figure 10. Share of Food Groups and Non-Food in Total Expenditures Before and After Food Staple Price Rises



Notes: Initial budget shares based on data collected in 1995-96 in Bangladesh. Simulated budget shares based on estimated price and income elasticities (Table 3). The simulated price shock is a +50% increase in food prices, and the income shock is a +35% increase in nominal income.

Table 4 shows simulation results for an assumed 50% increase in both staple and non-staple foods, but no change in income.

Table 4. Simulation Results for Rural Bangladesh, Assuming a 50% Increase in Staple and Non-Staple Food Prices and No Change in Income

Non-Staple Food Income Elasticity	**1.0**	**1.1**	**1.2**	**1.3**	**1.4**
% Change In Iron Intakes	-0.27	-0.29	-0.30	-0.32	-0.34
% Change in Energy Intakes	-0.14	-0.14	-0.15	-0.16	-0.16
% Change in Expenditures on Food Staples	0.43	0.43	0.43	0.43	0.43
% Change in Expenditures on Non-Staples	-0.23	-0.29	-0.34	-0.39	-0.44
% Change in Expenditures on Non-Foods	-0.23	-0.17	-0.10	-0.05	0.01
Absolute Change in Food Staple Calories	-74	-74	-73	-73	-72
Absolute Change in Non-Staple Food Calories	-196	-210	-224	-238	-251

Notes: The results outlined within lines correspond to the food demand matrix shown in Table 2; the initial daily total calorie intake was assumed to be 2000, divided between staples (1600) and non-staples (400). Staples were assumed to provide 50% of total iron intakes, and non-staples the other 50%.

The following observations may be made from the table above:

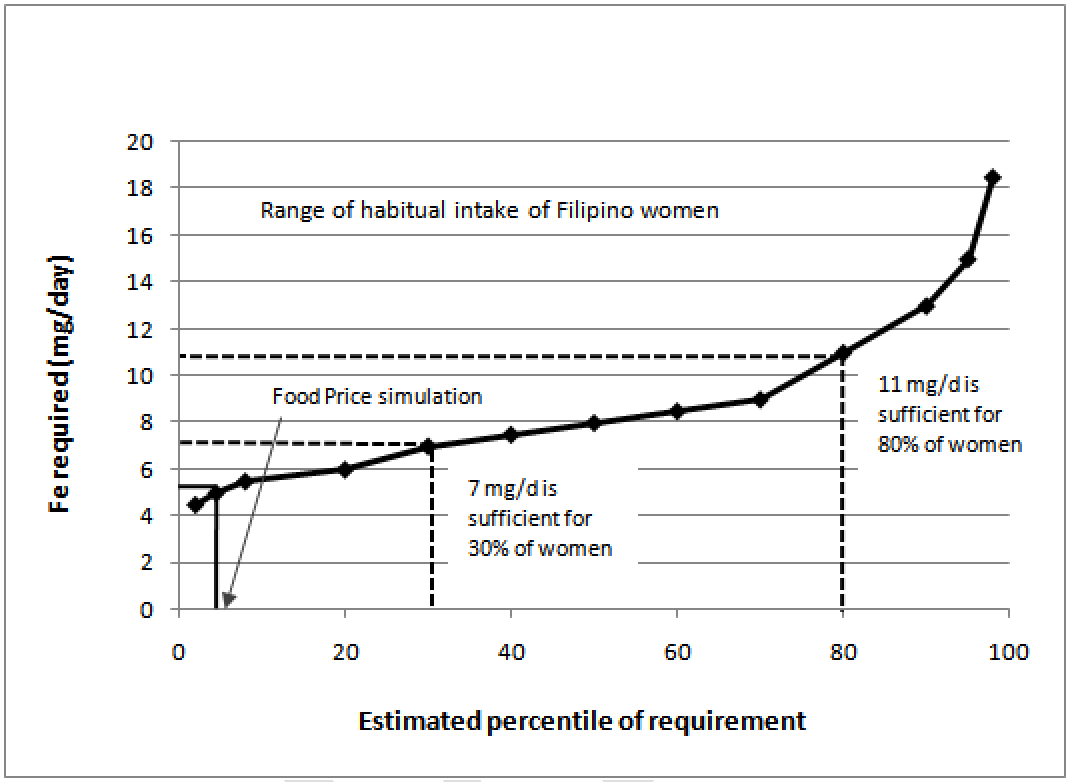
- As an order of magnitude, iron intakes decline by 30%. Energy intakes decline by 15%; however, note that *the decline in energy intakes is primarily due to the decline in consumption of non-staple foods.*
- Expenditures on food staples increase markedly due to inelastic demand; expenditures for non-staple foods and non-foods decline.

- To the extent that non-staple foods are considered a "luxury" (non-staple income elasticities at the high end near 1.4), the poor adjust by reducing non-staple food expenditures and non-food expenditures are little affected; to the extent that non-staple foods are considered more of a necessity (non-staple income elasticities at the lower end near 1.0), the poor adjust by reducing expenditures on both non-staple foods and non-foods.

How significant is a 30% decline in iron intakes? Figure 11 shows the cumulative distribution of women meeting their iron intake requirements at various levels of average iron intake. Because individual requirements for iron (and other nutrients) vary, some women meet their requirements at an average intake of 7 mg Fe/day (30% in the diagram) and others do not (70% in the diagram).

Given a food price increase of 50%, iron intakes would decline by an estimated 30% from 7 mg Fe/day to about 5 mg Fe/day. This would mean that only 5% of Filipino women would be meeting their daily requirements, an increase of 25 percentage points in women who are no longer consuming their required iron intakes.

Figure 11. 30% percent decline in iron intakes for Philippine Women



Note: Source: John Beard, Pennsylvania State University. The distribution of Fe requirements is modeled from a factorial accounting for body size, age, menstrual blood loss, and contraceptive use (Institute of Medicine, 2001). A Monte Carlo simulation with n>1000 was used. 7 mg /d is the estimated average Fe intake among Filipino women. 11 mg/d is the estimated average Fe intake if only high-iron (12 mg/kg Fe milled), biofortified rice were consumed.

The results presented in Tables 3 and 4 above are derived from consumption and nutrition data collected in rural Bangladesh, but are generalizable to other regions. Budget shares allocated by the poor in Africa, Asia, and Latin America to staple foods, non-staple foods, and non-foods are of similar magnitude as those in Table 2 above. Because of limited incomes, hunger is avoided by purchasing large amounts of food staples (roughly one-third of total expenditures before the food price rise), and allocating the remaining income between (i) the desire for some variety in the diet in addition to food staples (roughly one-third of total expenditures), and (ii) a range of necessities such as housing, clothing, sanitation, and so forth (roughly the last third of total expenditures). Thus, demand elasticities for the poor should not vary markedly from those shown in Table 4.

4.5 Effects on Farm Income of Rising Food Prices

While rising food prices hurt poor consumers, agricultural producers will be helped on the income side by high market prices for their products. To what extent will this compensate for a loss in food and nutrient intakes on the consumption side? To answer this question, we take the result for Bangladesh shown in Table 4 and assume that total income (on a nominal basis) has risen by 35%.

35% would be in the maximum range for a landowning household which depended primarily on their farm output for income. It is an interesting threshold also for the reason that the household has the option to choose to spend this extra income to just compensate for the increased cost of food (initially 70% of income goes for food expenditures, with a 50% increase in food prices then imposed).

The results for simulating a 50% increase in food prices and a 35% increase in nominal income are shown below in Table 5. Note that energy and iron intakes still decline (although by lower amounts). Because of the increase in the price of food, expenditures for non-foods become relatively more attractive. The household does not choose to maintain the same food intake choices as before.

Table 5. Simulating Impacts on Energy and Iron Intakes of a 50% Food Price Increase and a 35% Increase in Nominal Farm Income

	50% Increase in Food Prices (from Table 3)	Plus a 35% Increase in Nominal Income
% Change in Energy Intakes	-14	-6
% Change In Fe Intakes	-29	-11
% Change in Expenditures on Food Staples	43	45
% Change in Expenditures on Non-Staples	-29	21
% Change in Expenditures on Non-Food	-17	39

Absolute Change in Food Staple Calories	-74	-50
Absolute Change in Non-Staple Food Calories	-210	-76

Note: This figure appears in [14], Figure 8.

Conclusion

The solution to eliminating micronutrient malnutrition as a public health problem in developing countries is a substantial improvement in dietary quality, i.e. higher consumption of pulses, fruits, vegetables, fish, and animal products, which the poor already desire but cannot presently afford. Although the poor at the margin devote relatively high percentages of increased income to the purchase of high quality, non-staple foods, nutrient requirements (especially of women and preschool children because of their increased requirements for reproduction and growth) are such that consumption of non-staple foods must increase by several multiples before requirements are met. Therefore, achieving this solution will require several decades of economic growth and involve billions of dollars investments in infrastructure and agricultural research to increase the production of non-staple foods.

The analysis here has shown that the specter of a long-run trend increase in food prices, will make this task far more difficult. The recent financial crisis lowers incomes. Not only does this reduce dietary quality, but women can be expected to spend more time in earning income and so less time in childcare. Expenditures for health, sanitation, and education will decline.

To help address the consequences of these adverse trends, the time is long overdue to bring agricultural interventions to bear to reduce micronutrient malnutrition. Biofortification, fortifying fertilizers with minerals (e.g. zinc, selenium), introducing novel crops that are high in particular nutrients that are deficient in specific food systems, are all low-cost and sustainable interventions that complement supplement, fortification, and nutrition education [6].

