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Post-green revolution food systems and the triple burden of malnutrition

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ABSTRACT

Developing country food systems have changed dramatically since the Green Revolution period. At the same time, malnutrition still represents a challenge and is now understood to encompass the three simultaneous dimensions of undernourishment, micronutrient deficiencies, and over-nutrition manifest in overweight and obesity. These changes in food systems and in the understanding of the global malnutrition challenge necessitate fresh thinking about food systems-based strategies to reduce malnutrition. This paper introduces a special section that offers such new perspectives. We discuss trends with respect to indicators of the triple burden of malnutrition to understand the extent of global malnutrition challenges and then relate those to food systems transformation in developing countries.

Introduction

Despite impressive progress over the past two generations, malnutrition still poses a major public health and development challenge. By the narrowest popular measure, the United Nations Food and Agriculture Organization (FAO) estimates that 868 million people worldwide suffer undernourishment (FAO, 2012). Those estimates are more than 130 million people less than 20 years earlier, but still represent roughly 15% of the population of the developing world. Unfortunately, most countries are not on track to achieve the first Millennium Development Goal (MDG) of reducing by half the share of hungry people by 2015 or the World Food Summit Goal (WFSG) of cutting the number of hungry people in half by 2015 (FAO, 2001).

One big change from the 1960s and 1970s, when the threat of famine haunted policymakers and helped spur major investments in the Green Revolution, is a deeper understanding that malnutrition is a broader problem than just insufficient intake of dietary energy and protein – so-called 'undernourishment' – but that it also encompasses two other dimensions, namely micronutrient deficiencies, and overweight and obesity. The challenge is therefore now often referred to as the 'triple burden' of malnutrition (Pinstrup-Andersen, 2007; Labadarios, 2005). And most experts believe that far more people suffer from the one or both of the latter two forms of malnutrition than the estimated 868 million persons who are undernourished, although there is substantial overlap across categories.

Undernutrition's most immediate causes are inadequate dietary intake and infectious disease. Inadequate dietary intake can include deficits in quantity and/or quality, where quantity refers to total caloric intake and quality to variety, diversity, nutrient content and safety. Inadequate dietary intake weakens the immune system and increases susceptibility to disease. Infectious disease, in turn, increases nutrient requirements and weakens the immune system. In addition to these proximate causes, nutrition is distally affected by economic, political, social and economic factors. These include patterns of income distribution, agricultural practices, trade and food policies, religion, socio-demographic trends, effects of climate change, and cultural beliefs.

A more refined understanding of the nature of the world's malnutrition challenge necessitates some reconsideration of how best to attack the problem. When malnutrition was viewed more simply as a problem of undernourishment in low-income, agrarian economies, the natural prescription was to increase production of low-cost, energy-rich cereals that were the primary foods of poor farmers and farmworkers. Hence the Green Revolution, which

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emphasized higher agricultural productivity of staple grains and achieved a certain level of success in reducing malnutrition (Pinstrup-Andersen and Hazell, 1985; Evenson and Gollin, 2003). However, those successes were largely confined to reductions in protein–energy malnutrition and associated undernourishment, given the focus on increasing supplies of micronutrient-poor, calorie-dense staple grains. Today, some rethinking of the links between food systems and malnutritionis needed as we increasingly recognize that problems of micronutrient deficiencies and overweight and obesity burden developing countries as well and are far less amenable to resolution through increased farm-level productivity of staple crops.

In parallel to the broader understanding of malnutrition, developing country food systems have also changed dramatically since the Green Revolution period. This transformation has been driven by multiple factors, including rapid urbanization and increasing incomes in developing countries, the emergence of domestic and global commercial food value chains (FVCs), efforts by governments to establish safety nets for the food insecure, and advances in germplasm improvements that target other traits different than yields, among others (Pinstrup-Andersen, 2012a). Taken together, the ongoing transformation of food systems and the challenges posed the triple burden in developing countries, underscore the need for broadened perspectives on the links between food systems and malnutrition for the 21st century post-Green Revolution era. There remains a consensus that food-based strategies remain critical to alleviatemalnutrition. But the nature of those strategies is evolving as scientific understanding advances and agricultural, demographic and economic patterns evolve.

The manuscripts in this special section present sweeping reviews of the literature on pathways through which food systems influence nutritional outcomes. Together, they supplement more conventional approaches that, like the Green Revolution of an earlier era, aim to stimulate agricultural productivity growth, especially in low-income countries suffering high prevalence of food insecurity. Agricultural productivity growth is indisputably a necessary condition for further progress in the battle against global malnutrition. But it is also increasingly recognized as insufficient. The three review papers that follow this introduction offer a more encompassing, up-to-date perspective intended to provide guidance to governments, multilateral institutions, donor agencies, food firms and researchers on the design and implementation of food system policies targeting improved nutritional outcomes. The manuscripts focus on food systems at various levels, including productionand post-harvest approaches to reduce micronutrient deficiencies, ways in which the emergence of modern FVCs influence the triple burden of malnutrition, and the nutritional impacts of public food assistance policies aimed at establishing safety nets for those segments of the population often missed by commercial FVCs.

In this introductory paper we offer a background analysis to set the stage for the review papers that follow. First, we present regional trends on key indicators of the triple burden of malnutrition so as to understand more clearly the extent of malnutrition challenges at aggregate levels. Next, we describe critical transformations in food systems in the post-Green Revolution period, linking nutritional problems to the agricultural, demographic and dietary transitions that countries generally follow. We then highlight the contributions of the manuscripts in the special section, and conclude by offering a few key overall principles for food system approaches to improve nutritional outcomes.

Regional trends in malnutrition

Malnutrition, like food security, is a complex, multidimensional concept not amenable to measurement using a single indicator (Barrett, 2010). In this section we briefly review the best current estimates on prevalence and trends in key indicators of the three basic forms of malnutrition.

