What You Don't Know Can Hurt You: Micronutrient Content and Fungal Contamination of Foods in Developing Countries

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The negative effects of micronutrient deficiencies on human capital acquisition and economic productivity are well documented. A less well understood but potentially serious threat to human health in developing countries is the contamination of food crops by fungal toxins. This paper surveys what is known about the health and economic burdens attributable to insufficient micronutrients and toxic contamination of food in developing countries, discusses consumer demand for micronutrients and food safety, and describes some of the challenges to improving population nutrition, particularly in rural areas.

Key Words: food safety, micronutrients, aflatoxin, developing countries

Invisible threats to health plague much of the food supply in developing countries. Both a lack of micronutrients and an excess of chemical contaminants contribute substantially to the burden of disease. The estimated health toll of micronutrient deficiencies—so-called "hidden hunger"—is greater than that of general calorie and protein malnutrition (Caulfield et al. 2006). The negative effects of micronutrient deficiencies on human capital acquisition and economic productivity have been demonstrated in several recent studies. A less well understood but potentially serious threat to human health in developing countries is the contamination of the food supply by fungal toxins.

There is evidence of some response by the private sector to consumer demand for fortified foods among urban populations in developing countries. In rural areas where the majority of food is home-produced or purchased through informal markets, the challenges to regulation and fortification are much greater. These include a scale of production at which traditional approaches to fortification and screening for toxins are not economical, the inability of consumers to detect subtle but important chronic health effects, and problems of asymmetric information. This paper surveys what is known about the health and economic burdens attributable to insufficient micronutrients and toxic contamination of food in developing countries, discusses consumer demand for micronutrients and food safety, and describes some of the challenges in improving population nutrition, particularly in rural areas.

The Micronutrient Challenge

Micronutrient deficiencies during childhood can seriously impair physical and cognitive development, with life-long consequences for human capital accumulation and earnings (Behrman et al. 2009). Iodine deficiency is the leading cause of preventable mental retardation in the world. A study of the impact of iodized salt in the United States in the 1920s showed an increase in IQ scores of 1.3 standard deviations in parts of the country with high endemic deficiency (Feyrer, Politi, and Weil 2008). In utero iodine supple-

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mentation has been demonstrated to significantly affect educational attainment in Tanzania (Field, Robles, and Torero 2008). The effect was particularly strong for girls. This suggests that iodine deficiency may explain part of the gender gap in schooling, which in Tanzania is almost entirely accounted for by the lower rate at which girls pass the national secondary school qualifying exam.

Lack of iron during infancy has adverse long-term effects on cognitive, motor, and social function (Lozoff et al. 2006). Extrapolating from the existing evidence, one study estimated a median 4 percent reduction in GDP due to iron deficiency in ten developing countries, with the majority due to cognitive effects (Horton and Ross 2003). This is in line with the findings of Behrman et al. (2009), who use long-term follow-up data on participants in a randomized nutritional intervention to show that when human capital is treated as endogenous, differences only in cognitive skills, not physical attributes, are significant determinants of adult wages. There is however evidence from several studies that contemporaneous iron supplementation has a positive effect on the economic productivity of adults (Basta et al. 1979, Edgerton 1979, Li et al. 1994, Thomas et al. 2006). The largest study to date was a placebo-randomized controlled trial of over 17,000 adults in Indonesia, which showed increased physical stamina and fewer hours of sleep among adult males in the treatment group, and significantly higher earnings among those who were self-employed (Thomas et al. 2006).

In addition to its direct effect on energy levels, iron deficiency anemia, as well as deficiencies in vitamin A and zinc, compromise immune response to infectious diseases. Deficiencies in these three nutrients account for 19 percent of child deaths globally, more than double the number of lives claimed by malaria (Black 2003). One study estimated that eliminating micronutrient deficiencies would reduce the total burden of disease in developing countries by 18 percent (Mason, Musgrove, and Habicht 2003).