Chapter 5: Enhancing the Nutrient Content of Specific Foods

5.1. Commercial Food Fortification

The most common means for improving the nutritional quality of foods is through fortification during processing. Fortifying commonly consumed foods with key micronutrients can be an effective and economically efficient means of treating nutrition-related disorders. The Universal Salt Iodization initiative, for example, which began in 1990, has increased the proportion of the world's population with access to iodized salt from 20 percent to 70 percent in 2008, although iodine deficiency remains a public health problem in more than 40 countries.[7] Most efforts at food fortification involve key micronutrients such as vitamin A, vitamin D, iodine, iron, and zinc. Foods such as salt and other condiments such as soy sauce, maize and wheat flours, and vegetable oils are good candidates for fortification because they are widely consumed, and low-cost technologies can produce fortified foods that are acceptable to consumers.[8]

Fortified products must reach micronutrient-deficient consumers through existing or newly established distribution channels. The companies typically involved in fortifying foods have well-established distribution and marketing networks that can effectively deliver products to urban and rural populations, although some fortification technologies are easily applied by small-scale processors, who may be more effective in reaching remote populations.[9]

Consumer demand for fortified foods can be strengthened through education and marketing campaigns. This may involve public-private partnerships that build on the existing marketing strategies of the manufacturers and distributors. In West Africa, for example, the private voluntary organization Helen Keller International is working with the Association of Edible Oil Producing Industries to educate consumers about the benefits of vitamin A and to promote the use of fortified cooking oil.[10] These campaigns include strong in-store support for nutrition education.

Micronutrient fortification of foods and condiments is generally inexpensive and highly cost-effective. Salt iodization can reach 80-90 percent of the target population at a cost of approximately $0.05/person/year. Flour fortification with iron can reach up to 70 percent of the target population for about $0.12/person/year. The costs of reaching the remaining population, often in remote areas, will be higher, but these hard-to-reach individuals may derive a proportionally higher benefit from fortification, as they are often poorer individuals, with poorer diets, and less access to health care. The costs of fortification are not always clear to consumers. Most iodized salt, for example, is refined, packaged, branded and marketed in ways that add costs beyond those associated with iodization itself. If fact, it is technically possible to add one or several micronutrients to a product like salt without a substantial increase in the total cost.[11]

Fortification programs entail a range of initial investments including population-based needs assessments, trials to determine appropriate foods and micronutrient levels, industry start-up costs, development of appropriate communication and social marketing programs, and capacity-building for public sector regulation, enforcement, monitoring and evaluation. In some countries, such costs have been partially subsidized by international support through organizations such as the Micronutrient Initiative (MI) and the Global Alliance for Improved Nutrition (GAIN), as well as other donors.[12]

Experiences over the past two decades show that governments, in partnership with the private sector and/or aid agencies, can help develop fortified foods, expand distribution networks, and strengthen consumer demand for fortified foods. Mandatory fortification standards improves coverage and impacts, but the implementation of successful fortification programs requires the following elements:

- mobilizing political will to mandate and enforce universal fortification standards
- formation of multi-sector coalitions and transparent partnerships involving international organizations, private food producers, national governments and civil society
- a financially sustainable model for private sector actors (costs of initial expenditures for set up, recovery of costs, etc)
- advocacy and communications to help the population to accept and support the effort
- assisting the industries to overcome technical issues, especially small producers and processors
- integration of monitoring systems into routine data systems to track population coverage

5.2. Biofortification

Biofortification, the process of breeding nutrients into food crops, provides a sustainable, long-term strategy for delivering micronutrients to rural populations in developing countries. Crops are being bred for higher levels of micronutrients using both conventional and transgenic breeding methods; several conventional varieties have been released, while additional conventional and transgenic varieties are in the breeding pipeline. The results of efficacy and effectiveness studies, as well as recent successes in delivery, provide evidence that biofortification is a promising strategy for combating micronutrient deficiency.

Justification

Biofortified staple foods cannot deliver as high a level of minerals and vitamins per day as supplements or industrially fortified foods, but they can help by increasing the daily adequacy of micronutrient intakes among individuals throughout the lifecycle.[13] No single intervention will solve the problem of micronutrient malnutrition, but biofortification complements existing interventions to sustainably provide micronutrients to the most vulnerable people in a comparatively inexpensive and cost-effective way.[14]

Biofortification provides a feasible means of reaching malnourished rural populations who may have limited access to diverse diets, supplements, and commercially fortified foods. The biofortification strategy seeks to put the micronutrient-dense trait in those varieties that already have preferred agronomic and consumption traits, such as high yield. Marketed surpluses of these crops may make their way into retail outlets, reaching consumers in first rural and then urban areas, in contrast to complementary interventions, such as fortification and supplementation, that begin in urban centers.

Unlike the continual financial outlays required for supplementation and commercial fortification programs, a one-time investment in plant breeding can yield micronutrient-rich planting materials for farmers to grow for years to come. Varieties bred for one country can be evaluated for performance in, and adapted to, other geographies, multiplying the benefits of the initial investment. While recurrent expenditures are required for monitoring and maintaining these traits in crops, these are low compared to the cost of the initial development of the nutritionally improved crops and the establishment, institutionally speaking, of nutrient content as a legitimate breeding objective for the crop development pipelines of national and international research centers.

Currently, agronomic, conventional, and transgenic biofortification are three common approaches. Agronomic biofortification can provide temporary micronutrient increases through fertilizers. Foliar application of zinc fertilizer, for example, can increase grain zinc concentration by up to 20 parts per million (ppm) in wheat grain in India and Pakistan, but only in the season it is applied.[15] This is nearly the full target increment set by nutritionists and sought in plant breeding (further described below). This approach could complement plant breeding efforts but further research is needed.

Biofortification can be achieved through conventional plant breeding, where parent lines with high vitamin or mineral levels are crossed over several generations to produce plants that have the desired nutrient and agronomic traits. Transgenic approaches are advantageous when the nutrient does not naturally exist in a crop (for example, provitamin A in rice), or when sufficient amounts of bioavailable micronutrients cannot be effectively bred into the crop. However, many countries lack legal frameworks to allow release and commercialization of these varieties.

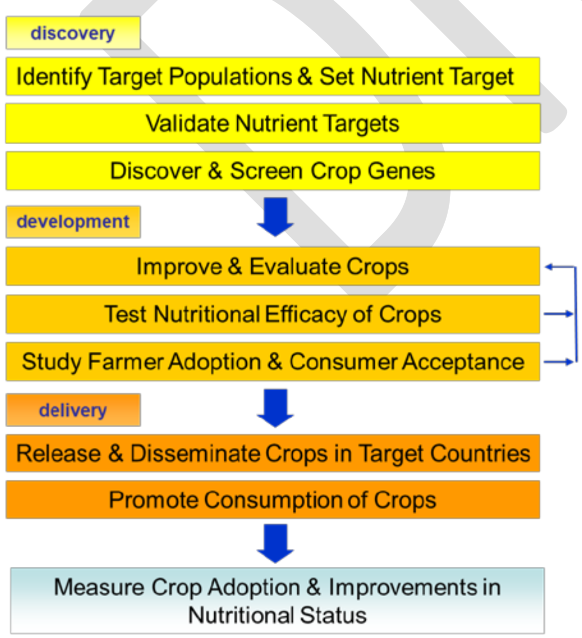
Implementing Biofortification

For biofortification to be successful, three broad questions must be addressed:

- Can breeding increase the micronutrient density in food staples to target levels that will make a measurable and significant impact on nutritional status?
- When consumed under controlled conditions, will the extra nutrients bred into the food staples be absorbed and utilized at sufficient levels to improve micronutrient status?
- Will farmers grow the biofortified varieties and will consumers buy/eat them in sufficient quantities?

To answer these questions, researchers must carry out a series of activities classified in three phases of discovery, development, and dissemination. This impact pathway is illustrated in Figure 12 and discussed in greater detail in Bouis et al. (2011).

Figure 12. Impact Pathway



Discovery

The overlap of cropping patterns, consumption trends, and prevalence of micronutrient malnutrition, as well as ex ante cost-benefit analyses, determine target populations and focus crops. Nutritionists then work with breeders to establish nutritional breeding targets. These target levels take into account the average food intake and habitual food consumption patterns of target population groups, nutrient losses during storage and processing, and nutrient bioavailability (Hotz and McClafferty 2007).

Under HarvestPlus, breeding targets are set such that, for preschool children 4-6 years old and for non-pregnant, non-lactating women of reproductive age, the incremental amount of iron will provide approximately 30 percent of the Estimated Average Requirement (EAR), that incremental zinc will provide 40 percent of the EAR, and that incremental provitamin A will provide 50 percent of the EAR. Bioavailability of iron was originally assumed to be 5 percent for wheat, pearl millet, beans, and maize (10 percent for rice, cassava, and sweet potato), that of zinc 25 percent for all staple crops, and for provitamin A 8.5 percent for all staple crops (12 molecules of beta-carotene produce 1 molecule of retinol, the form of vitamin A used by the body).

Plant breeders screen existing crop varieties and accessions in global germplasm banks to determine whether sufficient genetic variation exists to breed for a particular trait. Initial research indicated that selection of lines with diverse vitamin and mineral profiles could be exploited for genetic improvement.[16] Genetic transformation is an alternative method to incorporate specific genes that express nutritional density.

Development

Crop improvement includes all breeding activities. Initial product development is undertaken at international research institutes to develop varieties with improved nutrient content and high agronomic performance, as well as preferred consumer qualities. When promising high-yielding, high-nutrient lines emerge, they are tested by national research partners and the best-performing lines then selected to submit to national governments for release. The formal release process varies by country, but in general requires that a variety be grown and evaluated in several different locations (called multilocational trials) for at least two seasons, and its performance compared to other candidate and widely released varieties, before the national government approves the variety for dissemination. The breeding, testing, and release process can take 6 to 10 years to complete.

