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How cost-effective is biofortification in combating micronutrient malnutrition? An *ex-ante* assessment

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HarvestPlus is a global alliance of research institutions and implementing agencies that have come together to breed and disseminate biofortified crops for better nutrition. HarvestPlus is coordinated by the International Center for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI). HarvestPlus is an initiative of the Consultative Group on International Agricultural Research (CGIAR).

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Abstract

Biofortification is increasingly seen as an additional tool to combat micronutrient malnutrition. This paper presents, for the first time, evidence on the costs and potential benefits of biofortification for a large number of countries in Africa, Asia and Latin America. We use a modification of the Disability-Adjusted Life Years framework to conclude that the intervention can make a significant impact on the burden of micronutrient deficiencies in the developing world, and can do so in a highly cost-effective manner.

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I. Micronutrient Malnutrition and the Potential of Biofortification

The magnitude of micronutrient malnutrition is increasingly taking center stage in policy discussions on food and nutrition security. It is recognized that food security needs to refer not merely to adequate energy intakes, but also to ensuring sufficient intakes of essential micronutrients. Estimates of numbers of people affected by micronutrient malnutrition are high, with up to 5 billion people suffering from iron deficiency and about a quarter of all pre-school children (about 140 million) from vitamin A deficiency (United Nations, 2005; p. 14; p. 19). The fraction of developing-country populations at risk of inadequate zinc intake is estimated to be 25–33% (Hotz and Brown, 2004).

Public health interventions to address micronutrient malnutrition include fortification (of flour with iron, for example) and supplementation (twice-yearly vitamin A capsules for pre-school children). However, few governments have the resources to fund such programs on a continuing basis. Biofortification, which uses plant breeding techniques to enhance the micronutrient content of staple foods, is a new, complementary, approach.

The premise of biofortification is that the diets of undernourished people are based primarily on a few staple foods, as poor people lack the purchasing power for a more diverse diet containing sufficient quantities of micronutrient-rich foods. The objective of biofortification is to enhance the micronutrient content of staple food crops through plant breeding techniques, thus resulting in higher micronutrient intakes. Unlike commercial fortification, which requires the purchase of fortified food, biofortification particularly targets rural areas where food production stays within the community and the food grown is consumed either on-farm or locally. Further, repeat purchases are not necessary; for most crops, a one-time investment in dissemination of varieties with the nutrient-dense trait becomes self-sustaining. Research has shown that it is feasible to breed staple food crops to yield cultivars with increased micronutrient levels (Bouis, 2000).

The proof of concept that biofortified crops can have an impact on public health is beginning to emerge from efficacy studies where trials are conducted with human subjects under a controlled setting.[1] Given this evidence, the question is

[1] For example, there is evidence from a 9-month feeding trial in the Philippines that regular consumption of rice containing an additional 2.6 ppm of iron was efficacious in improving body iron stores among women with iron-poor diets (Haas et al., 2005). Similarly, a feeding trial of school children in South Africa

whether biofortification is also economically efficient, and it is this question that this paper attempts to answer. Biofortification is a long-term strategy requiring a significant up-front investment in agricultural research and development. Its success will depend on the current diets of target populations, how much of the staples they eat, in what forms, and with what other foods. Thus, its economics are quite different from those of interventions such as fortification of flour or sugar, or the distribution of vitamin capsules. Recognizing this, in the present study we estimate the cost-effectiveness of biofortification for a selection of crops and countries throughout the developing world.

In particular, this paper presents a synthesis of the evidence from several countries and crops that are targeted under HarvestPlus, a program that is engaged in biofortification research. The target nutrients are provitamins A[2] in cassava, maize and sweetpotato , and iron and zinc in beans, rice, and wheat. To capture variation in the specifics of cropping patterns and diets, we include two East African, one Central African and one West African country in our analysis. Similarly, three South Asian and one Southeast Asian country are included in our work, as are three Latin American countries.[3] The choice of target countries (11 in all) is based on a number of factors, including the magnitude of micronutrient deficiencies in these countries, the importance of a target crop in the diet, and the availability of reliable data. This is thus the first paper to provide a comprehensive overview of evidence spanning crops, countries and micronutrients. The results provide evidence on whether biofortification can be a useful approach to combating micronutrient malnutrition, as well as identify the conditions under which is it most likely to be successful. The reports used in this synthesis are listed in the references under "country reports".

In determining cost-effectiveness, we use the Disability-Adjusted Life Years (DALYs) framework, which captures both morbidity and mortality outcomes in a single measure. Relatively underutilized in the economics literature as a metric for welfare, the use of DALYs obviates the need for monetization of health benefits. This contentious issue has been the subject of long debate with little satisfactory resolution. Instead, benefits can be quantified directly using DALYs saved, and costs per DALY saved offer a consistent way of ranking a range of

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indicated that consumption of orange-fleshed sweetpotato, high in beta-carotene, led to improvements in their vitamin A status (van Jaarsveld et al., 2005).

[2] There is a distinction between provitamin A and vitamin A: plants contain *provitamins* A such as beta carotene, which are precursors to the *vitamin* A that is formed in the liver.
[3] In the case of Brazil, the estimates refer not to the entire country, but only to one region—the northeast—where poverty and undernutrition levels are high.

alternative health interventions, be they water and sanitation projects, or biofortification, as considered here.

For many crops, biofortified varieties are yet to be developed and disseminated. Our analysis is thus *ex ante* in nature. To accommodate uncertainties inherent in any *ex ante* analysis, we consider both pessimistic and optimistic scenarios; this approach also permits a check on the robustness of the results to changes in assumptions.

II. Quantifying Micronutrient Malnutrition

The Disability-Adjusted Life Years (DALYs) Framework

The first step in assessing the cost-effectiveness of any intervention, including biofortification, is to determine the magnitude of the problem that the intervention is trying to address. One strand of literature has focused on the productivity losses that occur as a consequence of malnutrition (for example, see Horton, 1999, and Horton and Ross, 2003). Other studies have examined the impact of malnutrition on mortality outcomes, cognitive development, or child growth (for example, Gillespie, 1998; a good review of the issues is contained in Alderman et al., 2004).

An increasingly popular measure for quantifying the magnitude of ill health is the "disability-adjusted life year", first detailed by Murray and Lopez (1996). It is also important to mention the contribution of Zimmerman and Qaim (2004), who first used the DALY framework in the context of biofortification. DALYs lost enable the addition of morbidity and mortality outcomes, and are an *annual* measure of disease burden. Also, DALYs provide a way to “add up” the burden of temporary illness (such as diarrhea) with more permanent conditions (such as blindness), resulting in a single index. Thus, DALYs lost are the sum of years of life lost (YLL) and the years lived with disability (YLD). The YLL represents the numbers of years lost because of the preventable death of an individual, while the YLD represent the numbers of years spent in ill-health because of a preventable disease or condition:

$$DALYs\ lost = YLL + YLD$$

A public health intervention is expected to reduce the number of DALYs lost, and the extent of such a reduction is a measure of the benefit of the intervention. Thus YLL saved represents years of life saved because a death has been prevented and YLD saved or averted refers to years of life spent in perfect health, because a non-fatal outcome or disability has been cured or prevented.

