THE ECONOMICS OF PLANT BREEDING AS AN AGRICULTURAL STRATEGY FOR REDUCING MICRONUTRIENT MALNUTRITION

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Summary

The combining of benefits for human nutrition and agricultural productivity, resulting from breeding staple food crops which are more efficient in the uptake of trace minerals from the soil and which load more trace minerals into their seeds, results in extremely high *ex ante* estimates of benefit-costs ratios for investments in agricultural research in this area. This finding derives from the confluence of several complementary factors:

- Rates of micronutrient malnutrition are high in developing countries, as are the consequent costs to human welfare and economic productivity.
- High trace mineral density in seeds produces more viable and vigorous seedlings in the next generation and efficiency in the uptake of trace minerals improves disease resistance, agronomic characteristics which improve plant nutrition and productivity in trace mineral “deficient” soils.
- A significant percentage of the soils in which staple foods are grown are “deficient” in these trace minerals, which has kept crop yields low. In

general, these soils in fact contain high amounts of trace minerals. However, because of chemical binding to other compounds, these trace minerals are "unavailable" to staple crop varieties presently used.

- Adoption and spread of nutritionally-improved varieties by farmers can rely on profit incentives, either because of agronomic advantages on trace mineral deficient soils or incorporation of nutritional improvements in the most profitable varieties being released.
- As staple foods are eaten in large quantities every day by the malnourished poor, delivery of enriched staple foods (fortified by the plants themselves during growth) can rely on existing consumer behavior.
- Benefits to relatively small investments in agricultural research may be disseminated widely, potentially accruing to hundreds of millions of people and millions of acres of crop lands.
- Breeding advances are derived from initial, fixed costs, with low recurring costs, and thus tend to be highly sustainable as long as an effective domestic agricultural research infrastructure is maintained.

1. Introduction

Taken together, mineral and vitamin deficiencies affect a greater number of people in the world than does protein-energy malnutrition. As trace minerals are important not only for human nutrition, but for plant nutrition as well, plant breeding holds great promise for making a significant, low-cost, and sustainable contribution to reducing micronutrient, particularly mineral deficiencies in humans, and may have important spin-off effects for increasing farm productivity in developing countries in a way that is environmentally-beneficial.

An underlying cause and fundamental constraint to the solution of the micronutrient problem is that non-staple foods, particularly animal products, tend to be the foods richest in bioavailable micronutrients, which the poor in many developing countries desire to eat, but cannot afford. Their diets consist mostly of staple foods, primarily cereals; in fact, per capita direct consumption of staple foods in the aggregate varies little by income level. For the poor, these staple foods are already primary sources of what micronutrients they are able to consume, particularly minerals.

The plant breeding strategy seeks to take advantage of this existing human consumption behavior by developing staple food crops that, in some sense, fortify themselves, for example, breeding staple crop genotypes that load high amounts of minerals and vitamins into their seeds.The strategy of breeding for mineral and vitamin enhancement of staple foods has several complementary advantages. No behavioral change on the part of consumers is required. Indeed the strategy seeks to take advantage of the consistent daily consumption of large amounts of food staples by all family members. Nevertheless, any intervention to improve micronutrient status targets women and children because of their elevated needs for minerals and vitamins.

Mineral-packed seeds sell themselves to farmers because, as recent research has shown, these trace minerals are essential in helping plants resist disease. More seedlings survive and initial growth is more rapid. Ultimately, yields are higher, particularly in trace mineral "deficient" soils in arid regions. As roots extend more deeply into the soil, and so can tap more subsoil moisture and nutrients, the mineral-efficient varieties are more drought resistant and so require less irrigation. Due to their more efficient uptake of existing trace minerals, these varieties require fewer chemical inputs. Thus, the new seeds can also be expected to be environmentally beneficial. After the onetime investment is made to develop seeds that fortify themselves, there are low recurrent costs — costs for supplementation, fortification, and nutrition education remain constant year after year.

2. Micronutrient Malnutrition: Extent, Costs, Alternative Interventions

As dismaying as the consequences of famines are, it is only relatively recently that nutritionists working in developing countries have been able to demonstrate conclusively that many more children and adults, particularly women in their childbearing years, suffer during times of relative economic and political stability due to a lack of essential vitamins and minerals in their diets, than due to a lack of calories. As people for the most part are not aware that their diets are lacking in these trace nutrients and hence do not associate these deficiencies with listlessness, poor eyesight, impaired cognitive development and physical growth, and more severe bouts of illness (sometimes leading to death), this general problem of poor dietary quality has been dubbed "hidden hunger".

For example, it has been known for several decades that severe vitamin A deficiency can lead to blindness in children. Surveys conducted by the World Health Organization in the 1960s established vitamin A-deficiency-related blindness as a serious public health problem in a large number of developing countries. In the early 1970s, through experiments conducted in India and Indonesia, it was discovered that such blindness could be safely prevented by administering capsules or syrup containing massive doses of vitamin A once every six months (vitamin A, which is fat soluble, is stored in the liver).

Later, in an observational study, researchers based at Johns Hopkins University and working in Indonesia, showed that there was a correlation between progressively serious eye damage in children and increased child mortality rates. This was empirical information that was consistent with a long-suspected link between vitamin A deficiency and the high child mortality rates common in developing countries. To test this hypothesis more rigorously, 10 000 Indonesian children were given high-dose vitamin A capsules (VAC) and 10 000 children were given a placebo (a low percentage of these children, no more than one percent, had clinically visible eye damage). Mortality rates were found to be 34 percent lower for children who received VAC (see *Global Importance of Vitamin A Deficiency in Humans and its Relationship to Malnutrition*).