Undernourishment is the outcome of insufficient macronutrient (caloric and protein) intake. It is estimated by FAO as the prevalence and number of people whose food intake is insufficient to meet their requirements. Dietary energy supply is used as a proxy for food intake. Undernourishment is an important factor contributing to negative health outcomes measured by anthropometric indicators such as the prevalence of underweight (low weight-for-age), wasting (low weight-for-height), or stunting (low height-for-age), especially among children. Stunting captures the life-long negative effects of food intake deficiency and disease (Victora et al., 2008), and afflicted 165 million children globally in 2011 for a prevalence of 26% (UNICEF, WHO and The World Bank, 2012). Wasting captures shorter-term, acute episodes of malnutrition. Underweight is a product of the other two indicators.

Micronutrient malnutrition refers to deficiencies in vitamins and minerals critical to good health and is the outcome of a combination of poor dietary composition and disease. There are many essential micronutrients but only vitamin A, iron, and iodine deficiencies are routinely monitored in a large-scale and cross-nationally comparable fashion. Vitamin A deficiency (VAD) impairs proper growth and increases vulnerability to infections. VAD affected over 163 million children under five in 2007, a prevalence of about 31% (UNSCN, 2010).

Overweight and obesity, for their part, are the result of excessive dietary energy intake and are generally measured by the Body Mass Index (BMI)[1]. This form of malnutrition, which is associated with increased risk of diabetes and cardiovascular disease (Schroeder et al., 1999; Sawaya et al., 2003; Reddy, 2002), is increasingly affecting developing countries and obesity reached a global prevalence of 12% in 2008 (Finucane et al., 2011).

A descriptive analysis of regional trends of selected nutrition indicators helps set the stage to characterize the triple burden of malnutrition. We concentrate on continental-level trends of stunting in children under 5 years of age for undernutrition, vitamin A and iron deficiencies in children under 5 years of age for micronutrient deficiencies, and the BMI in adults for obesity and overweight. These best-available estimates necessarily mask considerable underlying variation among and within countries and often require somewhat-herculean assumptions. We encourage readers to treat these as coarse estimates, but the patterns they reveal are nonetheless instructive.

Stunting is caused primarily by maternal undernutrition, which leads to poor fetal growth, and by poor nutrition and repeated infections in the first 2 years of a child's life (Waterlow, 1994). Stunting is a key indicator of undernutrition because it causes permanent impairments to cognitive and physical development that lowers attained schooling and reduces adult income (Black et al., 2008). Fig. 1 presents the prevalence of stunting in children less than 5 years of age for the period 1990–2011. Between 1990 and 2011, the prevalence of stunting in developing countries declined by about 17% points, from 45% to 28%. Today there remain 160 million stunted children in developing countries, compared to 284 million in 1990. Asia (excluding Japan) and Latin America & Caribbean exhibit the fastest progress in reducing the prevalence of stunting during this period, with rates falling from 48% to 27% and from 25% to 14%, respectively. In contrast, the prevalence of stunting in Africa and Oceania (excluding Australia and New Zealand) has decreased

[1] Body Mass Index (BMI), equals the body weight in kilograms divided by height in meters squared (kg/m^2) and is commonly measured in adults to assess underweight, overweight and obesity. The international references are as follows: underweight = BMI < 18.5; overweight = BMI $\geqslant$ 25; obese = BMI $\geqslant$ 30. Obesity is thus a subset of the overweight category.

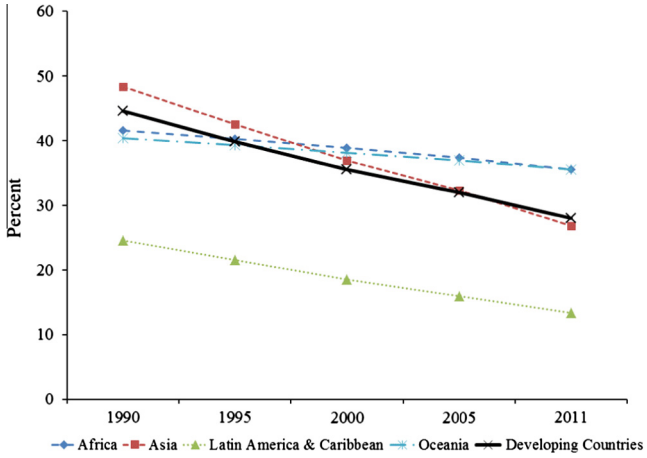

Fig. 1. Prevalence of stunting in children less than 5 years of age, 1990–2011. Source: UNICEF, WHO and The World Bank (2012).

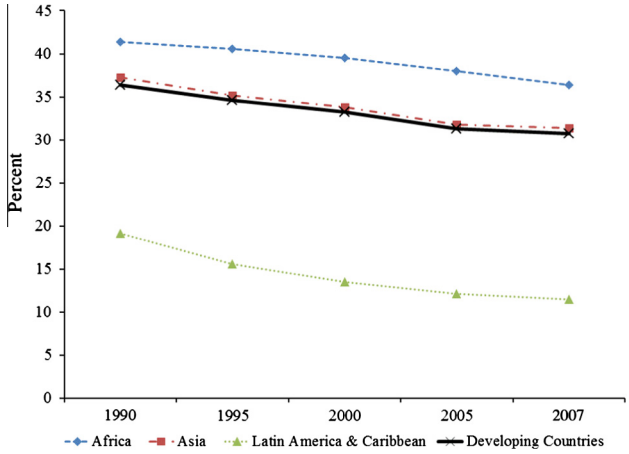

Fig. 2. Prevalence of vitamin A deficiency in children less than 5 years of age, 1990–2007. Source: UNSCN (2010).

only modestly in the past two decades, staying at around 36%. At a global scale, this is laudable progress. But it clearly masks both significantly variation among and within countries and underscores the considerable scale of the remaining challenge.

Micronutrient malnutrition is the second basic form of undernutrition. It is often referred to separately because it can also co-exist with excessive consumption of macronutrients (i.e., overweight and obesity, on which more below) and carries health consequences distinct from those associated with stunting. In this analysis we focus on trends in the prevalence of vitamin A and iron deficiencies because they are routinely monitored and are strongly associated with specific health consequences. We do not consider trends in other micronutrients, such as vitamin B12, zinc, and selenium, which are also critical for appropriate nutrition, because comprehensive estimates of their prevalence over time are not (yet) available.