The DALYs saved are thus a direct metric for analyzing the benefits of an intervention, and do not necessarily have to be monetized to ensure comparability across interventions. Unlike most agricultural technologies, biofortification does not lead to a shift in the supply function. Hence, changes in economic surplus are not relevant. Instead, it is the supply of dietary sources of iron (for example) that is increased, and it is the impact of this shift on public health that is captured here. DALYs saved also have the appeal of being consistent with "specific egalitarianism" whereby everyone—irrespective of income—is presumed to be entitled to a life free of ill-health. For this reason, cost-effectiveness measures expressed in terms of DALYs saved are increasingly being used in priority ranking exercises by agencies such as the World Bank and the WHO (World Bank, 1993).

The use of disability weights, ranging from zero to unity, enables the incorporation of the severity of the disability, with higher weights implying greater disability (and unity representing death). Further, since some outcomes affect only certain target groups (young children, or pregnant women, for example), disaggregation by gender and age-specific target groups is needed. Finally, since many of the adverse outcomes are permanent and may influence the remainder of an affected individual's lifespan, a conversion to an annualized measure is necessary. Thus, more formally, the DALY burden may be written as:

$$DALYs_{lost} = \sum_j T_j M_j \left(\frac{1 - e^{-rL_j}}{r} \right) + \sum_i \sum_j T_j I_{ij} D_{ij} \left(\frac{1 - e^{-rd_{ij}}}{r} \right)$$

where T_j is the total number of people in target group j,

M_j is the mortality rate associated with the given disease,

L_j is the average remaining life expectancy,

I_{ij} is the incidence rate of temporary disease i that is of interest,

D_{ij} is the corresponding disability weight,

d_{ij} is the duration of the disease (for permanent disabilities d_{ij} equals the remaining life expectancy L_j), and

r represents the discount rate that captures time preferences. That is, the use of the discount rate implies that health gains today count more than health gains in the future.

In adapting this framework to the present exercise, a few modifications to the original model have been made, as described in detail in Stein et al. (2005). First, we exclude the age-weighting term that assigns a higher weight to the disabilities of the young than to the illnesses of those who are older. This is because a form of age-weighting is already implicit in the above formula, as permanent outcomes that affect young children add up to more DALYs lost than do permanent outcomes affecting adults. Also, unlike in the original exercise, where the estimated life expectancy was interpreted as the maximum possible in a biological sense, we use country-specific figures in this paper. This can be justified on the grounds that the amelioration of a given micronutrient deficiency alone is not expected to change the average life expectancy in a country.

Of greater significance, perhaps, is the adaptation of this approach to the specific context of micronutrient malnutrition. This necessitated modifications in terms of the level of disaggregation used in determining the functional consequences of vitamin A, iron and zinc deficiencies. Expert opinion was solicited from nutritionists to detail specific outcomes that may be attributed to each of these deficiencies. In doing so, the approach was conservative. For example, adverse functional outcomes are proven only for clinical manifestations[4] of VAD, and only these clinical manifestations are incorporated in our analysis. To calculate burden of iron deficiency burden, the prevalences of moderate and severe anemia were considered, but not that of mild anemia. Also, only a percentage of all anemia cases are attributed to iron deficiency in this paper, as anemia may have multiple causes, of which insufficient iron intake is but one. Similarly, the only included outcomes are those for which there is evidence from meta-analyses. Where only an association has been noted (as, for example, in studies suggesting that VAD is associated with diarrhea, acute respiratory infection, stunting, and maternal mortality), such outcomes are excluded from the analysis. Thus, in attributing adverse disease and functional outcomes to micronutrient deficiencies, the estimates used here may be construed to constitute a lower bound.

These adaptations to the DALYs framework form the basis of the computed magnitudes of DALYs lost due to micronutrient malnutrition. The principal data sources used for the calculations are summarized in Appendix A; further details are in the country reports.

[4] Clinical manifestations include corneal scarring and problems with vision. Subclinical vitamin A deficiency is far more prevalent and insidious as it is not a disease in itself and is in a sense asymptomatic, but renders an individual more susceptible to infections.

Burden of Vitamin A Deficiency

VAD leads to vision impairment disorders, including night blindness, corneal scarring, and blindness. In addition, VAD is also implicated in increased mortality of children under 6 years of age, and in increased incidence of, and poor recovery from, measles. It has been estimated that 3% of the mortality of young children may be attributed to VAD, that 20% of corneal scarring and measles is due to VAD, and that all night blindness (both among children, and pregnant and lactating women) is due to VAD. The DALYs thus lost due to VAD are presented in Table 1.

Virtually all of the DALYs lost due to VAD, due either to mortality or morbidity, occur in children under 6 years of age, underscoring the disproportionate impact of the VAD burden on young children. The bulk (over 70%) of all DALYs lost are due to years of life lost due to premature mortality.[5]

The DALYs lost from VAD are high in African countries, where 0.4–0.8% of the population is affected. Thus, annually, 121,000 DALYs are lost to VAD in Kenya, while in Nigeria, nearly 800,000 DALYs are lost. In other words, between 0.5 and 1 percent of the national product is lost due to VAD, each year, in these countries.[6] In contrast, the magnitude of VAD is not as high in Latin America as it is in most regions of Africa. In the relatively poor northeastern region of Brazil, VAD leads to the loss of the equivalent of 0.1 percent of the national income each year. Note, once again, that these estimates are conservative because we take into account only VAD outcomes for which definitive causality has been shown in the literature.

Burden of Iron Deficiency

Iron deficiency leads to impaired physical activity (in all age groups) and impaired mental development (in children under 6 years of age). In addition, it is estimated that 5% of all maternal mortality is caused by iron deficiency. A mother's death, in turn, implies a still-born child, and deaths of her older

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[5] This explains why, for instance, the burden of VAD is higher in Uganda than in Kenya, countries with approximately similar population sizes. The number of deaths of children under 6 years of age (per 1000 live births) in Uganda (152) is higher than in Kenya (114), while life expectancies are approximately the same in the two countries.

[6] That is, had this proportion of the population been healthy, they would have been able to contribute to the national income, and the average gross national product provides an approximation of this loss to the economy.

children due to the absence of breast-feeding and the care the mother would have provided had she lived (for complete references see Stein et al., 2005). To estimate the DALY burden, we used published data on anemia prevalence. However, since not all anemia is due to iron deficiency, we assume that approximately 50% of anemia was due to insufficient dietary intake of iron (this percentage can vary by country). The percentages chosen were based on expert opinions from nutritionists.

As detailed in Table 2, in quantitative terms, the burden is, as expected, highest in the populous countries of India, Bangladesh and Brazil. Normalized for population size, the burden of iron deficiency ranges from 0.1% of the total population of the Philippines to 0.5% in Nicaragua. Much of this burden arises from disability, especially among children aged 5 years and under, who contribute 35–66% of the total toll.

These figures also illustrate the advantage of using the DALY methodology over methods that are based, for example, on mortality alone. The use of the DALY method, which can sum mortality and disability outcomes, indicates (for example) that the burden of iron deficiency is higher than that of VAD in northeast Brazil. Use of a "number of deaths caused" criterion would indicate that VAD was a far greater problem than was iron deficiency.