Referring to micronutrient supplementation and fortification,[1] a 1994 report by the World Bank asserted that "probably no other technology available today offers as large an opportunity to improve lives and accelerate development at such low cost and in such a short time" (World Bank 1995). This sentiment was echoed in 2008 by the Copenhagen Consensus, through which a panel of economists were charged with ranking the top 10 priorities for advancing global welfare. Micronutrient supplementation for children was ranked first, and fortification of staple foods was ranked third. As shown in Figure 1, fortification of staple foods with iron, vitamin A, and zinc is more cost-effective than other generally recognized low-cost and high-impact health interventions such as measles vaccination and oral rehydration therapy for severe diarrhea.

Trends and Prospects for Addressing Micronutrient Deficiencies

The level and frequency of the body's needs for particular micronutrients and the technical options for fortification and supplementation imply that the determinants of success in overcoming deficiencies differ greatly across micronutrients. Vitamin A, for example, can be stored by the body for long periods, and can therefore be delivered in large, infrequent doses. It is now standard practice to offer vitamin A supplements during early childhood clinic visits. Countries with high immunization rates, high female literacy, and low infant mortality rates also tend to have lower rates of vitamin A deficiency among pre-school aged children (Mason, Rivers, and Helwig 2005). Neither GDP nor national-level food availability is an important determinant of vitamin A sufficiency in this critical age group.

Unlike vitamin A, iodine and iron must be consumed regularly to maintain adequate levels in the body. The fact that only trace amounts of iodine are sufficient, and that iodine can easily be added to near-universally consumed condiments such as salt and soy sauce, has allowed remarkably rapid progress against iodine deficiency globally. From 1990 to 2000, the proportion of households in the developing world using iodized salt increased from 20 to 70 percent, and the global prevalence of this deficiency fell from 30 to 15 percent (Adamson 2004). In most developing countries, consumption of iodized salt is correlated with wealth: on average the wealthiest fifth are 60 percent more likely to consume iodized salt than the poorest fifth (Adamson 2004). Since in most places iodized salt costs no more on

[1] Fortification is the addition of micronutrients to staple foods; supplementation is the provision of micronutrients through pills or foods specifically designed to deliver these.

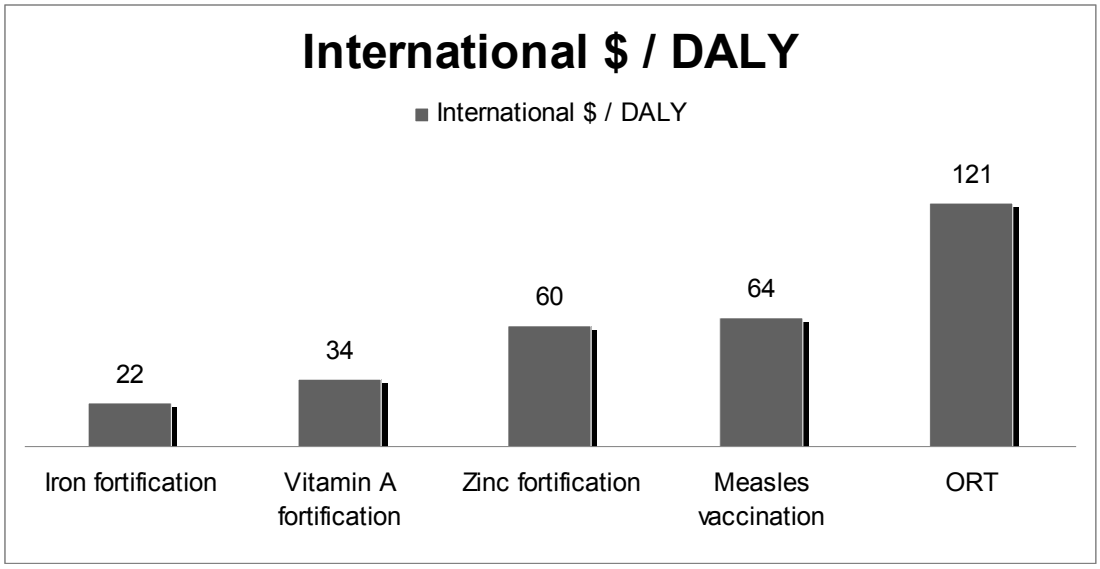

Figure 1. Cost per Disability-Adjusted Life Year at 80 Percent Coverage, Africa E. Region

Note: The disability-adjusted life is a standard metric that allows measurement of the disease burden due to death and life lived with disability.