Parallel to crop improvement, nutrition research measures retention and bioavailability of micronutrients in the target crop under typical processing, storage, and cooking practices.

Initially, relative absorption is determined using in vitro and animal models and, with the most promising varieties, by direct study in humans in controlled experiments. Randomized, controlled efficacy trials demonstrating the impact of biofortified crops on micronutrient status and functional indicators of micronutrient status (i.e. visual adaptation to darkness for provitamin A crops, physical activity for iron crops, etc.) provides evidence to support biofortified crops as alternative public health nutrition interventions.

Economics research on consumer and farmer evaluation of biofortified varieties, as well as varietal adoption studies, further informs crop improvement research during the development phase.

Dissemination

Biofortified crops must be formally released in the target countries prior to their delivery to the target populations. Economists lead consumer acceptance, varietal adoption, and seed and grain value chain studies to inform effective, efficient, and targeted delivery and marketing strategies to maximize adoption and consumption of these crops.

Current Status of Biofortified Crops

HarvestPlus leads a global interdisciplinary alliance of research institutions and implementing agencies in the biofortification effort. The Bill and Melinda Gates Foundation-funded Grand Challenges 9 is developing several transgenic crops. Much progress has been made with key crop, and varieties of high iron bean, high iron pearl millet, provitamin A sweet potato, provitamin A cassava , and provitamin A maize have been released to date. Full details of progress made with key crops is discussed in Saltzman et al (2013).[17]

Delivery and commercialization experience

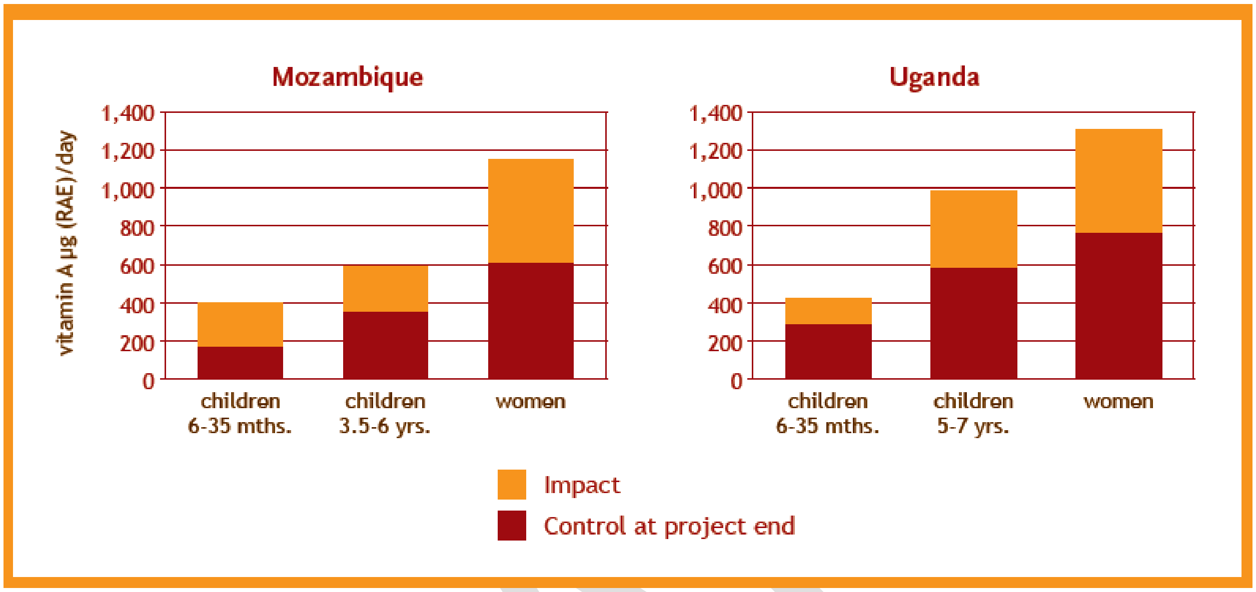
From 2007 to 2009, HarvestPlus and its various NGO partners distributed OSP to more than 24,000 households in Uganda and Mozambique (HarvestPlus 2010; Hotz et al. 2012b). The pilot delivery project was new to Uganda but built on two previous CIP projects in Mozambique, Towards Sustainable Nutrition Improvement and Eat Orange. Because there were no markets for sweet potato vines in Uganda and Mozambique, planting materials were delivered through NGO partners. An operations research component monitored implementation activities, while a parallel impact evaluation team carried out a randomized control study. The impact evaluation component tested two delivery methods: the intensive method included two years of planting material delivery and training, while the less intensive method included only one year of planting material delivery and training. The less intensive model was shown to be as effective as the more intensive one; in both countries the project led to increases in OSP adoption and consumption by farm households. As a result, vitamin A intakes as much as doubled for both children and women, the primary target groups for this intervention.

Dissemination can also utilize the private sector. In India, HarvestPlus is utilizing the existing well-functioning seed sector for pearl millet, and has partnered with a private seed company, Nirmal Seeds Ltd., to market and deliver ICTP 8203-Fe. By partnering with a leading commercial entity in pearl millet seed sales in the target state of Maharashtra, HarvestPlus is increasing demand in an existing market and building a sustainable strategy for future delivery. Because the high iron trait is an invisible one, demand for the ICTP 8203-Fe will be driven by its superior yield performance compared to the earlier version.

Effectiveness of biofortification

The primary evidence for the effectiveness of biofortification comes from orange sweet potato (OSP). Effectiveness was assessed through a randomized control trial in both countries. The pilot delivery project described above resulted in a 68 percent increase in the probability of OSP adoption in Mozambique and a 61 percent increase in Uganda.[18] OSP adoption resulted in substantial substitution of other sweet potato varieties in terms of area under cultivation; the project increased the share of OSP in total sweet potato areas by 59 percent in Mozambique and 44 percent in Uganda. Compared to intakes at baseline, vitamin A intake doubled for all three age/gender groups by project end in Mozambique, and in Uganda increased by two-thirds for younger and older children and nearly doubled for women. For the age group of greatest concern, children aged 6-35 months, OSP contributed 74 percent of the total vitamin A intake in Mozambique and 52 percent in Uganda (see Figure 13). In Uganda, the high prevalence of inadequate vitamin A intake among a subset of children 12–35 months, who were no longer breastfeeding, fell from nearly 50% to only 12% as a result of the project.[19]

Figure 13. Impact of REU Intervention on mean vitamin A intakes (µg Retinol Activity Equivalents (RAE)/day), Mozambique and Uganda by age group



Notes: Estimates are mean vitamin A intakes at project end (2009) in both countries. Mean vitamin A intakes at baseline were not significantly different between project and control households within each age group. For younger children in both countries, separate groups of children were assessed at the beginning and end of the project. For older children and women, the same group was followed over time. Retinol is the active form of vitamin A found in the body. Beta carotene is converted to retinol by the body and the amount of retinol derived from beta carotene is expressed as retinol activity equivalents (RAE).

Disability Adjusted Life Years (DALYs) are a commonly used metric for measuring the cost-effectiveness of health interventions. For example, in Uganda, calculations suggest that the intervention cost US$15–US$20 per DALY saved, which by World Bank standards is considered highly cost effective.[20] An ex ante cost-effectiveness study by HarvestPlus estimated that consumption of OSP could eliminate between 38 and 64 percent of the disability-adjusted life years (DALYs) burden of vitamin A deficiency in Uganda.[21]

Consumer Acceptance and Farmer Adoption

In the pilot delivery programs in Mozambique and Uganda, when beneficiaries were provided information (i) that consumption of orange sweet potato could protect their children from the consequences of vitamin A deficiency and (ii) that orange sweet potato varieties were just as high yielding as white varieties, these households produced and consumed orange varieties – commensurately lowering their production and consumption of white sweet potato.

Rural consumers want nutritious food and are willing to pay a price premium for it, indicating favorable valuation of and demand for staple foods with nutritional benefits. When given the same information as above under experimental conditions, “willingness-to-pay” studies for orange sweet potato, orange maize, and yellow cassava showed that consumers liked the sensory characteristics of the biofortified crops and will pay a higher price for high provitamin A varieties than for white varieties.[22]

Consumer acceptance of crops biofortified with invisible nutrition traits (such as high-iron pearl millet) has also been tested. In the case of high-iron pearl millet, it was found that even in the absence of nutrition information, the high-iron variety was preferred to the local variety.[23]

Conclusions

Major gaps in knowledge with respect to biofortification exist: more efficacy trials and effectiveness studies are needed to confirm and augment the promising evidence thus far obtained. Scientists must further refine indicators of individual micronutrient status and better understand the importance of cross-nutrient synergies. Additional delivery and marketing research will improve the effectiveness of delivery and marketing strategies in ensuring maximum adoption and consumption of biofortified crops. To mainstream biofortified traits, agricultural research centers must adopt breeding for nutrient density as a core activity, investing in breeding pipelines at NARES.

Finally, biofortification is complementary to existing interventions, but the best mix of biofortification, supplementation, fortification, and dietary diversity must be considered for each target country, and the coordination of these programs must be improved.

Looking forward, a range of institutions must be convinced to endorse the biofortification strategy. Key actors in expanding dissemination globally and ensuring sustainability include the UN and related agencies, international and regional programs such as Scaling Up Nutrition (SUN) and the Comprehensive African Agricultural Development Program (CAADP), international NGOs, seed and food companies and donor agencies. Only through broadening the biofortification coalition will long-term support for breeding and dissemination of biofortified crops be realized.

Chapter 6: Enhancing Supply Chains for Nutrition and Diversity

One of the key means of addressing micronutrient deficiencies is through consumption of a high-quality, diverse diet, as discussed in Chapter 4. Apart from increasing income and lowering food prices, there are specific actions that can be taken with agriculture to promote dietary diversity. Food chains and homestead gardening are discussed below.