Burden of Zinc Deficiency

There is evidence from meta-analyses implicating zinc deficiency in adverse functional outcomes associated with diarrhea, pneumonia and stunting in children. Some cases of diarrhea and pneumonia can be fatal. Thus, nearly 20% of diarrhea, nearly 40% of pneumonia, and 4% of mortality of children under 6 years of age, can be attributed to zinc deficiency. The data in Table 3 suggests that 0.1% of the population of the Philippines, and 0.3–0.4% of the population of South Asia, suffer the consequences of zinc deficiency on an annual basis.
The bulk of the burden is contributed by infants under the age of 1 year, and most of the DALYs lost reflect mortality.

Thus the burden of micronutrient deficiencies, both in terms of the numbers of people affected, and its economic cost (even when valued at national GDPs), is extremely high.[7] The next section examines whether biofortification can lead to a substantial reduction in the burden of micronutrient malnutrition.

[7] A direct comparison with WHO estimates of the DALY burden of micronutrient deficiencies is not feasible because of differences in methodology; however, the order of magnitude of their estimates is similar to those presented here (WHO, 2006).

III. Analyzing the Reduction in Burden of Micronutrient Deficiencies

The extent to which a food-based intervention such as biofortification can help ameliorate micronutrient deficiencies depends on a number of factors. First, once plant breeders have developed biofortified varieties, these have to be adopted by farmers. Conditional on adoption, biofortified crops have to be consumed by target groups in a form that minimizes processing losses of nutrients. Finally, enhanced micronutrient intakes have to translate into improved health outcomes and result in a reduced DALY burden.

As with any new technology or public health intervention, outcomes are uncertain at each of these stages. One way to deal with this problem is to specify probability distributions and then to compute the expected value of benefits. For many of the outcomes discussed here, however, such probabilities are difficult to assign. Instead, a scenario analysis is used. We specify a range of plausible outcomes at each stage, and compute benefits under the collective best-case and worst-case scenarios. These assumptions are elaborated below. In addition, Figure 1 shows a schematic representation of the impact pathway and the various factors that condition the impact.

Coverage Rates by Region (1)

The coverage rate, or the proportion of biofortified staples in production and consumption, is a key determinant of the magnitude of impact. The more biofortified staples farmers produce, and therefore the more biofortified staples target households consume, the greater the reduction in the prevalence of insufficient intakes. The biofortification strategy is to have the micronutrient dense trait mainstreamed—so that a multiplicity of biofortified varieties are available for each crop.

In this paper, we make assumptions on likely coverage, from both producer and consumer perspectives, based on experience with the spread and diffusion of other modern plant varieties in the countries under consideration.[8] For crops where the micronutrient trait is visible, such as with plants producing high levels of provitamins A, consumer acceptance also needs to be factored in. For this reason, we assume lower coverage rates for maize, sweetpotato and cassava, than for high-mineral rice and wheat. Experience suggests that with cereals in

[8] For simplicity, we do not take into account any trade effects, or the possibility of biofortified food aid.

Asia, which has well-developed seed systems in place, coverage rates are likely to be high. As a conservative estimate, we assume a 30% coverage under a pessimistic scenario, and a 60% coverage under the optimistic scenario. In Africa, which does not have such well-developed seed systems, we use much lower coverage rates, with a pessimistic assumption of 20% and an optimistic assumption of 40% for all crops. In Latin America, coverage rates are assumed to range between 25% and 30%. In northeast Brazil, however, where coverage of new varieties of cassava has always been low, we assume 10–25% coverage for this crop (see Evenson and Gollin, 2003, for a summary of adoption data for maize, cassava and beans). Farmers in northeast Brazil typically cultivate traditional varieties and do not receive much government support for agriculture (Gonzalez et al., 2005).

Increases in micronutrient content (2)

Since biofortification is still in the research phase for most crops, the expected increases in micronutrient content are based on best-guess estimates from plant breeders, who, in turn, base their figures on germplasm screening exercises. The expected increases are typically (but not always) higher than the minimum incremental breeding targets that have been determined by nutritionists as being necessary for demonstrating health (biochemical) impacts.

Current levels of beta-carotene in widely consumed varieties of cassava, maize, and sweetpotato, are nil. For cassava and maize, breeders hope that, under a pessimistic scenario, it will be possible to breed varieties containing 10 ppm beta-carotene, and under an optimistic scenario this figure could be as high as 20 ppm (Table 4).

The case of sweetpotato is different. Breeders have already identified varieties that are high in beta-carotene content, and these are being disseminated in East and Southern Africa on a pilot basis. The average beta-carotene content of these orange-fleshed sweetpotato varieties is approximately 32 ppm. Thus, unlike the case with cassava and maize, where varieties high in beta-carotene are yet to be developed, there is a smaller degree of uncertainty about the technical parameters that underlie the DALY analysis for sweetpotato.

With minerals, the expected increase in iron content ranges between 3 and 5 ppm for milled rice, 8 and 23 ppm for wheat, and 40 and 60 ppm for beans. The increases in zinc concentration are likely to range between 11 and 22 ppm for rice, 6 and 24 ppm for wheat, and 10 and 20 ppm for beans.

It is important to note here that these increases are all expected to be achieved using conventional breeding techniques; none of the scenarios pertain to transgenic crops. Thus, for example, provitamin A-dense "golden" rice is not considered here, as conventional breeding methods cannot enhance the provitamins A content of this crop. There is no naturally-occurring genetic variation in this trait that breeders can exploit.

Consumption of Staple Foods by Target Populations (3)

Clearly, the higher the level of consumption of a given staple food (including how many people consume the staple and how frequently), the greater the impact of any given increment in micronutrient intake. Thus, with a 400 g daily intake of a given food, a 10 ppm increase in micronutrient content will translate into a 4 mg increase in micronutrient intake, whereas a 200 gram intake will translate only into a 2 mg increase.

Obtaining data on food consumption and micronutrient intakes is difficult. For example, information on food intakes, by crop, for each age range, and for gender-specific target groups, is scanty. Ideally, such consumption estimates should be based on individual-level dietary recall data. Such data sets are rarely, if ever, nationally representative. Where food composition tables and unit record data are available from dietary recall surveys, these have been used to derive micronutrient intakes. Where nationally representative data sets are available, these tend to report food consumption at the household level and not at the individual level. When we used such data, as for example in our calculations for Bangladesh and India, we used consumer equivalent units to derive food consumption at the individual level. In Latin America, we used regression techniques to identify consumer equivalence. For many countries in Africa, food consumption surveys are dated, and are based on smaller sample sizes. In these cases, therefore, we used the most recent information available, and validated these figures through qualitative surveys. Additional details are contained in individual country reports.

Table 5 details the consumption figures used in each case. For ease of presentation the Table reports data for only one target group (children under 6 years of age), but the calculations consider all other relevant target groups. Consumption ranges from approximately 100 g of sweetpotato in Uganda to about 225 g of cassava (fresh roots) in the Democratic Republic of the Congo. Consumption levels of maize in East Africa are lower, ranging from 70 g in Ethiopia to 120 g in Kenya.

For beans, consumption levels are also low, and are approximately 45–55 g per day for children under 6 years of age in Latin America. Consumption of rice, the staple food in much of Asia, is higher among children, at 120–140 g per day. The consumption levels for adults are about 2–3-fold those of children. Finally, wheat consumption among young children is about 90 g per day.