Vitamin A deficiency (VAD) impairs proper growth and reproduction, leaves the body more vulnerable to infections, and is the leading cause of blindness in children (Holick and Chen, 2008). Iron is important for blood formation and its deficiency is a primary cause of anemia. Iron deficiency impedes cognitive development of children, affects pregnancy outcomes, and reduces work capacity for adults (Pollitt, 2001).

Fig. 2 presents the prevalence of vitamin A and iron deficiencies in children less than 5 years of age for the periods 1990–2007 and 2000–2007, respectively. For all developing countries combined, VAD prevalence has decreased only by 5% points from 36% in 1990 to about 31% in 2007 (UNSCN, 2010). As with undernourishment, there is substantial variability in progress across continental-scale country groupings. In Latin America & the Caribbean, which started with the lowest prevalence level, VAD has decreased by half in percentage terms, from about 20% to 10% between 1990 and 2007. Prevalence in Asia has followed a trend that is very similar to the trend of all developing countries combined. Africa experienced a decline in prevalence similar to the global aggregate, but starting from a relatively high level of about 42% in 1990, so that by 2007 still over one out of three African children under the age of five were vitamin A deficient.

Fig. 3 indicates that anemia prevalence is much higher than that for VAD or stunting, and that only relatively modest progress has been achieved in reducing anemia among children under five (UNSCN, 2010). For all developing countries, anemia prevalence has been reduced by only about 5% points, from 50% in 2000 to nearly 45% 2007. The extent of reduction in anemia prevalence is comparable across continents, but starting from quite different

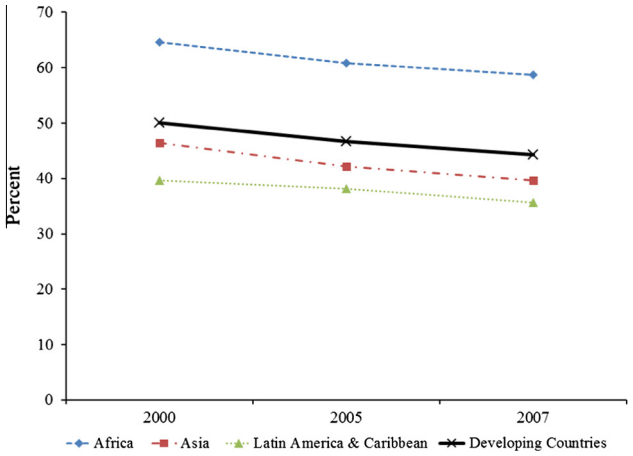

Fig. 3. Prevalence of anemia in children less than 5 years of age, 1990–2007. Source: UNSCN (2010).

levels in 2000 (65%, 48% and 40% prevalence in Africa, Asia and Latin America & Caribbean, respectively).

Reductions in the prevalence of vitamin A deficiency have been substantially smaller than in the prevalence of stunting. This reflects the global community's longstanding emphasis on improving agricultural productivity and decreasing inflation-adjusted prices of staple grains, which are inferior dietary sources of most micronutrients.

Fig. 4 shows the prevalence of adult obesity for 1980 and 2008 for developed and developing regions. North America had by far the highest level prevalence in 2008 (32%) and experienced the largest prevalence increase between 1980 and 2008 (over 20% points). The prevalence is likewise high in Europe (about 24%). What is perhaps more surprising is that adult obesity has also become an increased concern in developing regions. Latin America & the Caribbean and Oceania had high rates of obesity in 2008 (23% and 22%, respectively), roughly equivalent to those in Europe, and saw dramatic increases during the period 1980–2008 (16% and 18% points, respectively). Asia and Africa, for their part, had the lowest prevalence of adult obesity in 2008 (6% and 11%, respectively). Although low in levels, the prevalence in these two continents has more than doubled since 1980, so the trends arealarming.

These aggregate trends underscore both the extent of malnutrition and some basic geographic and inter-temporal patterns that

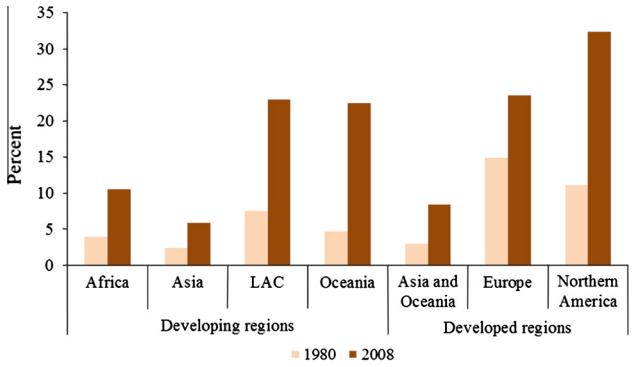

Fig. 4. The Prevalence of Adult Obesity by region, 1980 and 2008. Source: Constructed by authors based on Finucane et al. (2011).

can help guide the design of general strategies to reduce malnutrition on a global scale. But just as these trends fail to capture the substantial cross- or within-country variation in nutritional problems, they also say relatively little about the dynamic relationship that exists between the evolution of developing country food systems and the triple burden of malnutrition. A better understanding of such links is necessary to allow researchers and policy makers to identify promising food systems approaches to reduce malnutrition.