Source: WHO-CHOICE (2005), Horton (2006).

average than non-iodized salt, this is likely due to market access rather than price sensitivity (Haxton 2009). For large-scale salt manufacturers, the variable cost of iodization is minimal. However, artisanal salt producers, which collectively command substantial market share in some countries, are too small to economically modernize and to iodize their product.

Deficiency in iron is more directly a function of poverty than either vitamin A or iodine deficiencies. The primary sources of iron in the diet are meat and vegetables, consumption of which tends to increase with income. GDP and proportion of calories from meat are highly significant correlates of iron deficiency anemia in a cross-country regression (Mason, Rivers, and Helwig 2005). Progress against anemia over the past twenty years has been slow, except in countries with rapid economic growth such as China. Even in developed countries, where incomes are generally high enough to afford a varied diet, fortification of processed foods helps to ensure adequate intake of iron. North American consumers, for example, consume a quarter of the recommended daily iron intake through fortified flour (Adamson 2004). Over fifty countries, up from two in 1990, routinely fortify flour with iron, and countries with mandatory flour fortification laws include Bolivia, Botswana, Indonesia, and Niger (Adamson 2004). In countries such as Kenya, where such regulations are not in force, most major flour brands offer a fortified product, suggesting some market demand.

In areas where consumption of processed foods is low, staple crops can be fortified directly by selective breeding, genetic modification, or the addition of micronutrients to chemical fertilizer. One approach is the fortification of staple crops, through genetic modification, selective breeding, or the addition of micronutrients to chemical fertilizer. Biofortification through selective breeding is estimated to cost as little as $10 per disability-adjusted life year for some crops and regions (Meenakshi et al. 2007). Another approach is to promote consumption of existing foods rich in micronutrients. Social marketing to promote home vegetable gardens, for example, can be effective at reducing vitamin A deficiency, but is relatively expensive when compared to both supplementation and biofortification (Attig et al. 1993, Albrecht, undated). A newer strategy, for which evidence is just beginning to emerge, is the addition of micronutrients to own-produced food at the point of milling or in the home. All of these approaches rely on some degree of consumer awareness of and demand for micronutrients.

Consumer Demand for Micronutrients

Several recent studies have assessed demand among consumers in developing countries for micronutrient-rich crops and fortified cereals. A study using data from Indonesia showed that for a given level of food expenditure, mothers with better nutritional knowledge spent more on micronutrient-rich foods (Block 2004). Though part of the difference was explained by formal schooling, a significant share was not, indicating that other sources of nutritional knowledge, such as community health workers, are also important. Knowledge of the superior nutritional qualities of yellow versus white maize was likewise a significant determinant of its consumption among a sample of rural Zimbabwean households (Muzhingi et al. 2008).

A 2003 survey of customers at small maize mills, kiosks, and supermarkets in Nairobi, Kenya, found that 76 percent were aware of fortified maize, and that 44 percent of these purchased it regularly (De Groote and Kimenju 2008). Consumers who were unaware of fortified products were read an explanatory text, after which just over half claimed they would be willing to pay a premium for fortified maize meal. The average stated willingness to pay among this group was 14 percent, well above the 4 percent premium of the lowest-cost fortified brand over the average price of non-fortified maize. These results should be interpreted with caution, since stated willingness to pay is often overstated.