Processing Losses (4)
Processing losses between the harvest and the plate are particularly important in the case of provitamins A. For example, sun-drying, to which crops such as sweetpotato and cassava are commonly subject, can result in the complete degradation of provitamins A. Other processing techniques such as fermentation (to make *gari* in Nigeria or *injera* in Ethiopia, for example) can also influence the provitamins A content of foods eaten. Table 5 outlines the key parameters used for processing losses.

On the basis of qualitative surveys, it would appear that processing losses are the greatest in cassava in Africa, where between 70 and 90% of provitamins A may be lost during cooking (Manyong et al., 2005). In northeast Brazil, also, provitamins A losses from processing cassava into farinha are substantial, ranging between 54% and 64%. In the case of maize, methods of preparation of foods based on this cereal vary by country, and processing losses therefore vary also. Thus, in Ethiopia, processing losses may be as high as 90% if maize is used in the preparation of *injera*, while, in Kenya, processing losses during preparation of *ugali* are likely be 50%. Sweetpotato is consumed largely in boiled form, so post-harvest losses of beta-carotene are relatively low at 18–25%.

Note that there are no processing losses for rice, which is consumed in boiled form. Micronutrient content is expressed in milled form, thus milling losses are not relevant.

Dose Response (5)
Finally, the impact of any food-based intervention depends on the dose-response to increased nutrient intakes. Ideally, this would entail determining a biological relationship between enhanced micronutrient intakes and nutritional outcomes. Many such relationships are based on step functions, where the response to a nutritional supplement (that usually translates into intakes that are above the recommended dietary allowance or RDA) is measured. Theoretically, however, the relationship is a continuous one. We use an inverse hyperbolic function to capture this continuum, as proposed originally by Zimmerman and Qaim (2004), as shown in Figure 2, and elaborated by Stein et al. (2005).

Adverse health outcomes are a decreasing function of micronutrient intakes. Thus, an increase in intakes from biofortification would result in a reduction in the burden of deficiency of a magnitude given by the ratio of the areas A and A+B (Figure 2). A hyperbola which intersects the horizontal axis at the RDA value fixes this functional form as $1/x - 1/RDA$.[9]

Note that the use of this function implies that the greater the distance between current intake and the RDA, the greater the impact of a given increment in dietary intake. This is in line with well-established principles in nutrition suggesting that individuals with poor initial nutritional status show higher biological responses to an intervention than do those with better initial nutritional status.

Also important to mention is the bioavailability and absorption of the additional micronutrients that are available through the consumption of biofortified staples. For the purposes of this paper, we assumed that the diets of target populations are characterized by low bioavailability, and that this situation will prevail as diets continue to be cereal/root crop based. To compute the deficits in intakes, we used RDA values corresponding to "low bioavailability" for iron and zinc. Also, for the purposes of this paper, we used the same RDA values for all countries, to permit between-country comparisons.[10]

These various assumptions and parameters were used to measure the likely impact of biofortification in reducing the DALY burden of vitamin A, and iron and zinc deficiencies, under both pessimistic and optimistic scenarios.

Impact on VAD

As indicated in Table 6, the percentage reduction in the burden of VAD ranges between 3% and 30% in the case of cassava, and between 1% and 32% in the case of maize. In the case of sweetpotato, between 40% and 67% of the VAD burden may be eliminated through the successful dissemination of orange-fleshed varieties. The reason for the much greater impact of orange-fleshed sweetpotato

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[9] Note that ideally, the point of intersection with the horizontal axis should be a value greater than the RDA, as the RDA represents the level at which the requirements of most, but not all, individuals in the population are met. Since the requirements of 97.5% of healthy individuals would be met at the RDA, and because a higher number can be determined only somewhat arbitrarily, we used the RDA in our calculations. Note further that the use of the Estimated Average Requirement is not appropriate here, as the focus is *not* on determining prevalence rates of inadequate micronutrient intakes.

[10] For example, for countries such as the Philippines, where diets contain more meat products than in other countries considered in this study, a higher bioavailability figure may be more appropriate. Indeed, the RDA figures commonly used for this country are lower than those used here.

(OFSP) varieties is not difficult to discern. A child consuming 100 g of OFSP with 32 ppm beta-carotene would obtain nearly half the RDA of 440 Retinol Equivalents (assuming 18% loss, and a bioconversion factor of 1:12) from this one food alone. In contrast, a child consuming a much larger amount, 200 g, of cassava, with 10 ppm beta-carotene, would obtain less than 4% of the RDA of vitamin A after the 90% loss during processing is considered. Similarly, a child consuming 120 g of maize with 10 ppm beta-carotene, with 50% retention of the nutrient, would obtain only slightly more than 10% of the RDA. Note that the much higher processing losses of beta-carotene (particularly under the pessimistic scenario) and the lower consumption levels of maize in Ethiopia explain why the percentage reduction in DALYs lost, after biofortification, is lower in Ethiopia than in neighboring Kenya. Indeed, under the pessimistic scenario, there would be only a 1% reduction in the burden of VAD in Ethiopia with biofortification. In northeast Brazil, up to 20% of the burden of VAD can be eliminated through the consumption of biofortified cassava, under the optimistic scenario.

Impact on Iron Deficiency

The incremental iron expected is high with biofortified beans, even though consumption levels are low, at 50–60 g per day. This increase in iron is higher than in any of the other biofortified crops. The expected decrease in the burden of iron deficiency ranges between 3% and 22% in Central America, and between 9% and 33% in northeast Brazil.

In the case of rice, the reduction in the DALY burden of iron deficiency ranges from 4–8% under the pessimistic scenario and 11–21% under the optimistic scenario. Here, even though the expected increments are modest (certainly as compared to beans), consumption levels are much higher, being double or more those of beans. Further, the prevalence of anemia in South Asia is higher than in Central America.[11]

Impact on zinc deficiency

The reduction in the DALY burden of zinc deficiency afforded by the consumption of biofortified beans is 3–20% in Latin America. A much greater reduction in the DALY burden is seen from rice and wheat biofortification in Asia, with a 7–33% reduction using high-zinc rice in Bangladesh and a 6–37% decrease with high-zinc wheat in Pakistan. This is not surprising, given that the

[11] Note that the figures for India cited in another paper (Stein et al., 2007) are somewhat different; this is because a different methodology, using unit record data to compute a distribution of intakes, was used in calculating the reduction in DALY burden.

incremental zinc density, as well as consumption, is much higher for wheat and rice than for beans.

IV. Cost-Effectiveness of Biofortification

The figures discussed above suggest that biofortification can lead to reductions in the burden of micronutrient deficiency, even though the reductions are sometimes modest under the pessimistic scenario. The next question is how high the costs of achieving these reductions are, and how these compare with those of other interventions. As noted earlier, costs per DALY saved provide a consistent way of ranking alternative interventions.

The costs of biofortification include those of research and development, adaptive breeding, maintenance breeding, and dissemination. Investment in basic research and development is incurred in the initial years. Once promising parent lines are identified, there is a phase of adaptive breeding, where these traits are bred into popular varieties that are cultivated in target countries. This process can take up to 5 years. Once dissemination takes place, some costs are incurred annually in maintaining the high nutrient trait over time. Thus, the bulk of the investment is upfront. The key components of the costs used in this exercise are summarized in Table 7.