Food systems transformation and approaches to reduce malnutrition

Traditionally, public agricultural research and development strategies have focused primarily on agricultural productivity growth as the primary route to reduce malnutrition. This emphasis was reflected most clearly in the Green Revolution, which prioritized the development and diffusion of high-yielding varieties of the major staple crops, in combination with more intensive utilization of modern inputs such as inorganic fertilizer and irrigation (Lipton and Longhurst, 1989). There is vast evidence that high-yielding varieties associated with the Green Revolution made substantial contributions to increases in total staples output and to reductions in food prices (Hazell, 2009; Evenson and Gollin, 2003; Rosegrant and Hazell, 2000; Pinstrup-Andersen and Jaramillo, 1991), which in turn resulted in higher per capita caloric intake acrossdeveloping countries (Evenson and Gollin, 2003; Conway, 1997; Von Braun and Kennedy, 1994; Pinstrup-Andersen and Jaramillo, 1991; Ryan and Asokan, 1977). For example, Von Braun et al. (1989) surveyed rice farmers in the Gambia and showed an increase in total caloric production (from all crops) of nearly 50%; an increase in farmers' incomes and food expenditures of about 13% and 10%, respectively; and a per capita increase in caloric intake of nearly 5%. The literature clearly indicates that increased caloric intake associated with the Green Revolution reduced undernourishment and associated outcomes such as stunting and wasting in children and women (e.g. Von Braun et al., 1994; Hazell and Ramasamy, 1991).

Limitations of the Green Revolution approach

In spite of the positive impacts on caloric intakes, some researchers have been critical of the Green Revolution for at least two reasons. First, several studies argue – somewhat controversially – that the Green Revolution benefited disproportionally larger land owners who were most likely to adopt improved production technologies early, while largely missing the poorest farmers, workers and rural residents who are most affected by malnutrition (Conway, 1997; Lipton and Longhurst, 1989; Hazell and Ramasamy, 1991). Other research challenges these claims, underscoring the pro-poor food price and real wage effects of agricultural productivity growth (David and Otsuka, 1994; Evenson and Gollin, 2003; Minten and Barrett, 2008). But concerns about how reliably the gains from improved crop productivity translate into reduced malnutrition for all people remain.

Second, a stream of research examines the unintended nutritional consequences of the Green Revolution (Hazell, 2009). For example, from the 1970s to the mid-1990s the price of staple foods (e.g., rice, wheat) decreased relative to the price of micronutrient-rich foods (e.g., vegetables, pulses) in much of Asia. This was likely due to greater productivity gains in micronutrient-sparse staples and the resulting reallocation of land towards those crops. But as a result, micronutrient-rich foods became relatively (and in some cases, absolutely) less affordable, particularly to the poor (Bouis, 2000; Kennedy and Bouis, 1993; Kataki, 2002). The induced substitution effects led to more calorie-rich, but less diverse and micronutrient-rich diets. Moreover, as energy expenditure falls as populations increasingly move from manual agricultural labor to less vigorous non-farm activities, increased energy intake at some point begins to contribute to excess calorie intake manifest in overweight and obesity.

These concerns suggest the need for an updated, post-Green Revolution approach to food systems development that more explicitly considers the triple burden of malnutrition. In order to do so, it is essential to consider carefully how the malnutrition challenges a country faces evolve along with its food system. One simple primary indicator of the evolution of a country's food system is its agricultural labor productivity, measured as its agricultural GDP per worker engaged in agriculture. Fig. 5 shows the relationship between 2010 agricultural labor productivity – grouped into low (<$1000/worker-year), medium ($1000–$4499/worker-year), high ($4500–$11,999/worker-year) and very high (>$12,000/worker-year) categories – and the share of countries in each agricultural labor productivity category that exhibit excessive prevalence of different forms of malnutrition: undernourishmentmeasured as the prevalence of stunting $\geqslant$ 20%; micronutrient malnutrition measured as prevalence of vitamin A deficiency $\geqslant$ 10% or iron deficiency $\geqslant$ 20%; and overnutrition measured as prevalence of obesity among adults $\geqslant$20%. These thresholds correspond to the WHO classifications as rates signaling moderate public health significance, except for the obesity rate, which is the global median.

Several features of Fig. 5 are striking. First, virtually all countries face at least one malnutrition problem. Only one-third of the very high agricultural labor productivity countries face none of the three sorts of malnutrition at prevalence rates that signal a public health problem. And no country in the other categories enjoys that condition.

Second, a clear, strong relationship appears between country-level agricultural productivity and the nature of malnutrition issues faced. All countries with agricultural GDP per worker below $1000 exhibit high prevalence levels of both stunting and micronutrient deficiencies, but none have high prevalence of obesity. These countries have yet to experience the benefits of higher caloric intakes accruing to Green Revolution-style advances in agricultural productivity.

But as agricultural labor productivity rises, even just to lower middle-income country levels of $1000–$4499, stunting starts declining; 69% of countries in this category have stunting prevalence problems, alone or in combination with micronutrient deficiencies and/or obesity. Nevertheless, just like their low labor productivity counterparts, all of these countries exhibit high levels of micronutrient deficiency prevalence. These stylized facts suggest that focusing solely on increasing agricultural productivity (i.e., the traditional Green Revolution approach) can help reduce undernourishment problems, but does little to address

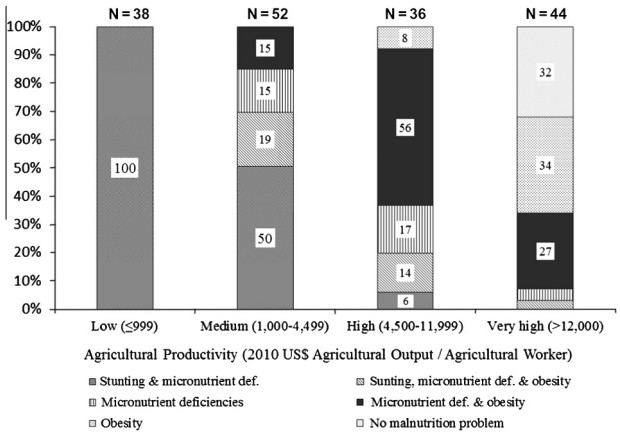

Fig. 5. Agricultural productivity and the burden of malnutrition: proportion of countries in each malnutrition category for each level of productivity (*N* = number of countries in category). *Notes*: Data for stunting and micronutrients deficiency are for children less than 5 years old. Data for obesity are for adults with BMI ⩾ 30 kg/m^2 (age standardized estimate). Prevalence thresholds for inclusion are: stunting ⩾ 20%; vitamin A deficiency ⩾ 10% or iron deficiency ⩾ 20%; and obese adults ⩾ 20%. Thresholds for stunting and micronutrients correspond to WHO classifications as moderate public health significance. The threshold for overweight is the global median for adults. Countries with a per capita GDP ⩾ US$15,000 are assumed to be free of vitamin A deficiency of public health significance, according to the WHO. Source: Food and Agriculture Organization, United Nations (2013).

micronutrient malnutrition. Moreover, in nearly a third of the countries in the middle productivity category, obesity is now a public health problem, mostly in combination with micronutrient deficiencies. In 19% of the cases, all three forms of malnutrition are sufficiently prevalent to pose public health concerns. Put starkly, mediumagricultural productivity countries are most likely to face the triple burden of malnutrition simultaneously.