Nutrition in food supply chains

Agricultural products reach consumers through food supply chains. Each link in a food supply chain affects the availability, affordability, diversity and nutritional quality of foods. How foods are handled throughout a chain influences their nutritional content and prices as well as the ease with which consumers can access them. This in turn shapes consumer choices, dietary patterns, and nutritional outcomes.

Opportunities exist at each link in the chain to deliver more diverse and nutritious foods. For example, proper household storage can preserve nutrients; food processors can use more nutritious inputs or can fortify foods during processing; logistics firms can employ nutrient-preserving techniques for storage and transport; and retailers can provide a more diverse range of foods consistently throughout the year. At every link in the chain, better technologies and management practices can preserve nutrients, reduce food losses and waste, enhance efficiency, and lower prices for nutritious foods.

Enhancing nutrition through food supply chains

The performance of food supply chains in providing abundant, affordable, diverse and nutritious foods can be improved at every link in the chain. This section provides some examples and evidence of measures that can improve the nutritional performance of supply chains, including through improving the overall efficiency of the supply chain to enhance the availability and accessibility of a wide range of foods, reducing post-harvest nutrient losses, and enhancing the nutritional quality of foods through fortification and reformulation.

Improving supply chain efficiency for nutrition

Improving the efficiency of the supply chains can help to meet the simultaneous challenge of lowering the costs of food to consumers and increasing the revenue of supply chain participants. Both lower prices (for consumers) and higher incomes (for smallholders and other producers) support the possibility of improving nutrition through a more adequate, varied diet.

Companies driving the transformation of modern food systems seek greater integration through vertical coordination of primary producers, input suppliers, and processors. Such integration seems to hold the greatest potential for livestock and other capital-intensive food products.[24] In an integrated system, consumer demand and product information flow from retailers upstream to suppliers, who make contractual arrangements with producers.[25] This can enable farmers to increase their productivity and profits through better access to inputs and receipt of timely payments.[26].

Integrating smallholders into domestic food value chains remains a challenge. Poor performance of other aspects of the value chain, such as storage, transport and distribution, can impede smallholder market participation. Investments in public goods that support the development of transport, communication and service infrastructure can substantially reduce producer risk, improve value chain performance, and so raise smallholder income.

A study in Kenya showed that investments in infrastructure can reduce the significant marketing costs smallholders incur to deliver crops to buyers. If these costs, estimated at 15 percent of retail value, can be reduced, farmer earnings can be increased without driving up food prices.[27] Other programs, such as some public-private partnerships, have improved overall market efficiency and smallholders' ability to engage with the market by facilitating the flow of information using modern communication technologies.[28] Policies that support the development of financial markets in rural areas can also improve the ability of small- and medium-size traders to purchase surplus production from smallholders.[29]

Reducing nutrient waste and losses

A recent FAO report estimates that roughly one-third of food produced globally for human consumption is lost or wasted.[30] In addition to the quantitative food losses, qualitative losses also occur as nutrients deteriorate in storage, processing and distribution. Rodents, insects, and microbial spoilage are the main reasons for loss. Food waste reduces the sustainability of food systems, as more production is required to feed the same number of people, which wastes seeds, fertilizer, irrigation water, labour, fossil fuels, and other agricultural inputs.[31]

In developing countries, most losses occur at the farm level and along the producer-consumer chain, before arriving at the consumer. In Karnataka, India, about 75 percent of post-harvest losses for rice and wheat occur at the farm level.[32] Table 6 shows the various amounts of loss for different activities for cereals in Eastern and Southern Africa, with about half or more of the loss occurring at farm level. The pre-consumer losses range from about 9 to 18 percent, with variations depending on the crop, climate and farming system.[33] Post-harvest losses also disproportionately affect foods that are channeled through traditional food supply chains.[34]

In higher income countries, waste at household level is the larger problem.[35] Griffen, Sobal and Lyson (2009) estimated that the amount of food wasted in the food system of one rural-suburban community in New York State (USA) in one year was sufficient to feed everyone in the community for 1.5 months. Sixty percent of the losses occurred after food was purchased by the consumer.

Table 6. Loss profiles for maize, sorghum, millet and rice

Climate type Crop Scale of farming	Tropical Maize Small-scale	Temperate Maize Large scale	Arid Sorghum Small scale	Arid Millet Small scale	Tropical Rice Small scale
Harvesting/field drying	6.4	2	4.9	3.5	4.3
Drying	4	3.5	--	--	--
Shelling/threshing	1.2	2.3	4	2.5	2.6
Winnowing	--	--	--	--	2.5
Transport to store	2.3	1.9	2.1	2.5	1.3
Storage	5.3	2.1	2.2	1.1	1.2
Transport to market	1	1	1	1	1
Market storage	4	4	4	4	4
Cumulative % weight loss*	17.9	11.3	12.6	9.3	11.4

Source: Rembold et al., (2011).

Reducing post-harvest losses has the potential to significantly increase food supplies and reduce food prices (assuming efforts to reduce waste generate greater benefits than their costs). This could potentially improve affordability and diversity, but this action does not at first seem specifically relevant to nutrition. But the losses of micronutrient-rich fruits, vegetables, and animal-source foods (meat, fish, dairy) are typically greater than losses of cereals and root crops. The losses thus disproportionately impact the exact foods that people could use most to enrich their diets. Chadha et al (2011) note that in Vietnam, Cambodia and Laos PDR about 17 percent of the vegetable crop is lost due to post-harvest problems. A study covering several Sub-Saharan African countries concluded that losses in small-scale fisheries reached 30 percent or more. Losses were particularly high in the drying, packaging and storage and transportation stages with key constraints related to poor fish-handling practices and outdated techniques and facilities.[36]

The actions that need to be taken could also serve a dual purpose and be made more "nutrition sensitive." For example, at-home techniques could be used for preservation and packaging and storage activities could be adapted so that they also help to preserve nutrients. Although interventions to effectively reduce post-harvest losses are known (e.g., small-scale post-harvest storage facilities, improved pre-harvest management, and/or increased food processing opportunities), little is known about the impacts of such initiatives on nutrition.[37]

Making food more diverse

Specific interventions aimed at diversifying what farmers produce and what households have at hand (through home gardens or raising small animals) can contribute to better nutrition.

Diversification at national scale

Agricultural policies, including R&D, could be used to make the food supply more diverse, although few countries have made diversification a specific policy objective. In Finland, for example, the government implemented agricultural policy reform to encourage consumption of more healthful foods, which included reducing subsidies for dairy products. Major investments were also made in the production and processing of berries, as well as media and education about the health benefits of berry consumption. As a result, many Finnish farmers switched from dairy to berry farming and national consumption of berries rose from initially very low levels to reach substantial amounts.[38]

Agricultural R&D could be made more nutrition-sensitive by being more inclusive of small producers and focusing more resources on important non-staple foods and integrated production systems. Relatively little public agricultural R&D focuses on increasing the productivity of nutrient-dense foods such as fruits, vegetables, legumes, and animal source foods. Improvements in the productivity of these foods would reduce their relative prices and could support the diversification of diets. Post-harvest research could extend the limited seasonal availability and reduce the nutrient losses and food safety hazards associated with these highly perishable foods.

Diversifying home and small farm food production

Projects that support the diversification of home and smallholder production hold potential for improving consumption of a variety of foods and reducing micronutrient deficiencies. Such projects can range from very small scale home garden projects to more complex integrated farming projects that include livestock and aquaculture as well as complementary activities to improve nutrition education, income generation, gender roles and others.

Small-scale home gardens are seen as promising interventions when micronutrient deficiencies are significant and vegetable and fruit consumption are low. Home gardening is already frequently practiced, can be effective at a small scale and is feasible in most locations, although water and labor constraints may pose challenges and should be considerations in project design. A recent review by Masset et al (2011) found that home garden programs increased the consumption of fruit and vegetables. They note, however, that the overall effect cannot be assessed as studies typically ignore substitution effects. For example, de Pee et al. (1998) found that home gardening increased the consumption of plant food but at the same time reduced the consumption of vitamin A-rich animal food. Masset et al (2011) do not find evidence of home gardens (or other interventions) on the nutritional status of children but attribute this result to the methodological weaknesses and statistical limitations of the studies. Experience has also shown that home garden projects are unlikely to be effective unless accompanied by nutrition information and education and by a focus on women's roles (such as child caring and food preparation) and empowerment (World Bank, 2007).

In some communities micronutrient intakes can be more effectively enhanced by strengthening animal husbandry. For example, FARM-Africa's Dairy Goat Development Project in Ethiopia was started because goats were found to play an important role in the mixed farming systems of the high- and mid-altitude areas of Ethiopia (Ayele and Peacock, 2003). The project focused on increasing income and milk consumption by improving the productivity of local goats managed by women, through a combination of better management techniques and genetic improvements. The intervention led to an increase in the per capita availability of milk by 119 percent, energy from animal sources by 39 percent, protein by 39 percent, and fat by 63 percent. Through pre- and post-intervention analysis of data of those households within the project area, FARM-Africa demonstrated a considerable improvement in the nutritional status and family welfare of project participants (Ayele and Peacock, 2003).

Few of the home production interventions that target nutrition have been successfully scaled-up. One exception is the Homestead Food Production (HFP) project, introduced in

Bangladesh by Helen Keller International (HKI) nearly two decades ago. This project initially focused on reducing vitamin A deficiency by promoting home gardens, but its scope has been widened to also address iron and zinc deficiencies by incorporating small-animal husbandry as well as nutrition education (Iannotti, Cunningham and Ruel, 2009). Evidence shows that HFP programmes in Bangladesh have improved food security for nearly 5 million vulnerable people in diverse agro-ecological zones. There is convincing evidence of HFP's impact on household production, improved diet quality, and intake of micronutrient-rich foods, but neither improvements in actual micronutrient status nor the cost-effectiveness of the approach have been fully demonstrated (Iannotti, Cunningham, and Ruel 2009).