The research and development costs used for the cost-effectiveness exercise are derived from HarvestPlus budgets. These are apportioned to countries taking into account both plant breeders' estimates of geographical allocations, and production shares. An example may be illustrative. Breeding efforts for cassava are focused on countries both in Africa and Latin America, with equal emphasis on both. Thus, half the research and development costs are allocated to each region. Within a region, approximate production shares are used to allocate costs. Thus, of the cassava costs in Latin America, northeast Brazil accounts for 67%. Further, we do not attempt to disaggregate research development costs for iron and zinc; we use the entire crop budget in each case. While this may be tantamount to double-counting, there is no natural way to separate these costs, apart from assigning a 50% share to each mineral, as screening and breeding for enhanced plant absorption of both nutrients occur simultaneously.

Adaptive breeding costs are derived from expert opinion solicited for each country, and are country-specific. Thus, it is estimated that the adaptive breeding phase would cost between $800,000 and $1,200,000 per year, for about 5 years, for cassava, in each country. The adaptive breeding costs are calculated to be $1,600,000 per year for rice in India and $200,000 per year for rice in Bangladesh. Similarly, dissemination and maintenance breeding are country-specific and estimated using expert in-country opinions and current budget levels. Dissemination costs include not only the incremental costs for seed systems, but also those associated with nutrition education.

In all cases the approach was to consider the *incremental* costs of incorporating nutrient-dense traits into plant varieties under development. Also, we emphasize that these costs refer only to conventional breeding techniques; regulatory costs associated with transgenic crops do not apply here. Costs and benefits are discounted at 3%, a figure commonly used in the health economics literature. All calculations assume a 30-year horizon, with dissemination commencing in year 10, and ceiling adoption levels (be they under the pessimistic or optimistic scenarios) achieved in year 20.

The resulting estimates of cost per DALY saved are presented in Table 8. The World Development Report for 1993 (World Bank, 1993), which reviewed many public health interventions, suggests that interventions costing less than $150 per DALY saved are highly cost-effective—this translates into approximately $196 per DALY saved in 2004 dollars.[12], [13]

Provitamin A-Dense Cassava, Maize and Sweetpotato

In the optimistic scenario, the costs per DALY saved for provitamin A-dense staples are all less than $20 for all crops and countries, with the exception of northeast Brazil. In the pessimistic scenario, costs per DALY saved for cassava are between $124 and $137 for Africa, and greater than $1000 in northeast Brazil. With maize, biofortification would cost $113 per DALY saved in Kenya and $289 in Ethiopia (recall that this latter figure assumes only a 10% retention of beta-

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[12] To quote from the report: "Governments need to … move forward with … promising public health initiatives. Several activities stand out because they are highly cost-effective: the cost of gaining one DALY can be remarkably low—sometimes less than $25 and often between $50 and $150" (World Bank, 1993, p. 8).

[13] As an additional exercise, we also computed benefit-cost ratios, as these are commonly reported. Ratios that exceed unity are indicative of a worthwhile investment. These require benefits to be monetized; that is, a dollar value needs to be assigned to the DALYs saved. Needless to say, this valuation is problematic: if GDP per capita is used to value benefits, this tends to favor high-income countries. We use a somewhat arbitrary value of $1000 per DALY saved for all countries. The results in Appendix 9 suggest that benefit-cost ratios are all high, and well in excess of unity in all cases. The only exception is zinc in Nicaragua under the pessimistic scenario, where the value of the benefits appears too low to justify costs. The use of an alternative figure, say US$500, per DALY saved, does not affect the thrust of the results. Biofortification continues to be cost-effective. But with this lower valuation of benefits, biofortification of beans with zinc in Latin America is no longer profitable.

carotene after processing). Nevertheless, even under the pessimistic scenario, all but the northeast Brazilian and Ethiopian figures demonstrate that the intervention would be highly cost-effective.

Iron-Dense Beans, Rice and Wheat
With iron, also, costs per DALY saved are highly cost-effective under the optimistic scenario. For rice in South Asia, the costs are particularly low, at between $3–4 per DALY saved. The costs are somewhat higher in the Philippines at about $54 per DALY saved. Even under the pessimistic scenario, costs are around $18 per DALY saved using biofortified rice in South Asia. Costs of iron biofortification of wheat are also extremely low in South Asia—as little as $1 per DALY saved. With high-iron beans in Latin America, costs are between $20–65 per DALY saved under the optimistic scenario, but rise to $439 per DALY saved in the pessimistic scenario.

Zinc-Dense Beans, Rice and Wheat
Once again, in South Asia, biofortification is extremely cost-effective, with cost per DALY saved lower than $11, even under the pessimistic scenario, for both wheat and rice. Costs per DALY saved with beans in Latin America are higher, but still highly cost-effective under the optimistic scenario. It is only under the pessimistic scenario that costs per DALY saved greatly exceed $196 in Latin America.

How Does Biofortification Compare with Fortification and Supplementation?
An important question is how the costs per DALY saved with biofortification compare with those associated with other micronutrient interventions—fortification and supplementation. Until recently, the literature in this area was limited. Estimates from an influential 1994 World Bank report, which in turn were drawn from Levin et al. (1993), suggest that for vitamin A, supplementation costs approximately US$9.3 per DALY saved (in 1994 dollars, corresponding to about $12 in 2004 terms). Fortification costs are about $29 per DALY saved, equal to almost $37 dollars in 2004 terms. For iron, the corresponding figures in 2004 dollars are $17 per DALY saved by supplementation and $6 per DALY saved by fortification. [14]

More recent evidence is emerging from the WHO-CHOICES project, which has put together these costs for broad groups of countries. Table 10 summarizes this information, which suggests, for instance, that vitamin A fortification and

[14] These figures are converted from the $12.80 per DALY saved for supplementation and $4.40 per DALY saved for fortification reported by Levin et al. (1993).

supplementation costs between $22 and $90 per DALY saved, assuming a 50% coverage rate. Iron intervention costs $40–70 per DALY saved in Asia; costs in Latin America are much higher. Costs for higher coverage rates (such as 80% or 95%) are typically higher.

Methodological differences preclude a direct comparison of these figures with those for biofortification. For example, costs for the alternative interventions relate primarily to deployment and not to research and development costs. Also, the WHO figures have a 10-year time horizon, unlike the 30-year time period used here. Nevertheless, with these caveats in mind, biofortification appears relatively more cost-effective than other interventions in most regions under the optimistic scenario (where coverage rates are comparable to those of other interventions, at 40–60%). The significant exceptions are in northeast Brazil for vitamin A, and in Latin America for zinc. In both cases, fortification is more cost-effective.

V. Discussion and Conclusions

This paper presents, for the first time, evidence from a large number of countries and crops that biofortification can significantly impact the burden of micronutrient malnutrition and that it does so in a cost-effective manner. Most costs per DALY saved for biofortification fall in the 'highly' cost-effective category. Also, in all but one case, benefit-cost ratios of biofortification exceed unity. That is, benefits far outweigh costs. These results are encouraging for biofortification, especially since the underlying cost assumptions err on the high side—for example with the 'double counting' of costs for the two minerals in a given crop.