A field experiment in Uganda found that providing nutritional information increased consumers' actual willingness to pay for biofortified orange sweet potato by over 50 percent (Chowdhury et al. 2009). Participants in a separate treatment who were asked to report how much they would *hypothetically* be willing to pay for the biofortified food reported values that were on average twice as high. While the incentive compatibility introduced by requiring participants to pay reduces potential bias, one-shot purchase decisions may not be representative of habitual willingness to pay.

The only long-term evaluation of a micronutrient fortification program is by Banerjee, Duflo, and Glennerster (2009), who assess the impact of a village-level flour fortification program implemented by an NGO in Rajasthan, India. Community meetings were held to raise awareness about anemia and introduce the fortification program. The program provided an iron-fortified pre-mix to small village millers used by local people to mill own-produced wheat. Millers were instructed to offer fortification for free to consumers, and to always fortify the flour of those who opted in initially. Demand for free fortification increased for the first six months, and at its height significantly reduced anemia in the target population. However, a combination of imperfect compliance among millers, who did not always fortify the flour of those who had opted into the program, and an apparent decline in interest among consumers, some of whom stopped traveling the extra distance to a participating mill, led to a drop-off in fortification over time. By the end of the two-year evaluation period, only 30 percent of flour was fortified.

Contaminants

Food contaminants can be broadly characterized as pathogens, biologically produced toxins in plants or produced by pests, and toxins from other sources such as agrochemical residues and environmental pollutants. The primary means of addressing contamination with pathogens is through improvements in sanitation and hygiene, the literature on which is vast and beyond the scope of this review. As developing countries transition out of labor-intensive agricultural practices, the use of pesticides and herbicides tends to increase. Lack of regulation, lax enforcement, and price sensitivity all lead to the use of older, non-patented, less expensive, and generally more acutely toxic and environmentally persistent agents (Ecobichon 2001). Contamination with agricultural chemicals is likely to be a much bigger problem in developing countries than in developed countries with stronger regulations and stricter enforcement. However, the existing literature on the health effects of exposure to agricultural chemicals deals with this as an occupational hazard of farm work rather than a food safety problem, on which there is a dearth of evidence.[2] There is more evidence on the health effects of

[2] A limited amount of work has examined the perceptions and behavioral responses of agricultural workers to these health risks. See for example Stewart (1996) and Dasgupta, Meisner, and Huq (2007).

and behavioral response by both consumers and producers to biologically produced toxins, in particular fungal byproducts known as mycotoxins. This section focuses on the extent and effects of contamination by these compounds, with particular attention to aflatoxins, the most potent type of mycotoxin.

The fungi that produce aflatoxins are endemic in the soil of most tropical countries. Fungal contamination of crops is enabled by insect and other pest damage, which may occur in the field or after harvest. Groundnuts (peanuts) and maize (corn), important staple foods in much of sub-Saharan Africa, are the worst-afflicted crops. At low levels of exposure, aflatoxins increase the risk of liver cancer; at moderate levels, immune system function is suppressed, increasing susceptibility to infectious disease and slowing child development. At higher levels, aflatoxicosis can result in liver failure and death (Strosnider et al. 2006). Human exposure to aflatoxins varies greatly across countries, from undetectable levels across Europe to near universal exposure in the Gambia and Senegal (Wild et al. 1993). The combination of high hepatitis B prevalence and chronic aflatoxin exposure is thought to be responsible for 75 percent of the approximately 200,000 annual deaths due to liver cancer in sub-Saharan Africa (Hainaut and Boyle 2008).

The carcinogenic effects of aflatoxins have been understood for much longer than the immunosuppressive effects, and are the basis of strict regulation in developed countries. Most of the work on the economic effects of aflatoxin contamination of food crops in developing countries relates to the impact of these regulations on trade. One study found that a change in the European Union maximum allowable aflatoxin standard resulted in 1.4 fewer deaths per billion a year, and decreased African exports by 64 percent or US$670 million annually (Otsuki, Wilson, and Sewadeh 2001). While the economic impacts of domestic health effects are less well understood, they are potentially even more important. Aflatoxin exposure is believed to be a large and under-recognized contributor to the global burden of disease (Williams et al. 2004). The following section describes current consumer awareness and practices, and discusses possible approaches to reducing the contamination of the food supply with fungal toxins in places where regulation is unlikely to be effective.