As agricultural labor productivity rises to the $4500–$11,999 level, only 20% of countries suffer from widespread stunting. Nevertheless, almost all countries (92%) still have micronutrient deficiency problems, most often in combination with obesity (64%). The prevalence of obesity in high agricultural labor productivity countries is substantially higher relative to countries in the medium productivity category. About two-thirds of the countries in this category suffer from high prevalence of obesity among adults.

Once agricultural labor productivity reaches very high levels, above $12,000, widespread stunting is rare. But the proportion of countries with problems in the other two burdens decreases only modestly relative to their high agricultural productivity counterparts. Over half of countries in this category have obesity problems and about 35% have high micronutrient deficiency prevalence levels.

Taken together, what do these broad patterns suggest? First, the traditional Green Revolution approach, focusing on increased productivity of major staple crops to reduce undernourishment, remains necessary in low agricultural labor productivity countries. However, this approach is by no means sufficient to solve the challenges posed by the triple burden of malnutrition, especially the challenges of micronutrient deprivation and obesity. The Green Revolution focus on agricultural productivity should be extended to other crops rich in essential micronutrients. Moreover, a narrow focus on agricultural productivity risks ignoring growing global obesity problems.

Food system transformation

In addition to the nature of the global nutritional challenges today, dramatic changes in food systems also call for broader strategies to alleviate malnutrition. According to Pinstrup-Andersen and Watson (2011), a food system may be described as a process that converts natural and human-made resources and inputs into food. For the purposes of identifying appropriate policy interventions and assessing their impact, it is useful to conceptualize a food system as a dynamic system that changes in response to the behavior of various decision-makers in the system, including policymakers, farmers, consumers, processors and traders.

Today, developing country food systems differ fundamentally from their characteristics during the Green Revolution period. Fig. 6 highlights a few key differences between a typical food system in the late 1970s or early 1980s and today. In 1980, about 74% of people in low- and middle-income countries resided in rural areas. Thus, the share of food sold in local wet rural markets and grown for household consumption was relatively high while the share of modern FVCs (e.g., supermarkets) in total food consumption was small (Reardon and Timmer, 2007). In the same year, the share of the low- and middle-income countries' labor force in agriculture was approximately 69% (FAO, 2013a,b), expending considerable energy in manual labor. In addition, domestic public food-based safety nets to provide food assistance to those missed by the commercial sector were practically non-existent in developing countries other than those supported foreign food aid

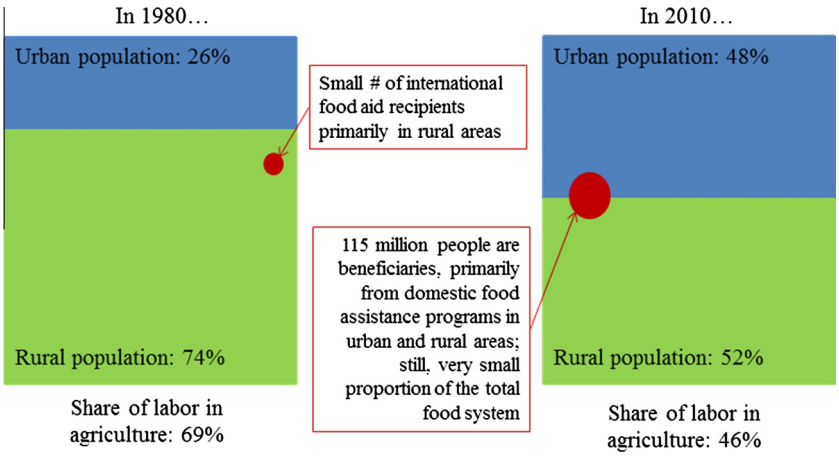

Fig. 6. Key differences between developing country food systems of the 1970s–1980s and in the 2010s. Source: Authors creation based on FAO, 2013a,b and IEG (2011).

shipments from high-income countries (Barrett and Maxwell, 2005; IEG, 2011).

Developing country food systems are dramatically different today. A larger portion of people in developing countries now live in urban areas and depend on commercial FVCs to deliver their food, while they typically work in less physically demanding jobs than agriculture, expending far fewer calories in daily labor. In 2011, only about 52% of low- and middle-income country people resided in rural areas and the share of agricultural labor had fallen to about 46% (FAO, 2013a,b). Consequently, the share of food sold in local rural markets and grown for household consumption is now significantly smaller than in 1980, except for relatively remote rural areas that house a small and shrinking share of the global population. Meanwhile, modern food retail and wholesale has expanded rapidly in Africa, Asia and Latin America (Reardon et al., 2003, 2007, 2009), and foreign direct investment of global food manufacturers in developing countries has increased substantially (Regmi and Gehlhar, 2005). This 'food system revolution' occurred in three general waves (Reardon et al., 2009; Reardon and Timmer, 2012). The first was driven by the rise of large first- and second-stage food processors. First-stage processors sell foods used as intermediate products while second-stage processors prepare foods for direct sales to consumers. The second wave was characterized by the rise of supermarkets in the retail sector, followed by the third wave, characterized by the expansion of fast-food chains and large scale wholesale and logistics companies, leading to the lengthening of the supply chains. Thus, the food system revolution affects the whole system, not just farming, processing or retail (Reardon and Timmer, 2012).