Depending on the context and the scenario, and subject to the caveats noted in the text, biofortification appears to be more cost-effective than supplementation or fortification. In South Asia, biofortification enjoys a clear advantage. This is reasonable, given both that the populations in South Asian countries are largely rural, and that seed distribution systems function relatively well in this part of the world. This is largely true in Africa as well. Relative to other interventions, the only instances where biofortification may not enjoy a comparative advantage are in Latin America.

Our analysis considers the impact of consumption of a single biofortified staple. In reality, diets often consist of more than one staple (cassava and beans, rice and wheat, or maize and beans, for example).In these situations, the consumption of more than one biofortified staple is likely to have an enhanced impact (for example, if vitamin A improves iron absorption). Capturing the impact of an intervention with multiple micronutrients—and their interactions—in the analysis is an area for further research.

The challenges to implementing biofortification should not be underestimated. Attention will need to be paid to community awareness, dissemination, and behavior change communication, features common to health and nutrition programs, but foreign to most previous agricultural interventions. These aspects of biofortification will be especially important when the micronutrient trait is visible, as is the case with color changes bestowed by high provitamin A content. The results of this analysis suggest that the pay offs from thus linking agriculture and public health approaches, which often function independently, can be very high. In summary, our analysis suggests that biofortification is a viable strategy, and an important complement to the existing set of interventions to combat micronutrient malnutrition.

Figure 1. Schematic of steps involved in calculating ex ante impact.

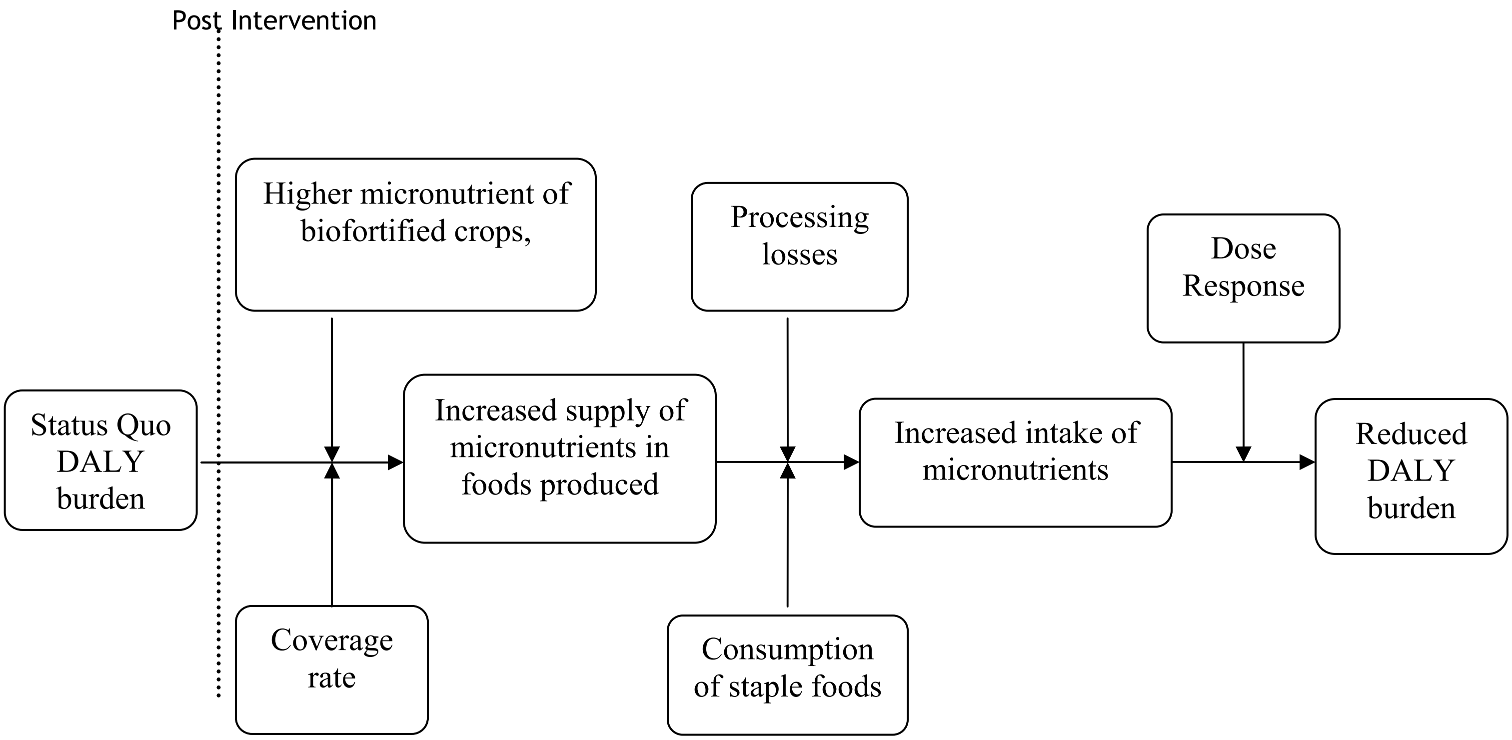
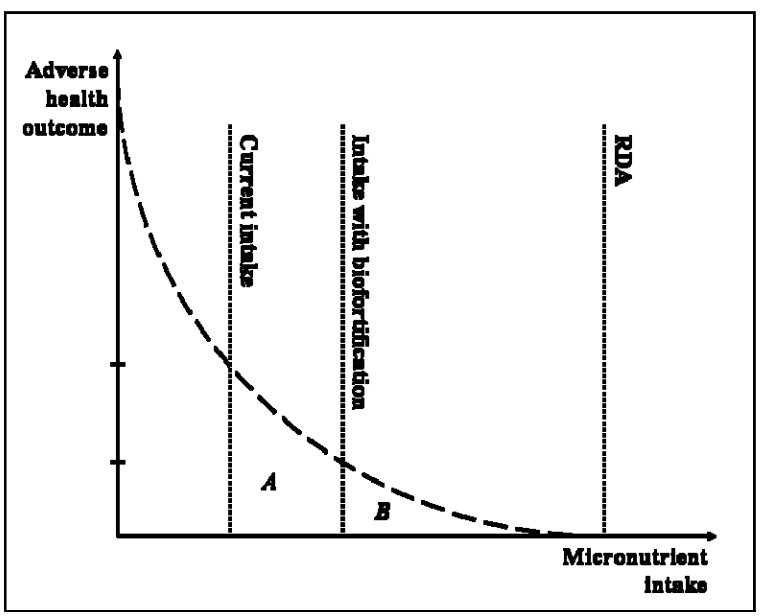


Figure 2. Modeling the impact of increased intakes on health outcomes.



Source: Zimmerman and Qaim (2004).

Table 1: Burden of Vitamin A Deficiency, by Country.

Country	Total DALYs lost (in millions)	YLL as percent of DALYs lost	DALYs as percent of population
Ethiopia	0.39	73	0.5
Kenya	0.12	71	0.4
Uganda	0.16	73	0.6
D.R. Congo	0.39	98	0.8
Nigeria	0.80	98	0.6
Northeast Brazil	0.05	90	0.1

Source: Calculations based on data sources summarized in Appendix A.

Table 2: Burden of Iron Deficiency, by Country.