Consumer Awareness of and Response to Mycotoxin Contamination

Developing countries where awareness of aflatoxin has been studied include Uganda (Kaaya and Warren 2005) and Benin, Ghana, and Togo (James et al. 2007). Consumers in all of these countries were generally unaware of their chronic exposure to aflatoxin or its effects. However, other considerations such as taste may motivate consumers to remove discolored or damaged maize cobs prior to storage, and to sort out damaged and discolored grains immediately before milling. Indeed, sorting maize grains before consumption is a common practice across Africa, and has been found to reduce mycotoxin contamination by between 30 and 70 percent (Fandohan, Hell, and Marasas 2008). However, since mycotoxin contamination is not always visible, this approach will never be able to fully eliminate exposure. An additional challenge is that in resource-poor settings, little is wasted. Damaged and discolored grains are often fed to livestock. Livestock productivity is negatively affected by consumption of contaminated feed, and toxins are passed on to humans through animal products. In some areas, small-scale alcohol producers purchase the moldy grain, resulting in a particularly toxic brew.

Synergies and Trade-offs in Farm Management

While farmers can influence to some degree the extent of fungal growth in their fields and stores, some risk factors are beyond their control and others often beyond their means. Growth of mycotoxin-producing fungi is associated with plant stressors generally, including drought, pest damage, and insufficient plant nutrition (Bruns 2003). Mycotoxin accumulation is therefore generally correlated with low yields, leading to a dangerous intersection of food scarcity and high rates of contamination. Drought conditions prevailed in Kenya in 2004 and 2005, when over 150 people died of acute aflatoxicosis after eating highly contaminated maize (Strosnider et al. 2006).

Storage conditions are another important factor in mycotoxin accumulation. Storage of improperly dried grain in poorly ventilated conditions can lead to rapid fungal growth. While traditional storage practices are associated with relatively

low post-harvest losses by weight, which average 5 percent or less in most settings (Boxall 2001), they may be less effective at preventing aflatoxin contamination. A community intervention in Guinea to encourage improved sorting, drying, and storage conditions of groundnuts reduced blood aflatoxin levels among people in treatment villages by 50 percent five months after harvest (Turner et al. 2005).

One farm management practice through which mycotoxin accumulation may be negatively correlated with yield is varietal choice. Flint maize varieties, traditionally grown in Africa, tend to be more resistant to both pest and fungal damage (Betrán, Isakeit, and Odvody 2002). More susceptible dent varieties have been used to develop many of the more recently introduced high-yielding hybrid varieties (Smale, Heisey, and Leathers 1995). The effect of maize variety on aflatoxin accumulation is striking: toxicity can vary by two orders of magnitude across fungus-inoculated grains of different varieties (Mideros et al. 2009).

Farmers in Malawi typically grow local varieties[3] for their own consumption, partially due to the superior storage properties of these relative to modern hybrids (Smale, Heisey, and Leathers 1995). As such, farmers already face a trade-off between yield and post-harvest storage properties. Awareness of the health implications of fungal contamination may shift this balance in favor of better-storing varieties. Understanding subsistence farmers' preferences over food safety could help inform public and private investment in developing crop varieties that both are mycotoxin-resistant and have other attractive qualities such as high yield and drought tolerance.

Lessons from Other Contexts

The results of Bannerjee, Duflo, and Glennerster (2009) showing low willingness of rural farmers in India to add micronutrients to their wheat point to a puzzle and a major challenge. Why are consumers unwilling to go out of their way for a highly effective health investment, and what does this mean for the prospects of improving nutrition among poor, rural populations?

