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How Cost-Effective is Biofortification in Combating Micronutrient Malnutrition? An *Ex ante* Assessment

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This paper is dedicated to the memory of Erika Meng, a valued friend and colleague.

Summary. — Biofortification is increasingly seen as an additional tool to combat micronutrient malnutrition. This paper estimates the costs and potential benefits of biofortification of globally important staple food crops with provitamin A, iron, and zinc for twelve countries in Africa, Asia, and Latin America. Using a modification of the Disability-Adjusted Life Years framework we conclude that overall, the intervention can make a significant impact on the burden of micronutrient deficiencies in the developing world in a highly cost-effective manner. Results differ by crop, micronutrient, and country; and major reasons underlying these differences are identified to inform policy.

Key words — biofortification, micronutrient malnutrition, cost-effectiveness, DALYs

1. MICRONUTRIENT MALNUTRITION AND THE POTENTIAL OF BIOFORTIFICATION

Micronutrient malnutrition has increasingly taken center stage in policy discussions on food security. It is recognized that food security refers not merely to adequate energy intakes, but also to ensuring sufficient intakes of essential micronutrients. Vitamin A, iron, and zinc are considered to be deficient in diets in developing countries. Estimates of numbers of people affected by micronutrient malnutrition are high,

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Table 1. *Burden of micronutrient malnutrition, by country (millions of DALYs lost each year)*

	Target crop and nutrient	Vitamin A	Iron	Zinc
Bangladesh	Rice, iron and zinc		0.49	0.44
Brazil (Northeast)	Cassava, provitamin A	0.05		
Democratic Republic of Congo	Cassava, provitamin A	0.39		
Ethiopia	Maize, provitamin A	0.39		
Honduras	Beans, Iron and zinc		0.02	0.01
India	Rice and wheat, iron and zinc		4.00	2.83
Kenya	Maize, provitamin A	0.12		
Nicaragua	Beans, iron and zinc		0.03	0.01
Nigeria	Cassava, provitamin A	0.80		
Pakistan	Wheat, iron and zinc		0.92	0.64
Philippines	Rice, iron and zinc		0.07	0.08
Uganda	Sweet potato, provitamin A	0.16		

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

with up to 5 billion people suffering from iron deficiency and about a quarter of all pre-school children (about 130 million) suffering from vitamin A deficiency (United Nations, 2005, p. 14, 19). The fraction of developing-country populations at risk of inadequate zinc intake is estimated to be 25–33% (Hotz & Brown, 2004).

While ensuring access to a diversified diet is the most sustainable solution for micronutrient deficiency, it is not an immediately achievable solution in many developing countries as poor people lack the purchasing power to afford a diversified diet. Current public health interventions to address micronutrient malnutrition include fortification and supplementation. Fortification is a food-based commercial approach requiring the physical addition of specific micronutrients to food products during processing. Fortification largely targets urban populations and requires a viable processing industry, as well as government and/or industrial support to ensure quality control and distribution. To the extent that processed foods may not reach the large populations living in rural areas, these populations benefit to a lesser degree from this public health intervention. Supplementation is another intervention under which, for example, vitamin A capsules are administered to pre-school children twice a year. However, few governments have the resources to fund such programs on a continuing basis.

Biofortification, which is the development and dissemination of micronutrient-enhanced staple crop varieties, is a complementary food-based intervention. The objective of biofortification is to enhance the micronutrient content of staple food crops—which predominate in the diets of the poor—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 home production and consumption of staple food crops are significant, and where consumption of marketed surplus is most likely to remain within the community. Repeat purchases are not necessary; a one-time investment in dissemination of nutrient-dense varieties becomes self-sustaining.

Recent efficacy studies conducted with human subjects under a controlled setting demonstrate that biofortification can have an impact on public health. For example, there is evidence from a 9-month feeding trial in the Philippines that regular consumption of rice containing an additional 2.6 parts per million (ppm) of iron was efficacious in improving body iron stores among iron-deficient women (Haas *et al.*, 2005). Similarly, a feeding trial with school children in South Africa showed that consumption of orange sweet potato, high in beta-carotene, led to improvements in their vitamin A status (van Jaarsveld *et al.*, 2005). A similar result was also obtained in a community setting in Mozambique (Low *et al.*, 2007).

The success of biofortification depends on many factors, including the degree to which biofortified staples are adopted by farmers and accepted by consumers, and its cost-effectiveness. Recognizing this, the present study estimates the cost-effectiveness of biofortification for several crops and countries in the developing world. Because for most crops, biofortified varieties with the requisite increases in micronutrient levels are yet to be developed, the analysis is *ex ante* in nature. Also, given the inherent uncertainties in any *ex ante* analysis, we consider both pessimistic and optimistic scenarios; this permits a check on the robustness of the results to changes in assumptions.

The micronutrients we consider are provitamin A[1] in cassava, maize, and sweet potato, and iron and zinc in beans, rice, and wheat. To capture variation in the specifics of cropping patterns and diets, we include three East African countries, one Central African country, and one West African country in our analysis for cassava, maize, and sweet potato, as these dominate the diets in the selected countries. For example, Kenya and Ethiopia in East Africa have maize-based diets, while cassava is a primary staple food in Nigeria and the Democratic Republic of Congo. Similarly, the potential for rice and wheat is assessed for three South Asian countries and the Philippines, as are the prospects for cassava in Brazil[2] and beans in two other Latin American countries. Other factors determining the choice of these countries (12 in all, see Table 1) include the magnitude of micronutrient deficiencies in these countries, and the availability of reliable data on food and micronutrient intakes.

2. QUANTIFYING MICRONUTRIENT MALNUTRITION USING DISABILITY-ADJUSTED LIFE YEARS

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. Instead, benefits can be quantified directly using DALYs averted, and costs per DALY averted offer a consistent way of ranking a range of alternative interventions that affect health outcomes. Other approaches have attempted to quantify productivity losses and impaired cognitive development that result as a consequence of micronutrient