A recent review of household food production strategies and their effect on nutrition by Girard et al (2012) notes that many factors determine the effectiveness of such strategies in influencing nutritional outcomes. For one, when infectious disease is common, additional interventions are needed as production strategies will be limited in their impacts. They also find that the impacts of production strategies are difficult to discern since it is difficult to predict how much of the additional output is sold, how much consumed at home and how much of the food consumed at home is consumed by women and children. Girard et al (2012) concludes that the existing evidence, although scarce, indicates that production strategies can improve intakes of micronutrient-rich foods by women and young children when they have clear nutrition objectives and integrate nutrition education and gender considerations.

As suggested above, production projects are more likely to succeed when gender roles are taken into account in project design and implementation (Berti et al., 2004; Quisumbing and Pandolfelli, 2010). Gender-specific time constraints are particularly important. Strategies that place new time demands on women may reduce the time available for breastfeeding, child care, food preparation, fetching water, all of which are related to nutrition. New time demands may also reduce time available to raise nutrient-dense foods in kitchen gardens or acquire such food from the market. Policies and projects that make productivity-enhancing, time-saving technologies and approaches for activities traditionally undertaken by women, such as fetching water and firewood, weeding, hoeing, food processing and local marketing of produce, could make important contributions to the nutrition of women and children (Herforth, Jones and Pinstrup-Andersen, (forthcoming); Kes and Swaminathan, 2006; Gill et al. 2010).

Chapter 7. Food safety and Agriculture-associated diseases (adapted from McDermott and Grace, 2012)

In poor countries, diseases associated with agriculture have important health impacts. Food that nourishes can also sicken and kill. This chapter focuses on managing the health risks associated with food safety and other agriculture-associated diseases. Nutrition and health interactions are important, as the full benefits of improved nutrition cannot be realized without control of diarrheal and other diseases.

7.1 Agriculture-associated diseases and their impacts

To frame the discussion, a typology of four agriculture-associate disease categories, based on causation and transmission pathways and ranked by overall impact on human health as measured in DALYs are presented.[5] Such diseases may be associated with agriculture inputs, primary agricultural production, post-harvest processing and handling along marketing chains, or even final preparation by the consumer. As with any typology of disease, there are overlaps and ambiguities; the categories are not intended to be absolute but rather to have pragmatic relevance for policy and practice.

Most of the absolute burden falls on poor countries. Among low-income countries, diseases directly associated with agriculture (zoonoses of domestic animals and food-borne disease) make up at least 16% of all infectious disease and 6% of the total burden. (For comparison, in high-income countries they make up just 4% of the infectious disease burden and only 0.1% of the total disease burden.) The direct economic, social, and environmental costs of these diseases are probably proportionate to the adverse health impacts: for example, fungal toxins (mycotoxins) in food lead to trade losses of up to US$1.2 billion a year. Indirect costs of disease are also important. Impaired human health lowers both labor productivity and human capital accumulation (as through schooling and training), worsening livelihood outcomes in both the short run and the long run. Malnutrition, itself responsible for 3% of the disease burden in low income countries (WHO, 2008), enhances vulnerability to disease and is in turn exacerbated by disease symptoms — leading (for example) to a 30-fold increase in the risk for death from diarrhea (Flint et al. 2005).

[5] The DALY (Disability Adjusted Life Year) is a measure of healthy years of life lost due to premature death and disability, using the International Classification of Diseases produced by the World Health Organization (WHO 2008).

Table 7. Agriculture Associated Diseases (adapted from McDermott and Grace, 2012)

Zoonoses and emerging infectious disease. At least 61% of all human pathogens are zoonotic (transmissible between animals and man), and zoonoses make up 75% of emerging infectious diseases (Taylor et al. 2001). A new disease emerges every four months; many are trivial, but HIV, SARS, and Avian influenza illustrate the huge potential impacts. *Zoonoses and zoonotic diseases recently emerged from animals are responsible for 7% of the total disease burden in least-developed countries.*	**Food-associated disease.** Diarrhea is one of the top three infectious diseases in most poor countries, killing an estimated 1.4 million children each year (Black et al. 2010). Between 33% and 90% of diarrhea is attributed to food (Schlundt et al. 2004; Flint et al. 2005), and animal source food is the most risky (Lynch et al. 2006). More than 90% of food sickness is caused by biological pathogens (Thorns 2000). Toxins and chemical hazards associated with food are also important health threats, and in many cases can be prevented only by farm-level intervention. *Food-associated disease is responsible for 5% of the disease burden in the least developed countries.*
Water-associated disease. These include the diseases spread by contaminated irrigation water, such as cholera, cryptosporidiosis and chemical intoxication (Drechsel et al. 2010), as well as diseases which breed in irrigation and water storage systems, such as schistosomiasis and malaria. Coliforms and other bacterial pathogens causing diarrhea are very important. For most diseases, water is only one contributing factor. *Around 6% of the disease burden in least-developed countries is attributed to water-associated disease.*	**Occupational disease and drug resistance.** People working in agrifood systems are directly exposed to a range of biological, chemical, and physical hazards. The use of antibiotics in farm animals is known to contribute to the crisis of drug resistant bacteria in human medicine, although there is debate about its importance and the best way of tackling it. *The contribution to disease burden of this category has not been comprehensively assessed; it appears to be an order of magnitude less than the other disease categories.*

Diseases are influenced by socio-economics, environments, and public health services. There are two broad scenarios that characterize poor countries. At one extreme are neglected areas which lack even the most basic services; in these ”cold spots,” diseases persist that are controlled elsewhere, with strong links to poverty, malnutrition, and powerlessness. At the other extreme are areas of rapid intensification, where new and often unexpected disease threats emerge in response to rapidly changing practices and interactions between people, animals, and ecosystems. These areas are hot spots for the emergence of new diseases (of which 75 percent are zoonotic). They also are more vulnerable to food-borne disease, as agricultural supply chains diversify and outpace workable regulatory mechanisms.

7.2 Complex Tradeoffs - managing and mitigating disease risks

What cannot be measured cannot be effectively and efficiently managed. Addressing agriculture-associated diseases requires assessing and prioritizing their impacts, by measuring not only the multiple burdens of disease but also the multiple costs and benefits of potential interventions—across health, agriculture, and other sectors in different social and political contexts. .

There are few examples of such comprehensive assessments of the health, economic and environmental costs of a particular disease. But even with better assessment tools, there remains the challenge of using the results to inform policy decisions. Decisionmakers require more than metrics: they need clear evidence on control options and the expected health and economic returns, and they need to consider the sociopolitical factors that affect the feasibility, sustainability, and acceptability of implementation. One interesting example, an ex-ante assessment of brucellosis control in Mongolia (Roth el al, 2003) brought together information from agriculture, public health, hospital and household costs, to predict that positive public health and economic benefits could be obtained from vaccinating livestock. In this case of brucellosis, these assessments were relatively straightforward. For other agriculture-associated diseases, however, there are high levels of uncertainty regarding epidemiology, impacts, and control options. (This is true especially for emerging diseases and diseases sensitive to new drivers, such as climate change and evolving agroecosystems and food chains.) Other diseases have persisted despite medical interventions—especially the neglected tropical zoonoses—indicating a need to tackle the underlying determinants of disease, such as poverty, inequity, lack of information, and powerlessness.

For poor people, food safety and other disease risks often require different strategies and incentives. Applying standard food safety policies, procedures and regulations often exclude small-scale value-chain actors or pushes them to informal markets with higher risks and fewer gains. As a basis for framing sound policies, information is needed on the multiple burdens of disease and the multiple costs and benefits of control, as well as the sustainability, feasibility, and acceptability of control options. An example of cross-disciplinary research that effectively influenced policy is the case of smallholder dairy in Kenya. In light of research assessing both public health risks and poverty impacts of regulation, there was a dramatic shift in policy and regulation. This shift stopped pending legislation outlawing the selling of milk through the informal milk sector and officially recognized and supported the informal sector by establishing a system of training and certification for small-scale market agents. Not only did this improve the quality and safety of milk but it also led to economic benefits later estimated at US$26 million per year (Kaitibie et al. 2008.). This positive change required new collaboration among research groups, the government, nongovernmental organizations, and the private sector, as well as new ways of working. This policy shift is appropriate for the current context of milk marketing in Kenya and will be reviewed as this marketing chain evolves.

A similar innovative risk-management approach applies to the use of sewage water for irrigating vegetables and other crops. The nutrients and water are critical inputs into a sector that supports the livelihoods of between 20 and 50 million farmers and feeds up to one billion consumers—while creating a risk of disease when crops are eaten raw. In such instances, risk reduction and livelihood support have to be carefully balanced. An *ex ante* assessment in Ghana evaluated an integrated package of risk-based measures relating to the use of wastewater for irrigation; it was judged capable of averting up to 90 percent of an estimated 12,000 DALYs, at an overall cost of less than US$100 per averted DALY (IFPRI & ILRI 2010).

Many agriculture-associated diseases are characterized by complexity, uncertainty, and high potential impact. They call for both *analytic* thinking, to break problems into manageable components that can be tackled over time, and *holistic* thinking, to recognize patterns and wider implications as well as potential benefits. A simple example of an analytic approach is illustrated in the new decision support tool developed to address Rift Valley fever in Kenya. In savannah areas of east Africa, climate events trigger a cascade of changes in environment and vectors, causing outbreaks of Rift Valley fever among livestock and (ultimately) humans. Improving information on step-wise events can lead to better decisions about whether, when, where, and how to institute control (Anon 2010).