One reason for consumer apathy with respect to preventative health may be the consumers' inability to detect the effects of health behaviors. Many health behaviors have effects that are too noisy for consumers to detect. One example is that of mosquito nets. Mahajan et al. (2008) administered a rapid diagnostic test for malaria in the Indian state of Orissa, and found malaria rates to be about 50 percent lower among those using insecticide-treated nets. However, those using nets reported malaria rates approximately equal to those not using nets. In the case of the iron fortification study described above, self-reported weakness decreased when take-up was high, but the number of days worked did not change in the treatment group. The benefits of fortification may thus not have been strong enough to inspire long-term behavior change.

Another possibility is that present-biased preferences (Laibson 1997) are to blame for poor decision making about health. Evidence on consumer demand for financial commitment devices (Ashraf, Karlan, and Yin 2006) suggests that many people have inconsistent preferences over time. Since the consequences of preventative health behaviors are generally delayed but costs are immediate, present-biased preferences are expected to reduce investments in health.

Finally, long-run health outcomes are not particularly salient in day-to-day decision making. When faced with an explicit choice, people may be willing to pay much more for a health good than when this is one of the many things they could seek out and purchase. The literature on demand for safe drinking water contains some pertinent examples. In Zambia, a door-to-door campaign to promote a home water treatment solution led to over 50 percent of households purchasing the product at the market price, whereas only 21 percent of households reported using the solution in a baseline survey, and 99 percent volunteered knowledge of the product (Ashraf, Berry, and Shapiro 2007). The second example comes from Bangladesh, where contamination of groundwater with arsenic causes a number of health problems, including cancer. After a national campaign to test arsenic levels and paint the handles of contaminated wells red, 29 percent of households switched to an uncontaminated well. Additional education and periodic reinforcement with the message that arsenic is a health hazard nearly doubled the proportion of households switching water sources (Ahmed et al. 2006).

[3] Maize is not indigenous to Africa; "local" in this context refers to open-pollinated varieties for which farmers have saved seeds over the years.

A study designed to isolate the determinants of chlorine treatment of drinking water in rural Kenya also suggests the importance of salience, while providing even stronger evidence on price effects (Kremer et al. 2009). Dilute chlorine solution for the treatment of drinking water has been marketed in Kenya since 2003, and costs about US$0.30 for a one-month supply. Although three-quarters of rural consumers are familiar with this product, and 70 percent volunteer that drinking untreated dirty water can cause health problems, only around 5 percent of households regularly treat their water. Offering a 50 percent discount achieved only around 10 percent take-up.[4] When coupons for 12 free bottles of chlorine solution were distributed through clinics in a separate sample, usage was initially around 60 percent, but after one year only 20 percent of women were still redeeming their monthly coupons (Dupas, Kremer, and Zwane 2009). Finally, when ease of use and free distribution were combined through installation of chlorine dispensers at communal water sources, take-up was initially 40 percent and increased over five months to 60 percent (Kremer et al. 2009).[5] This example shows that a combination of consumer awareness, convenience, and low time and monetary costs can lead to dramatic changes in preventative health behavior.

Conclusion

There is strong evidence that micronutrient deficiencies in the developing world have serious health and economic consequences. Contamination of food with mycotoxins is a less well understood but potentially very serious problem. Consumer awareness about the benefits of consuming micronutrient-rich foods can have a substantial effect on demand, at least in the short run. However, as shown by research on water treatment, consumer awareness alone is insufficient. Low cost, convenience, and reminders are also important. To the extent that food producers and processors could profit from delivering safer, healthier foods, these actors may be able to stimulate consumer demand through marketing efforts. The public sector also has an important role to play in raising awareness about food quality and safety issues and providing certification for goods that meet health and safety standards.

In rural areas of developing countries, where education levels are low, access to media is limited, and government is thin on the ground, the goal of ensuring a safe and nutritious food supply is especially daunting. Understanding the economic constraints to production and consumption of healthier and safer foods, identifying viable business models for small-scale fortification of staples, and testing approaches to the regulation or certification of marketed produce in this context are important areas for investigation.

[4] Coupon distribution followed a program of free distribution.

[5] These figures are for take-up as measured by chlorine tests of drinking water; self-reported usage was higher.

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