Another key feature of today's food systems is that many developing countries are establishing food-based safety nets – 'food assistance programs' (FAPs) – for those individuals who are at risk of experiencing macronutrient and micronutrient deficiencies. The World Bank (2013) estimates that, on average, nearly 115 million people benefited annually from safety nets in developing countries from 2010 to 2012. FAPs encompass a variety if interventions ranging from cash transfers to school feeding programs. At the same time, distribution of food aid has moved away from transoceanic shipments from high income countries toward in kind local and regional food procurement as well as direct cash transfers to food insecure individuals and households (Lentz et al., 2013). We note that even in publicly-funded FAPs, food systems throughout the developing world rely primarily on the commercial sector to source commodities, either directly in the form of procurement for institutional distribution or indirectly via the use of cash transfers and food vouchers.

Four stages of country food system transformation

The preceding two sets of observations together describe four stages of food system development, nutrition problems and diet transition (Nugent, 2011; World Bank, 2006; Paarlberg, 2012). Stage I consists of low-income countries where a diet transition has not yet begun, a large share of the population is rural, the supply chain is short, food processing is rather limited and the cost of the food commodity is a large share of household budgets. In this stage, most farmers are semi-subsistence smallholders who consume much of what they produce and many are net food buyers. Undernourishment and micronutrient deficiencies and infectious diseases resulting from unclean water, poor sanitation and hygiene and lack of primary health care are common and occur primarily in rural areas, resulting in high child morbidity and mortality rates. The prevalence of obesity is low.

Stages II and III comprise lower and upper middle-income countries, respectively. As incomes, urbanization and the opportunity costs of women's time increase, the food supply chain becomes longer and includes additional segments. The proportion of total household income spent on food is lower than in Stage I, and a smaller share of what the consumer pays for food consists of the farmgate cost of the food commodity itself. As a result, post-harvest activities become more important for nutrition and the analysis of the nutritional impacts of changes in the food system begins to move from the impact of changes in agriculture to changes in the post-harvest food supply chain. Countries in these stages typically exhibit increasing reliance on street foods and imported foods, resulting in dietary changes toward more processed foods with less fiber and more fats, oils, sugar and sweeteners. These countries often face a combination of undernourishment, micronutrientdeficiencies and obesity. As countries move from Stage II to Stage III, energy deficiencies and infectious diseases are gradually replaced with excessive energy intake, overweight, obesity and associated chronic diseases. Micronutrient deficiencies continue to be widespread in many of these countries.

Finally, Stage IV consists of high income countries where the share of food in household budgets is small and the share of food-away-from-home is relatively high. Only a miniscule proportion of the population is engaged in agricultural production, thus farmers are far removed from consumers and the FVCs drive most food production and processing in response to consumer demand, which firms try hard to influence through advertising and other means. In these countries, obesity becomes the overriding nutrition-related health problem although micronutrient deficiencies may continue to be prevalent, especially in pregnant and lactating women and preschool children among specific socioeconomic groups. Undernourishment remains a concern, but only for a very small minority of the population, and FAPs are widely deployed to try to reduce undernourishment and micronutrient deficiencies.

Broader approaches are necessary to alleviate malnutrition

The nature of today's malnutrition problems, together with the continued transformation of food systems in developing countries, call for broader approaches and interventions aimed at improving nutritional outcomes than was the case a generation or two ago. We need to do better than merely replicating the incomplete successes of the 1960s–1980s' Green Revolution period because food systems today are radically different. The Green Revolution approach to prioritizing agricultural research so as to expand food availability and variety remains relevant in those low-income countries – most of which remain heavily agrarian – where undernourishment still is the dominant nutritional problem.

But agricultural productivity growth of the major staple crops alone is not sufficient to address the nutritional challenges of today. Appropriate approaches necessarily vary across the four stages of food system transformation. In particular, we need to pay heightened attention to what happens beyond the farm gate so that food systems work in favor of improved nutrition. We also need to re-evaluate production agriculture approaches so as to recognize the triple malnutrition burden and avoid the narrow focus on productivity gains of a small number of staple crops that are commonly deficient in essential minerals and vitamins.

Pathways through which food systems affect nutrition

Several recent studies have proposed pathways through which food systems influence nutrition. Hoddinott (2012) suggests six pathways components, including changes in household incomes and savings, in crops (including changes in varieties within the same crops), in production methods, in markets for food products, in the use of time, and in intra-household resource allocation. Arimond et al. (2011) suggest five pathway elements that include

increased food for own consumption, increased incomes, reductions in market prices, shifts in consumer preferences, and shifts in control over resources within households. The World Bank (2007) suggests yet another framework, consisting of food production for the household's own consumption; food production for household income generation; reduction in real food pricesassociated with increased agricultural output; empowerment of women as agents instrumental to household food security and health outcomes; and the indirect relationship between increasing agricultural productivity and nutrition outcomes through the agriculture sector's contribution to national income and macroeconomic growth. Gillespie and Kadiyala (2005) offer a similar set of pathways to the World Bank's, but emphasizes the links between agricultural policy and food prices, the allocation of additional income generated from agricultural activities, as well as the increasing feminization of the agricultural labor force.

The studies cited above clearly reject the commonly held notion that the quantity of food produced is the food system's sole, or even primary, link to human nutrition. They seem to agree that food production for own consumption, food availability, incomes, prices, gender-specific time allocation, and consumer behavior provide important links between the food system and household access to food and nutrition (Pinstrup-Andersen, 2012b). Below, we provide a brief discussion on each pathway to illustrate how they influence nutrition.

Food production for own consumption

The types of crops produced are relevant for the nutrition of rural residents who keep a portion of the agricultural output for own consumption. Opportunities for enhancing consumption diversity and reducing micronutrient deficiencies may be pursued on semi-subsistence farms and isolated local wet markets where the diet may otherwise consist of one of two basic staples. Research and policy interventions to promote the production, marketing and consumption of so-called "orphan crops", i.e., food crops for which little or no attention has been paid by researchers and policy-makers, offer such an opportunity, especially for micronutrient dense crops like most fruits, legumes and vegetables.