An example of holistic thinking is pattern recognition applied to disease dynamics, recognizing that emerging diseases have multiple drivers. A synoptic view of apparently unrelated health threats—the unexpected establishment of chikungunya fever in northern Italy, the sudden appearance of West Nile virus in North America, the increasing frequency of Rift Valley fever epidemics in the Arabian Peninsula, and the emergence of Bluetongue virus in northern Europe— strengthens the suspicion that a warming climate is driving disease expansion generally (Gould & Higgs 2009).

Complex problems often benefit from a synergy of various areas of expertise and approaches. Complex problems also require a longer term view, informed by the understanding that short-term solutions can have unintended effects that lead to long term problems—as in the case of agricultural intensification fostering health threats. Not every problem requires this broad-spectrum approach, so a first task is to identify specific problems that call for integrative solutions.

New, integrative ways of working on complex problems, such as the One Health (Anon 2008, World Bank 2010) or Ecohealth (IDRC, 2012) approaches require new institutional arrangements. Agriculture, environment, and health sectors are not designed to promote integrated, multi-disciplinary approaches to complex, cross-sectoral problems. For short-term outbreaks, joint task forces may be adequate, as in preventing an avian influenza outbreak (Grace et al. 2010). For longer-term planning and assessment, stronger cross-sectoral mechanisms may be required: joint animal and human health units; integrated knowledge management and information sharing; and integrated training programs. Institutional arrangements must carefully consider incentives for changing behavior, tailored to local contexts, needs, and cultures.

7.3 Conclusions

Agriculture and health are intimately linked. Many diseases have agricultural roots—food-borne diseases, water-associated diseases, many zoonoses, most emerging infectious diseases, and occupational diseases associated with agrifood chains. These diseases create an especially heavy burden for poor countries, with far-reaching impacts. This brief views agriculture-associated disease as the dimension of public health shaped by the interaction between humans, animals, and agroecoystems. This conceptual approach presents new opportunities for shaping agriculture to improve health outcomes, in the short and long term.

Understanding the multiple burdens of disease is a first step in its rational management. As agriculture-associated diseases occur at the interface of human health, animal health, agriculture, and ecosystems, addressing them often requires systems-based thinking and multi-disciplinary approaches. These approaches, in turn, require new ways of working and institutional arrangements.

Chapter 8: Time Allocation, Nurturing Behavior, and Income-Control Linkages

Gender roles for better nutritional outcomes

Men and women typically play differentiated roles in food systems and within the household, although these differences vary widely by region and are changing rapidly (FAO, 2011). Women make important and growing contributions to food production, processing, marketing and retailing and other parts of the food system. Within the household, women traditionally bear the primary responsibility for preparing meals and caring for children and other family members, although men are assuming more responsibilities for these roles in many societies. Gender differences in the rights, resources, and responsibilities — particularly resources necessary for achieving food and nutrition security for and within the household, and responsibilities for food provisioning and caretaking — often impede the achievement of household food and nutrition security.

Gender-sensitive interventions can improve nutritional outcomes by recognizing women's role in nutrition from agricultural production, food provision, and care and by promoting gender equality throughout the system, including in some cases increasing the role of men in household maintenance, food preparation and childcare. In agriculture, technologies that enhance the labour-productivity of rural women (such as better farm tools, water provision, modern energy services, and household food preparation) can free their time for more important activities. For example, a study from India demonstrated that women who used a groundnut decorticator were able to process about 14 times more groundnuts and used significantly less physical effort than doing so by hand. Similarly, a new hand tool designed for making ridges for vegetable crops, allowed women to double the number of rows finished in one hour (Singh, Puna Ji Gite and Agarwal, 2006). Such changes in technology may open up opportunities for women to earn higher incomes or to use time (and increased income) for added attention to the family.

In addition to agricultural production, women are also active in other parts of the food system, including food marketing and processing. For example, in Latin America and Africa women dominate employment in many of the high-value agricultural commodity chains. Although new jobs in export-oriented agro-industries may not employ men and women on equal terms, they do often provide better opportunities for women than exist within the confines of traditional agriculture (FAO, 2011).

Raising women's incomes has important implications for nutrition outcomes, because women still play a central role in shaping household food consumption patterns. Women who earn more income have stronger bargaining power within the household. This enables women to exert more influence over decisions regarding consumption, investment and production, which results in better nutrition, health and education outcomes for children (Smith et al., 2003; Quisumbing, 2003; FAO, 2011, Duflo, 2012; World Bank, 2012).

Dietary Quality and Intra-Household Food Distribution

Related to income-control, there may be significant inequalities in the intra-household distribution of food. In particular, adult women and female children may receive a disproportionately low share of the household intake of non-staple plant foods and animal/fish. Poor micronutrient status not only has adverse direct consequences for mothers, but may also impact on the nutritional status of infants during fetal development and lactation.

This of course may vary by culture. For instance, some ethnographic studies on Bangladesh as cited below, document strong evidence of gender discrimination in intra-household food distribution [39]:

> "According to the women they undergo self-deprivation because they have to feed men and children well. Since men undertake a lot of manual labor, they are perceived as having greater food requirements, while children go to school and need sufficient food for the development of their brains. Thus, when food is scarce women sacrifice their share. Girls may also be fed less frequently than boys, which women justified by the fact that they are often not in school. They also mentioned that the girls must get used to such deprivation."

In contrast to the Bangladesh case, the ethnographic and linguistic studies from the Philippines document no evidence of favoritism towards male compared to female [40]:

> "….nearly all the parents interviewed claimed that they were not favoring their sons over their daughters when it comes to the distribution of food to the children …. Adults interviewed do not think that working members of the family are necessarily entitled to extra food. This is viewed as being 'unfair' to other members because, 'everyone is doing his/her own share in the household.' …. Parents express repugnance at the suggestion that males should be entitled to better food than females, or that family members that earn more should be entitled to better food."

Similarly, the absence of gender discrimination is also evident in the linguistic analysis [41]:

> "Linguistic analysis of Filipino kin terminology has a striking lack of gender differentiation [42], a pattern that is generally incompatible with strongly discriminatory patterns against females. For example, the Tagalog language has a general term for child (anak), but no specific word for either "daughter" or "son." Fertility studies, too, almost invariably show that Filipinos are just as likely to desire a daughter as a son. Indeed, a few studies [43] have shown a slight preference for a girl among Philippine parents."[44]

Gender preferences observed ethnographically in the intrahousehold distribution of food are examined empirically in Table 8 [45]. An individual's total calorie share (CS) within the household is used to construct an index of intra-household inequality in food distribution [46]:

$$R_i^x = \left(\frac{\dfrac{X_i^x}{\sum_{i=1}^{n} X_i^x}}{\dfrac{C_i}{\sum_{i=1}^{n} C_i}} \right)$$

where:

C_i is the total calorie intake from all foods of individual i of a household with n members, X_i

is the calorie intake of individual i for any specific food or food group. The numerator is individual i's share for a particular food (FS), and the denominator is individual i's total calorie share (CS).

This index assumes that explicit hunger in the household is relatively evenly distributed among household members as represented by CS, while preferences for certain persons within the household may be expressed by how individual foods are distributed.

According to this FS/CS index, a value greater than 1 (less than 1) for a particular food or food group will indicate a favorable (unfavorable) position of that individual.

The preferred foods are animal/fish products, followed by non-staple plant foods, followed by staple foods. In Table 8, the highest values above 1.0 for animal/fish foods and for non-staple plant foods, are shown for preschool children in both Bangladesh and the Philippines. In both countries, it is the parents and teenage children who consume relatively lower quality diets. In Bangladesh, there is some preference demonstrated for males over females (preschool and adult age groups) for animal/fish products. In the Philippines, adult men consume relatively high amounts of animal/fish products while women consume relatively high amounts of non-staple plant foods.

Table 8. FS/CS Index, Comparison of Rural Bangladesh and Philippines, by Age and Gender

	Cereal		Plant		Meat & Fish	
	Bangladesh	Philippines	Bangladesh	Philippines	Bangladesh	Philippines
Male, ≤ 5 years	0.93	0.96	1.20	1.12	1.88	1.24
Female, ≤ 5 years	0.93	0.96	1.23	1.10	1.46	1.29
p-value	0.90	0.53	0.55	0.72	**0.03**	0.42
Male, 5+ to 10 years	0.99	0.99	1.03	1.03	1.10	1.08
Female, 5+ to 10years	0.99	0.99	1.02	1.01	1.07	1.10
p-value	0.88	0.45	0.90	0.60	0.39	0.67
Male, 10+ to 19 years	1.01	1.01	0.95	0.93	0.96	0.97
Female, 10+ to 19 years	1.01	1.00	0.96	1.03	0.93	1.00
p-value	0.76	**0.01**	0.35	**0.00**	0.12	0.38
Male, 19+ to 55 years	1.00	1.01	1.01	0.95	1.07	0.99
Female, 19+ to 55 years	1.01	1.00	0.99	1.06	0.88	0.94
p-value	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.07**
Male, > 55 years	0.97	1.02	1.11	0.92	1.26	1.10
Female, > 55 years	0.99	1.02	1.06	0.90	1.00	0.79
p-value	**0.00**	0.96	**0.02**	0.88	**0.00**	0.21

P-value corresponds to the *t-test* of equality of means of male and female within each age and income group. *P-values* significant at 10% level or below are shown in boldfaced.