Country	Total DALYs lost (in millions)	Percent share of YLDs of children under 5 to total DALYs	DALYs as percent of population
Bangladesh	0.49	66	0.4
India	4.00	66	0.4
Pakistan	0.92	50	0.6
Philippines	0.07	37	0.1
Northeast Brazil	0.20	66	0.4
Honduras	0.02	41	0.3
Nicaragua	0.03	53	0.5

Source: Calculations based on data sources summarized in Appendix A.

Table 3: Burden of Zinc Deficiency, by Country.

Country	Total DALYs lost (in millions)	Percent share of DALYs of children under 1 in total DALYs	DALYs as percent of population
Bangladesh	0.44	71	0.4
India	2.83	70	0.3
Pakistan	0.64	77	0.4
Philippines	0.08	71	0.1
Northeast Brazil	0.10	66	0.2
Honduras	0.01	70	0.2
Nicaragua	0.01	74	0.2

Source: Calculations based on data sources summarized in Appendix A.

Table 4: Micronutrient Content of Biofortified Crops under Pessimistic and Optimistic Scenarios (parts per million)

Crop	Vitamin A	Iron	Zinc
Cassava*			
Pessimistic	10		
Optimistic	20		
Maize*			
Pessimistic	10		
Optimistic	20		
Sweetpotato*	32		
Beans			
Baseline		40	30
Pessimistic		80	40
Optimistic		100	50
Rice			
Baseline		3	13
Pessimistic		6	24
Optimistic		8	35
Wheat			
Baseline		38	31
Pessimistic		46	37
Optimistic		61	55

*Note: These crops currently have no beta-carotene; the baseline is thus zero.
Source: HarvestPlus plant breeders.

Table 5: Average Staple Crop Intakes by Children Under 6 Years of Age, and Assumptions on Processing Losses, by Nutrient and Country.

Nutrient, crop and country/region	Consumption among children <6 years (grams per day)	Processing losses Pessimistic (%)	Processing losses Optimistic (%)
Provitamins A			
Cassava (fresh weight)			
DR of Congo	225	90	70
Nigeria	176	90	70
Northeast Brazil	122	64	54
Maize			
Ethiopia	71	90	50
Kenya	120	50	40
Sweetpotato			
Uganda	96	25	18
Iron and Zinc			
Beans			
Honduras	56	5	0
Nicaragua	45	5	0
Northeast Brazil	57	5	0
Rice			
Bangladesh	140	0	0
India	118	0	0
Philippines	121	0	0
Wheat			
India	87	20	10
Pakistan	69	20	10

Source: Calculations are based on data sources summarized in Appendix A.

Table 6: Reduction in DALY Burden of Micronutrient Deficiency through Biofortification Under Pessimistic and Optimistic Scenarios, by Nutrient and Country (percent).

Vitamin A

	Pessimistic	Optimistic
Cassava		
DR Congo	3	32
Nigeria	3	28
NE Brazil	4	19
Maize		
Ethiopia	1	17
Kenya	8	32
Sweetpotato		
Uganda	38	64
Iron		
Beans		
Honduras	4	22
Nicaragua	3	16
Northeast Brazil	9	36
Rice		
Bangladesh	8	21
India	5	15
Philippines	4	11
Wheat		
India	7	39
Pakistan	6	28[15]
Zinc		
Beans		
Honduras	3	15
Nicaragua	2	11
Northeast Brazil	5	20
Rice		
Bangladesh	17	33
India	20	56
Philippines	13	43
Wheat		
India	9	48
Pakistan	5	33

Source: Our calculations.

[15] In Pakistan, average iron intakes for young children are believed to be sufficient; hence the DALY calculations refer only to the impact of improved intakes among older children and adults.

Table 7: Key Biofortification Costs, by Category, Nutrient and Country ($ per year).

Crop (nutrient) and country/region	R&D costs (years 1-8)	Adaptive breeding costs (years 5-10) high assumption	REU costs (years 11-18) high assumption	Maintenance Breeding costs (years 11-30) high assumption
Cassava (provitamins A)				
DR Congo	248,588	800,000	959,560	200,000
Nigeria	302,813	1,200,000	2,663,375	185,000
Northeast Brazil	386,604	1,000,000	1,468,425	100,000
Maize (provitamins A)				
Ethiopia	313,970	600,000	545,250	60,000
Kenya	301,436	600,000	474,000	100,000
Sweetpotato (provitamins A)				
Uganda	317,068	736,000	1,882,283	147,200
Beans (iron and zinc)				
Honduras	222,662	140,000	41,213	20,000
Nicaragua	229,036	140,000	98,175	20,000
Northeast Brazil	382,374	1,400,000	1,468,425	200,000
Rice (iron and zinc)				
Bangladesh	300,076	200,000	285,090	100,000
India	779,100	1,600,000	1,950,000	200,000
Philippines	247,225	100,000	101,400	200,000
Wheat (iron and zinc)				
India	748,550	1,600,000	1,150,000	200,000
Pakistan	483,300	1,200,000	575,000	200,000

Source: HarvestPlus budgets, and country-specific expert opinion.

Table 8: Cost per DALY Saved with Biofortification, Under Pessimistic and Optimistic Scenarios, by Nutrient and Country.

Nutrient and country/region	**Cost per DALY saved ($)**	
Vitamin A	Pessimistic	Optimistic
Cassava		
DR Congo	123.80	7.60
Nigeria	137.40	7.90
Northeast Brazil	1006.46	126.50
Maize		
Ethiopia	289.00	10.70
Kenya	112.70	18.40
Sweetpotato		
Uganda	29.50	8.60
Iron		
Beans		
Honduras	401.60	65.50
Nicaragua	439.20	64.50
Northeast Brazil	133.90	20.00
Rice		
Bangladesh	17.90	4.80
India	16.70	3.40
Philippines	234.40	54.50
Wheat		
India	9.80	1.10
Pakistan	13.00	3.10
Zinc		
Beans		
Honduras	1494.30	160.20
Nicaragua	5939.60	576.40
Northeast Brazil	1899.70	152.60
Rice		
Bangladesh	6.80	1.50
India	5.70	1.30
Philippines	55.00	12.20
Wheat		
India	10.60	1.30
Pakistan	18.40	2.40

Source: Our calculations.

Table 9: Benefit-Cost Ratios of Biofortification, Under Pessimistic and Optimistic Scenarios, by Nutrient and Country.

Nutrient and country/region	Benefit-cost ratios	
Vitamin A	Pessimistic	Optimistic
Cassava		
DR Congo	4	66
Nigeria	4	63
NE Brazil	<1	4
Maize		
Ethiopia	2	47
Kenya	4	27
Sweetpotato		
Uganda	17	58
Iron		
Beans		
Honduras	1	6
Nicaragua	1	8
Northeast Brazil	4	20
Rice		
Bangladesh	56	207
India	60	298
Philippines	2	9
Wheat		
India	51	453
Pakistan	77	326
Zinc		
Beans		
Honduras	<1	2
Nicaragua	<1	1
Northeast Brazil	<1	3
Rice		
Bangladesh	158	674
India	88	383
Philippines	9	41
Wheat		
India	47	393
Pakistan	54	420

Source: Our calculations.

Table 10: Costs per DALY Saved, for Fortification and Supplementation, by Region and Nutrient, Assuming 50% Coverage ($).