Food availability through markets

Food availability primarily depends on the private sector and government policies. For example, trade liberalization may increase the availability of imported foods with undesirable characteristics such as processed foods with a high content of fats and sweeteners. Public and private investments in the food value chain may improve food safety and quality. Increased availability of meat, dairy products, fruits and vegetables may reduce micronutrient deficiencies while greater availability of fats, oils, sugar, sweeteners and energy-dense, nutrient-poor foods may contribute to overweight, obesity and chronic diseases. A high degree of diversity in the food supply chain, whether from own production or the market may facilitate increased dietary diversity and better nutrition.

Incomes

Changes in the food system may affect incomes of (potentially) malnourished people in several ways. First, research and technology may generate an economic surplus by improving the productivity of basic inputs (e.g., land, water, labor), not only in agriculture but in other parts of the food system. Second, productivity improvements induce changes in the returns to these resources, thus stimulating employments and wages. Second, changes in labor demand, wages and access to productive resources (e.g., land and water), labor-using technology, investments in rural infrastructure, changes in land tenure and water policies, and other fiscal and monetary policies. Third, changes in the food system may modify the gender-specific composition of and control over household income control, as well as cash flow over time. Those changes will, in turn, influence household food acquisition behavior and the extent to which food access is converted to food utilization and improvednutrition.

Food prices

Changes in food and non-food prices influence a household's purchasing power and as such its access to food. Changes in relative prices are also important, as lower prices for one food commodity relative to the price of another will usually increase consumption of the former and reduce consumption of the latter. Unit-cost reducing technological change in food production, processing and marketing, as well as commodity-specific taxes and subsidies and trade restrictions such as export restrictions and import duties, are examples of interventions that may change relative prices.

Before such commodity-specific policies are proposed, it is important to clearly specify the nutrition problem to be solved: is it dietary energy deficiencies, micronutrient deficiencies or obesity-related chronic diseases? Can changing relative prices reduce the importance of one problem without contributing to another? The choice of price-related policies is often difficult because most developing countries experience all three of these problems. For example, taxes on meat, vegetable oil, sugar and sweeteners may reduce the risks of chronic disease among low- and high-income people while increasing the deficiency of iron, essential fatty acids and dietary energy in low-income population groups.

Gender-specific time allocation

Opportunities in the food system for improving – and potentially harming – the nutritional status of pregnant and lactating women and children during the first 2 years of life are often related to how the food system affects women's time allocation. Projects and policies often seek to empower women and improve their well-being as well as that of children by attempting to generate employment. However, some food system practices make breastfeeding, which is critically important during the first 6 months of life and beyond, very difficult either because employment takes the lactating mother away from the baby for long periods or because the employment activities are otherwise incompatible with breastfeeding. Furthermore, employment creation by women may harm nutrition by reducing their time available for other important nutrition-related activities such as child care, cooking, fetching clean water and agricultural or domestic work.Thus, changes in the food system should consider the net effect of changes in women's time before introducing new demands for women's work.

Consumer behavior

Improved knowledge regarding nutrition and its relationship to the food system is needed for all food system agents, but particularly for consumers because they ultimately make their dietary choices. Nutrition education and dissemination of information through labeling and social marketing for consumers has been a commonly used tool to improve nutrition. However, recent behavioral research suggests that "the potential for information-based interventions is fundamentally limited, given that it is based on a view of human behavior that is at odds with psychological and neuroscientific evidence that much human behavior is not actually driven by deliberations upon the consequences of action, but is automatic, cued by stimuli in the environment" (Marteau et al.,

2012). If this is so, policy advisors may focus on re-arranging the environment to produce the cues needed to achieve health and nutrition goals Wansink (2006).

Manuscripts in this special section

Food systems transformation has occurred at different speeds across countries. The implications for nutrition exhibit a wide range of variation as a result. Today, the linkages between food systems and nutritional outcomes are recognized as more complex than in the past. This also makes assessment of the impact of interventions especially challenging, but also particularly important. The manuscripts in this special section offer in-depth literature reviews to shed light on the links between food systems and nutrition in the post-Green Revolution period. They consider some of the pathways through with food systems influence nutrition discussed above. In particular, they emphasize under-researched and under-emphasized dimensions of food systems that merit increased attention by both the research and development practitioner communities. For example, although agricultural productivity improvements remain an essential element of any holistic strategy to improve foodsystem performance, especially as manifest in nutritional outcomes, that topic has been so extensively covered, including in recent years, that we thought there would be little value added from yet another overview paper on the topic here. So instead we focus on three topics that merit far more attention than researchers have given them to date.

Miller and Welch (2013) examine the importance of agricultural practices (e.g., cropping systems, soil fertility and animal production) to increase the supply of micronutrients in the food supply and discusses post-harvest strategies to preserve and enhance micronutrient availability beyond the farm gate. They consider alternative production agriculture-oriented approaches based on biofortification and micronutrient-rich fertilizers, together with post-harvest approaches to preserve or enhance micronutrients in food, such as fortification, as a means to solving micronutrient deficiency problems worldwide through the food system. The authors posit that significant progress in reducing micronutrient malnutrition will require promoting varied diets composed of affordable, appealing, safe, and nutrient dense food groups, but that there are multiple obstacles to achieve this objective.

Based on their careful review of the available scientific evidence, Miller and Welch suggest opportunities for investments that can reduce the prevalence of micronutrient malnutrition. First, commercial fortification of foods should be expanded to a global scale because it offers a cost-effective strategy to prevent malnutrition among the increasing share of the global poor who access their food through commercial FVCs. Second, the authors call for additional investments in both conventional plant breeding and genetic engineering to accelerate the development of biofortified foods. This is particularly important to reduce micronutrient deficiencies among rural populations in developing countries who make less use of commercial FVCs. Third, investments in appropriate food processing and food storage technologies for developing countries can be cost-effective in reducing micronutrient deficiencies. Finally, technological advances should encompass efforts to build human capacity in agriculture, food processing, and nutrition education.