Chapter 9. Public Policy

9.1 Addressing Obesity

Changes in activity and dietary patterns in developing countries are part of a "nutrition transition," where countries simultaneously face not only the emerging challenge of rising levels of overweight and obesity and related non-communicable diseases but continue to deal with the problems of undernutrition and micronutrient deficiencies (Bray and Popkin 1998). This transition corresponds closely to rises in income and the structural transformation of the food system, as seen primarily in industrialized and middle-income countries, in what Popkin, Adair and Ng (2012) describe as "the primary mismatch between human biology and modern society". All this suggests that the nature of the nutrition problem and its solutions may differ depending on location and how one engages with the food system. The rapid increase in overweight and obesity even in low income countries means that policymakers must continue fighting undernutrition and micronutrient deficiencies, while preventing or reversing the emergence of obesity.

Food price subsidies and taxes

Food taxes and subsidies have been used to increase consumption of staple foods and they may be used more systematically to promote nutritious diets.

As part of larger food assistance programs, staple foods such as rice and wheat have long been subsidized in many low- and middle-income countries in order to address problems of undernutrition. In response to the rice price crisis of 2007 and 2008, several Asian countries used consumer price subsidies and reduction in value added tax (along with other types of market interventions, such as export bans) to moderate domestic prices of staple foods (ESCAP, 2009).

Although less common, subsidies have also been used to encourage the consumption of foods such as fruit and vegetables which are thought to be more nutritious. Taxes are likewise used to discourage consumption of foods and beverages which are deemed less nutritious. Proposals for taxes on food ingredients deemed to be less appropriate in a healthy diet are increasingly common and such taxes have been tried in several countries (WHO, 2008; Capacci et al, 2012; Eyles, et al, 2012; Mozaffarian et al., 2012).

Assessments of the nutritional impacts of food subsidies and taxes vary, but are generally consistent with economic theory; that is, people tend to consume more of foods that are subsidized and less of foods that are taxed. Caution must be used in designing such subsidies, as they can have unintended consequences. Particularly when not effectively targeted, they may lead to increased prevalence of overweight and obesity, when they encourage overconsumption of energy-rich, less nutritious foods. Additionally, poor consumers are more responsive to price changes than affluent consumers so tax and subsidy policies may have disproportional impacts on different population groups. These and other factors pose challenges to the use of taxes and subsidies to improve dietary choices and nutritional outcomes.

Food taxes to improve nutrition are normally considered in terms of how increased taxes may be used to address problems of overweight and obesity by discouraging the consumption of foods thought to be less nutritious. Studies of existing food tax policies in Europe and North America generally find that tax rates are too low to have a noticeable impact on consumption patterns (Mozaffarian, 2012; Capacci et al, 2012; Mazzocchi and Traill, 2012; Eyles et al., 2012). Such taxes are however effective inraising government revenue which may be used to cover the health costs associated with obesity or to promote consumption of more nutritious foods.

Many studies of the impact of food taxes are based on simulation exercises. A recent systematic review of 32 simulation studies in OECD countries found that taxes on soft drinks and foods high in saturated fats could reduce consumption and improve health outcomes (Eyles et al., 2012). A simulation exercise in the United States showed that among adolescents a 10 percent increase in the price of a fast-food meal was associated with a 3 percent higher probability of consuming fruit and vegetables and a 6 percent lower probability of being overweight (Powell et al, 2007). A simulation study from the U.K. showed that taxing less healthy foods by 17.5% could avert as many as 2,900 deaths annually due to cardiovascular disease and cancer, and that using the revenues from these taxes to subsidize fruits and vegetables could avert an additional 6,400 such deaths (Nnoaham et al., 2009).

These simulations illustrate the complexity involved in designing interventions that improve nutritional outcomes for everyone. Taxing pork in China, for example, could reduce consumption of excess energy and saturated fats by higher-income consumers who are at risk of obesity, while at the same time causing an undesired decline in protein consumption by the poor (Guo et al. 1999). Thus taxes on some energy-dense foods could help address obesity but worsen problems of undernutrition and micronutrient deficiencies for members of poor households.

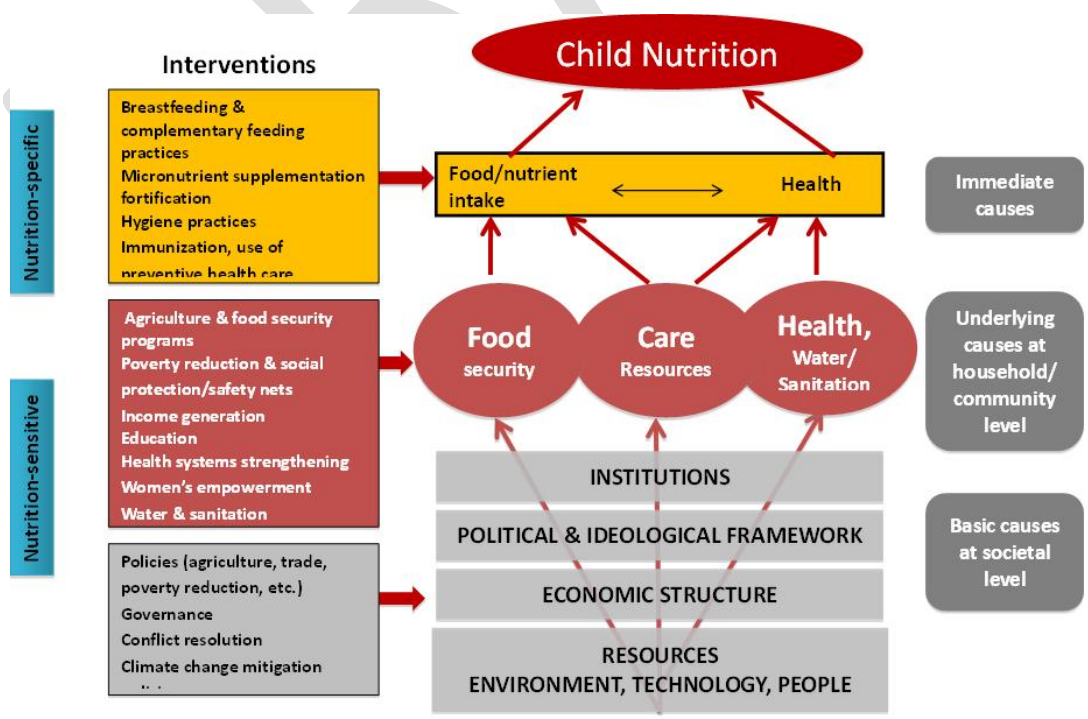
Taxing a single food or food ingredient may not lead to an overall improvement in diets because people could increase consumption of other similarly unhealthy items. Real-world experience suggests that such taxes are difficult to implement. Denmark instituted a tax on fatty foods in 2011, including dairy products, meat and high-fat processed food. The tax was unpopular because it applied to a wide variety of foods including some that were perceived as being more harmful than others, and it was commonly circumvented by shoppers who could easily shop in neighboring countries. The tax was abolished in 2012.

[47] Nevertheless, the basic idea seems to appeal to policymakers, and other countries such as Hungary, are continuing to experiment with food taxes to address obesity.[48]

9.2. Integrated Agriculture, Nutrition, and Health Programs and Policies

There is major consensus in development around the importance of child stunting and interventions within the 1000 days window through pregnancy to a child's second birthday. Improving child nutrition is complex. However there has been broad agreement on the components and a conceptual framework for how to improve child nutrition, originally developed by UNICEF in 1990 and at the core of the Scaling up Nutrition (SUN) movement. The three core components are food, care and health. To improve these are 13 largely nutrition-specific actions to be taken, clearly articulated by SUN and based on analyses in a seminal issue of the Lancet (2008). Beyond these nutrition-specific interventions, usually provided through funded community and public health programs, there is greater emphasis on nutrition-sensitive actions and enabling policies and investments so that broader agriculture, nutrition and health development efforts can support improved nutrition and reduce the need for additional targeted nutrition-specific interventions. Though agriculture, nutrition and health are entwined in many ways – both positively and negatively – individual policies and programs still operate largely out of sectoral silos (Gillespie et al, 2012).

Figure 14. Conceptual framework of drivers and determinants of undernutrition. Source: modified from UNICEF, 1990[19]