Region	Vitamin A		Iron		Zinc	
	Supplementation	Fortification	Supplementation	Fortification	Supplementation	Fortification
Asia	55	22	70	43	7	2
Latin America	90	43	487	215	79	27
Africa	52	41	30	27	120	82

Sources: Vitamin A and zinc figures are from http://www.who.int/choice/results/en/. Asia refers SEARD, Latin America to AMRB and Africa to AFRE WHO-CHOICE regional definitions. Iron figures are from Baltussen et al (2004). Regional definitions are as above, except for Africa, where the iron figures pertain to AFRD.

Appendix A: Data Sources for Key Country-Specific Variables.

Variable: Country	Staple food consumption	Micronutrient intakes	Prevalence of micronutrient deficiencies and related adverse functional outcomes
ASIA			
Bangladesh	B1, B2	B1, B2, B3	B3, B4, B5, B6, B7, I2
India	I1	I1	I2, I3
Pakistan	Pa1	Pa2	Pa2
Philippines	Ph1	Ph1	Ph2
AFRICA			
DR Congo	DRC1, DRC2	DRC3	DRC4, DRC5
Ethiopia	E1	E2	E3, E4
Kenya	K1, K2	K3, K4	K5, K6,K7,K8
Nigeria	Ng1	Ng1, Ng2	Ng3, Ng4
Uganda	U1	U2	U2, U3
LATIN AMERICA			
Northeast Brazil	Bz1	Bz1, Bz2	Bz2, Bz3
Honduras	H1	H1	H2, H3
Nicaragua	Nc1	Nc1	Nc2, Nc3

Key

Bangladesh

B1. Bangladesh Bureau of Statistics, Household Income-Expenditure Survey, 2000.

B2. IFPRI household level data from "Bangladesh: Commercial Vegetable and Polyculture Fish Production—Their Impacts on Income, Household Resource Allocation, and Nutrition 1996-1997"

B3. Institute of Food and Nutrition Science, Bangladesh, Bangladesh Institute of Development Studies.

B4. Bangladesh Bureau of Statistics (BBS). 2002. *Child Nutrition Survey of Bangladesh* 2000, Dhaka: BBS.

B5. Helen Keller International (HKI) and Institute of Public Health and Nutrition (IPHN). 1999. *Iron Deficiency Anemia Throughout the Lifecycle in Rural Bangladesh,* Dhaka: HKI.

B6. National Institute of Population Research and Training (NIPORT). 2001. *Bangladesh Demographic and Health Survey 1999-2000,* Dhaka: NIPORT, Mitra and Associates and Maryland: ORC Macro.

B7. Institute of Food and Nutrition Science, Bangladesh, Bangladesh Institute of Development Studies

India

I1. Calculated from National Sample Survey Organization, 2000. Consumer Expenditure Survey, 55th round: 1999-2000

I2. International Institute of Population Sciences and ORC Macro, 2000. *National Family Health Survey (NFHS-2) 1998-99: India*, Mumbai: IIPS and ORC Macro.

I3. National Institute of Nutrition, 2003. *Prevalence of micronutrient deficiencies*, NNMB Technical Report 22: Hyderabad.

Pakistan

Pa1. Multimicronutrient Intervention Study, 2000-2004;

Pa2. Pakistan National Nutrition Survey, 2001-2002. Multimicronutrient Intervention Study, 2000-2004.

Philippines

Ph1. Food and Nutrition Research Institute, *National Nutrition Surveys*

Ph2. National Nutrition Council, 2004. *The Nutrition situation in the Philippines, 1990-2003*.

DR Congo

DRC1. Bureau d'Etude, d'Aménagement et Urbanisme (BEAU) et FAO. 1986. Consommation de produits vivriers à Kinshasa et dans les grandes villes du Zaïre. Kinshasa. Republic of Zaire.

DRC2. Goosens, F., B. Minten, and E. Tollens. 1994. Nourir Kinshasa: Une analyse du systeme d'approvisionnement local d'une metropole africaine (Feeding Kinshasa: An analysis of the local supply system of an African metropolis). L'Harmata. Paris. 397

DRC3. Mbemba F. & Remacle J. 1992: Inventaire et composition chimiques des aliments et des denrées alimentaires traditionnels du Kwango-Kwilu au Zaïre, Kinshasa.

DRC4. RDC/UNICEF. 2002. Enquête nationale sur la situation des enfants et des femmes en RDC. MICS2/2001, rapport d'analyse. Kinshasa, RDC

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E2. Assumed to be the same as that in Kenya

E3. MOH. 2004. Health and Health Related Indicators. Planning and Programming Department of the Ministry of Health, Addis Ababa, Ethiopia. 60 p

E4. Wolde- Gebriel, Zewdie, Tosheme Demeke and Clive West. 1991. Xerophthalmia in Ethiopia: a nationwide ophthalmological, biochemical and anthropometric survey. *European Journal of Clinical Nutrition*. 45: 469-478

Kenya

K1. Central Bureau of Statistics and Human Resources and Social Services Departments Ministry of Finance and Planning, *Welfare Monitoring Survey 3, 2000.*

K2. Government of Kenya, and UNICEF. 1999. *Anaemia and status of iron, vitamin A and zinc in Kenya. A report of the National Micronutrient Survey*. Nairobi, Kenya: Government of Kenya and UNICEF.

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K6. Ministry of Health. 2002. *Evaluation of Kenya's 2002 Supplemental and Routine Measles Immunization Activities*. Nairobi, Kenya: Ministry of Health.

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Ng2. Oguntona, E.B. and Akinyele, I.O. 1995. Nutrient composition of commonly eaten foods in Nigeria. Food Basket Foundation publication series. Ibadan, Nigeria

Ng3. Maziya-Dixon, B., I.O. Akinyele, E.B. Oguntona, S. Nokoe, R.A. Sanusi, and E. Harris. 2004. Nigeria Food Consumption and Nutrition Survey, 2001-2003. Summary. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Ng4. Nigeria Ministry of Health. 1999. The Nigeria Demographic and Health Survey (NDHS). Abuja. Nigeria

Uganda

U1. National average, based on food available for consumption (from production data)

U2. Kawuma, M. and Sserunjogi L. Kamuli Blindness and Vitamin A Deficiency Survey. Ministry of Health, Tech. Report Series 1 No 1 December 1992

U3. Uganda Bureau of Statistics and ORC Macro, 2001. Uganda Demographic and Health Survey 2000-2001, UBOS and ORC Macro, Calverton.

NE Brazil

Bz1. Calculated from Living Standards Measurement Study data

Bz2. Regional databases of the Pan American Health Organization (PAHO), Iron Deficiency Project Advisory Service (IDPAS), Micronutrient Initiative

Bz3. ORC Macro: Brazil Demographic and Health Survey 1996

Honduras

H1. Calculated from unpublished data at IFPRI

H2. Instituto Nacional de Estadistica (Honduras)

H3. Regional databases of the Pan American Health Organization (PAHO), Iron Deficiency Project Advisory Service (IDPAS), Micronutrient Initiative

Nicaragua

Nc1. Living Standards Measurement Study data

Nc2 Regional databases of the Pan American Health Organization (PAHO), Iron Deficiency Project Advisory Service (IDPAS), Micronutrient Initiative

Nc3. Ministry of Health, Government of Nicaragua

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