Gómez and Ricketts (2013) examine how the transformation and expansion of modern FVCs, together with their interactions with the traditional sector, are impacting the triple malnutrition burden. The authors propose a novel FVC typology (modern, traditional, modern-to-traditional, and traditional-to-modern) and offer hypotheses concerning the relationship between each FVC category and distinct forms of malnutrition. Their analysis suggests that it is difficult to make generalizations regarding the impacts of emerging FVCs on nutrition, because those effects depend on the context and because there may be important tradeoffs among different forms of malnutrition. For example, modern FVCs may simultaneously increase over-nutrition and reduce micronutrient deficiencies among urban middle and high income people in urban areas. In contrast, traditional FVCs can play a key role in facilitating access to foods richin micronutrients for urban, low income people and for the majority of rural resident. The authors call for investments to improve post-harvest and distribution infrastructure as a means to reduce micronutrient deficiencies among low income populations.

The Gómez and Ricketts paper also highlights the nutritional relevance of FVCs that involve interactions between traditional and modern FVC participants. For example, intensive processed/packaged food distribution strategies by modern manufacturers through traditional retailers can contribute to over-nutrition in urban areas, but can prevent or reduce undernourishment in remote rural areas. In addition, smallholder farmers and traders that connect with modern supermarkets may receive nutritional benefits indirectly, through elevated incomes generated by off-farm employment in farm and post-harvest activities.

Lentz and Barrett (2013) focus on the nutritional impacts of public food assistance programs aimed at establishing safety nets for those segments of the population who might otherwise be missed by commercial FVCs. The authors review the evidence on the economic and nutritional impacts of international FAPs and policies. FAPs are quite small in comparison to the broader food system, with domestic programs much larger than international FAPs. The powerful implication is that performance of the domestic private food system is more important to food security than FAPs, which must therefore be designed to complement and reinforce private FVCs rather than undermine or replicate them.

Lentz and Barrett nonetheless underscore the importance of FAPs for certain populations who may not benefit from the transformation of private food systems. The authors develop a FAPs typology based on the targeted population and find evidence that overall, the returns on investments in FAPs are high but depend on a variety of factors, including timing, targeting and cost structures, among others. The nutritional benefits of FAPs are largest when they target pregnant woman and young children and when they prevent interruptions of food access and utilization so as to preempt the adverse effects of malnutrition. In spite of the scientific evidence favoring such programs, however, the authors show that political economy considerations tend to favor FAPs targeted towards older, better off, urban populations, whereas programs oriented towards prenatal and early childhood interventions are generally underfunded.

Conclusions

In this paper we set the stage for and introduce the three review papers that comprise the special section on linkages between post-Green Revolution food systems and the triple burden of malnutrition. Our analysis of regional malnutrition indicators highlights the extent of malnutrition challenges at an aggregate level, the spatial heterogeneity and variation across forms in the extent of malnutrition and progress in reducing it. We next discussed how the traditional Green Revolution approach has succeeded in reducing undernourishment, but has been very slow in reducing micronutrient deficiencies and is largely unhelpful to solving rising obesity problems in developing countries. In addition, our analysis underscores the need to take into account the ongoing and inevitable food systems transformation and the associated transitions in malnutrition problems across developing countries.

The manuscripts in this special issue explore selected areas of private and public intervention, at different levels of the food system, which can positively influence nutritional outcomes. Taken together, the manuscripts identify three overarching considerations for the development of a research agenda to identify appropriate food systems-based approaches to alleviate the triple burden of malnutrition. First, we need to diversify commodity research beyond merely boosting yields or agricultural productivity of major staple crops. We must diversify the portfolio of commodities for which productivity increases should be sought. Research agendas should include such objectives as micronutrient fortification of staple and non-staple foods as well as soil and water management systems that add nutritional content to foods. Moreover, we must broaden the crop research agenda beyond staples and into micronutrient-rich fruits, legumes and vegetables, as well as intopost-harvest processing and distribution issues. Following these actions would extend the cereals production focus of the Green Revolution to address micronutrient deficiency and overweight problems more effectively.

Second, researchers and policymakers must recognize that, unlike 50 years ago, urbanization and income growth have resulted in most people in developing countries now depending on food purchased from commercial FVCs for much of their diets. Those commercial FVCs involve a mix of traditional (e.g., 'mom and pop' stores, street vendors, smallholder traders and farmers) and modern (supermarkets, food manufacturers, multinational restaurant chains) actors. Public policies exert some influence in the commercial FVC sector, including investments in public goods and setting and monitoring food safety and quality standards, among others. However, most innovations and institutional arrangements are driven by private firm choices. Therefore, a post-Green Revolution research agenda should focus on the incentives and behaviors of food systems firms and consumers so as to identify appropriate interventions that can favorably influence nutritionaloutcomes.

Third, commercial FVCs necessary miss certain, typically poorer, segments of the population. In such cases it is necessary that governments step up and establish safety nets, in the form of food assistance programs, to ensure that these individuals have access to adequate diets. In the design of these FAPs, it is critical to balance the high returns of targeting the most vulnerable individuals with political economy considerations, which may require targeting less vulnerable populations in order to build coalitions necessary to sustain food safety nets over time. Such policies are required not only for humanitarian reasons but also for stability reasons to avoid food riot episodes that likely lead to social, economic and political instability (Barrett, 2013).

A broader research agenda that takes into account the aforementioned principles, together with appropriate, evidence-based policy design and implementation strategies, can go a long way in helping solving the triple burden of malnutrition. Nonetheless, interventions to improve nutritional outcomes should avoid the one-solution-fits-all mentality. Far too much variation exists across and within countries and over time in the nature of malnutrition problems and the characteristics of food systems for cookie cutter solutions to work. Therefore, it is important to develop nuanced interventions to enhance the positive impacts of policies aimed at improving nutritional outcomes and to invest significantly in building skilled cadres of local analysts, managers and policymakers able to absorb research findings and adapt interventions appropriately to local and changing circumstances.

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