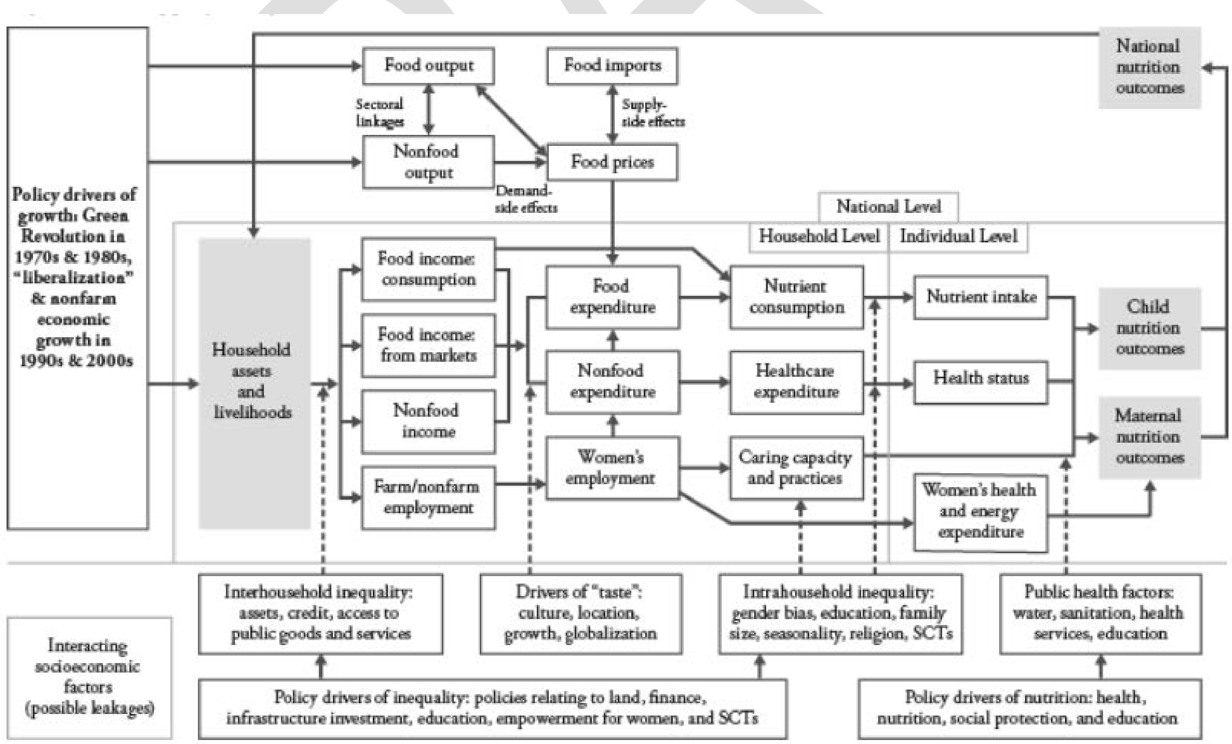
9.2.1. Integrated Programs

Conceptually, improving agriculture and food and linking this with public health programs should improve diets and reduce stunting. Given the importance of agriculture for food production and economic growth in low and middle income countries, research has focused at trying to understand the contribution of agriculture to nutrition. This is of particular interest in India, in which malnutrition has remained stubbornly high despite improved agricultural growth. In their analyses, Headey et al (2011) and Gillespie et al. 2012 have come up with 7 pathways for agriculture to contribute to better nutrition:

1. Agriculture as a *source of food* (production translating into consumption).
2. Agriculture as a *source of income* (through wages earned or marketed sales).
3. Agricultural policy and *food prices* (market policy, price setting, price volatility).
4. Agricultural income *spending* (nonfood expenditure relating to nutrition/health).
5. Women's *status and control over resources* (relating to food, health, and care).
6. Women's *time and knowledge* (ability to care, feed and promote health).
7. Women's *nutrition and health* (energy expenditure, healthy pregnancy, longevity).

Linkages between these pathways are show in Figure 15.

Figure 15. The Agriculture-Nutrition Disconnect



Source: Gillespie S, Harris L, Kadiyala S. 2012. *The Agriculture-Nutrition Disconnect in India, What Do We Know?* Discussion Paper 01187, International Food Policy Research Institute, Washington, D.C.

Overall, the evidence of nutrition-sensitive interventions, either agriculture and food (see Webb and Kennedy 2012 for a review of reviews) remains unconvincing. Reviews consistently note the problems of inadequate study design including weak or absent counterfactuals and low power. At present, numerous agriculture and public health actors are working together to deliver and evaluate, through randomized trials or other longitudinal cohort designs different integrated programs for diet, nutrition and health impacts. These include:

- Integrated agricultural or homestead food production combined with nutrition-specific maternal and child health programs
- Water and sanitation interventions linked with maternal and child health programs
- Assessing nutrition outcomes in longer-term poverty support programs and
- Comparing food assistance, food vouchers and cash transfers of the longer-term impact of nutrition.

Beyond targeting mothers and young children in preventive and clinical health programs, it is increasingly recognized that agriculture and food interventions must be gender-sensitive, to improve availability of, and access to, diverse and nutritious foods within poor rural communities and to ensure that young infants receive the care they require. It is expected that over the next 3-5 years, there will be an increasing body of evidence, both statistical and economic (cost-effectiveness), to guide integrated program design and implementation to improve diet quality in the short-term and stunting in the medium term.

9.2.2. Harmonized Policies

The integrated interventions and programs described above need to be enabled by better national policies, more effective institutions and greater technical, operational and managerial capacity across the agriculture, nutrition and health sectors. Beyond improving the individual sectoral capacities for improving nutrition, enabling processes should support cross-sectoral arrangements. In some cases, this will be the simple alignment and co-location of actions and policies. In other cases, joint actions and policies may be required. This is an active area of policy and institutional research as well as advocacy at international level.

Chapter 10. Conclusions: Priorities for Research

This paper discusses several ways in which agriculture can be transformed to provide the dietary quality which is required for good health. Ultimately, more knowledge and consensus-building is required to identify the best, most cost-effective agriculture-related pathways to reduce malnutrition. Such knowledge will improve the efficiency of nutrition-sensitive interventions, but is certainly no barrier to taking immediate actions. First, there must be a better understanding of the relationship between diets and better nutrition outcomes, what economists might call the health production function.

Are additions of single nutrients effective, at what levels? Vitamin A supplements have been shown to reduce mortality in preschool children; there has been wide-acceptance of this result. These supplements provide single high doses of retinol (each six months) which is stored and released over time. Can far lower amounts of additional provitamin A provided by foods, but on a daily basis, improve functional outcomes?

What combinations of nutrients are effective, at what levels? For example, micronutrient powders have been shown to be efficacious. These deliver multiple micronutrients to under twos at relatively high levels. Similarly as above, can lower amounts of additional minerals and vitamins provided by foods improve functional outcomes?

What food groups (which provide a range of nutrients and compounds), at what levels? Dietary diversity indicators (how many food groups consumed) are associated with better child and mother nutrition outcomes. But which food groups are most important? What specific combinations of more nutrients and compounds (provided by more diverse diets) are associated with these better nutrition outcomes?

Additional research is also needed to determine at which lifecycle stages such dietary improvements are effective. The first 1,000 days is a highly critical period, but can foods alone provide useful levels of nutrients and other compounds? What nutritional outcomes are associated with better diets (single nutrients, multiple nutrients, dietary diversity) for preschoolers, female and male adolescents and adults, and the elderly? Furthermore, current data about undernutrition and overnutrition prevalence levels by age-gender group in rural and urban areas in developing countries is weak; strengthening is required for appropriate targeting of interventions.

Once the efficacy of dietary of interventions is better understood, the specific programs and policies that can be scaled up most cost effectively can be more thoroughly analyzed. A broad range of interventions should be examined.

Sector-wide policies to increase incomes and lower food prices must first answer:

- What magnitude of income increases are required, that is what are nutrient and dietary diversity income elasticities for various age-gender groups?
- How important is it to reverse the trend in rising prices of non-staple foods, what are the own-price and cross-price elasticities for specific non-staple food groups?

Interventions focused on **specific food markets** must ask:

- How cost-effective at scale are food fortification and biofortification?
- What are the opportunities to reduce margins between farmgate and retail prices for foods with high nutrition value (value chains)?
- How can regulating and improving food safety increase access to nutritious foods?

For **community-, household- and individual-level interventions**, questions include:

- How cost-effective at scale are home gardens?
- How can programs and policies that empower women be better integrated into nutrition efforts?
- What opportunities are offered by general education and nutrition education, within given income and food price constraints?

Each type of intervention should be examined first through ex-ante benefit-cost analyses and then in practice.

Implications for CGIAR and FAO Activities

The Green Revolution was highly successful in raising cereal yields and, in so doing, lowered the cost of calories for the poor, broadly and successfully reducing hunger. Due to increased productivity, incomes of small-holder farmers were increased despite lower cereal prices. What analysis in this paper has shown, however, is that productivity increases for non-staple foods has been given too little emphasis, leading to rising prices for minerals and vitamins over a period of decades. Vitamin and mineral deficiencies, in particular for preschool children and women of reproductive age whose requirements are greatest due to rapid growth and reproduction, remain at high levels – with devastating consequences for their quality of life and economic productivity.

Due to a number of factors including climate change and reduced past investments in agricultural research, the world once again faces the prospect of rising cereal prices. Rising cereal prices exacerbate the problem of poor dietary quality because the poor must pay more of their limited food budgets for cereals to keep from going hungry. And they must pay higher prices for non-staple foods from what little remain of their meager food budgets.

No doubt the global community will find political will to invest in more rapid growth of cereal yields, to once again lower cereal prices and to keep them relatively low. This, to be sure, is a critical objective. The hope, however, is that **the CGIAR and FAO will give just as high a priority to dietary quality in the required new round of increased investments in agriculture.**

The following provide examples of what can be done:

- Invest at higher rates in sustained productivity increases (including extension to farmers) for a range of non-staple foods – vegetables, fruits, pulses, animal products.
- Make the mineral and vitamin content of the edible portions of new crop varieties as core breeding objectives, not just yields and other agronomic characteristics that contribute to farm profits; scientific breakthroughs are reducing the cost of including these additional nutrition breeding objectives.
- Consider dietary quality in economic policy analysis related to food security, not just energy intake.

The CGIAR and FAO must learn to work cooperatively across disciplinary and institutional boundaries to make agriculture more nutrition-sensitive, for example by:

- Expanding the number of nutrition and health professionals on their staffs, and investing in and rewarding efforts to work collaboratively across disciplinary divisions -- for example, by investigating how new methods of storage, processing, and cooking could preserve valuable nutrients and compounds that are otherwise lost, or could reduce undesirable compounds; breeding strategies could complement these efforts, for example by discovering key genes that slow down provitamin A degradation.
- Engaging with NGOs who focus on improved nutrition and health in rural areas, in developing and implementing food-based strategies to achieve their goals – for example in the area of home gardening and livestock production.

- Engaging with health ministries to achieve a joint understanding of how agricultural policies can either hinder or help achieve nutrition and health goals – for example, by discussing cost-effective safety improvements for particular food value chains.

The world is evermore inter-dependent as environmental resources become more scarce. This paper has discussed several ways in which agriculture can be transformed to provide the dietary quality is required for good health.

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