Such a large reduction in mortality was so startling and unexpected only a decade and a half ago that eventually it was necessary to conduct seven similar experiments in other countries in Africa and Asia (with similar results on average) before there was widespread acceptance in the international nutrition community by the late 1980s that widespread distribution of VAC could significantly reduce child mortality and should be given high priority for government intervention. These dramatic, new research findings in the area of vitamin A deficiency, in turn, helped to focus more attention and spur further research related to other micronutrient deficiencies, in particular iron and iodine deficiencies.

Statistics now compiled by the World Health Organization (WHO) on a regular basis on the extent of micronutrient deficiencies demonstrate the enormous magnitude of the problem. WHO reported in 1994 that 3.1 million pre-school age children had eye damage due to a vitamin A deficiency and another 227.5 million are sub-clinically affected at a severe or moderate level. Annually, an estimated 250 000 and 500 000 pre-school children go blind from this deficiency and about two-thirds of these children die within months of going blind.

It is estimated that globally, 3.5 billion people are iron-deficient. The problem for women and children is more severe because of their greater physiological need for iron. In developing countries, more than 40 percent of non-pregnant women and 50 percent of pregnant women have anemia. Of the approximately 500 000 maternal deaths that occur each year due to childbirth, mostly in developing countries, anemia is the major contributor or sole cause in 20 to 40 percent of such deaths. Iron deficiencies during childhood and adolescence impair physical growth and mental development and learning capacity. In adults, iron deficiency reduces the capacity to undertake physical labor (see *Iron Nutrition in Man: Global Perspectives on Iron Deficiency and Malnutrition*).

Iodine deficiency is the greatest single cause of preventable brain damage and mental retardation in the world. More than 2 billion people live in iodine deficient environments. Deficiencies in iodine that occur in late infancy and childhood have been shown to cause mental retardation, delayed motor development, growth failure and stunting, neuromuscular disorders, and speech and hearing defects. Even mild iodine deficiency has been reported to reduce intelligence quotients by 10-15 points.

Deficiencies in several other micronutrients, zinc in particular, may be similarly widespread with equally serious consequences for health. However, as there are no specific indicators to screen for deficiencies in these nutrients (other than a positive health response to supplementation), they have not received as much attention (see *Global Importance of Zinc Deficiency in Humans: its Relation to Malnutrition and Strategies for its Prevention*).

Three worldwide conferences sponsored by a number of international and bilateral agencies held in the late 1980s and the early 1990s spurred the international community and individual countrys governments to greater action. Substantially more money was made available for combating micronutrient deficiencies. Ambitious goals were set for the virtual elimination of vitamin A and iodine deficiency and the significant reduction in iron deficiency in developing countries by the year 2000.

Initially, there was some optimism that supplementation programs could solve much of the micronutrient deficiency problem quickly and easily, but this turned out not be to the case. Universal supplementation is an expensive and logistically difficult task.

Targeted supplementation involves the costs and associated logistical problems of identifying those in need. In both regimes, compliance can be a problem. For example, in the case of iron deficiency, although capsules need to be taken frequently, there is some risk of toxicity if they are taken too often.

Fortification is an alternative approach that has been used successfully in developed countries. However, since markets for foods are not well developed in the developing world, identifying appropriate food "vehicles," processed by a relatively small number of manufacturers, is sometimes impossible. Where appropriate "vehicles" are available and fortification statutes have been put into law, there have been problems with ensuring that manufacturers comply with these laws.

To provide some sense of the magnitude of the recurrent annual costs involved in fortification and supplementation, a lower-bound estimate of the cost of iron supplementation is $2.65 per person per year, when all administrative costs are taken into account. A lower bound estimate for iron fortification is 10 cents per person per year.

In a populous country such as India (total population 1 billion) there may be as many as 32 million anemic pregnant women in any given year. These numbers imply that treating only half of those women in any one year through a well-targeted supplementation program could cost as much as $43 million per year. Iron fortification of half the entire population could cost $50 million per year.

Notwithstanding these cost estimates, the benefits of properly managed interventions can be quite significant. A World Bank document estimates that deficiencies of just vitamin A, iodine, and iron alone could waste as much as five percent of gross domestic product (GDP) in developing countries, but addressing them comprehensively and sustainably would cost less than one-third of a percent of GDP. Nevertheless, it is difficult, through existing strategies, for governments and international agencies to mobilize resources of the magnitude implied above, which are needed to address such a pervasive problem.

Supplementation and fortification have the advantage that their successful implementation does not require a substantial change in individual behavior, but these interventions treat the symptoms rather than the underlying causes of micronutrient deficiencies. This has led many to advocate the use of "food-based" interventions, such as nutrition education and promotion of home vegetable gardens, which address the underlying cause-poor quality diets, and importantly, provide a range of nutrients in the diet. This approach, however, involves motivating substantial changes in human behavior, which can be both expensive and difficult.

Given the high payoffs to reducing micronutrient deficiencies, and the initial disappointment with supplementation and fortification programs as ways to solve the problem quickly and completely, several nutrition education and home gardening projects have been implemented. Only in a few cases has their effectiveness been carefully evaluated. There is now some consensus that in any one country a mix of several approaches is required, for example, supplementation, fortification, promotion of breastfeeding, nutrition education, home gardening, and disease reduction, but there is little agreement on how best to allocate scarce funds among these strategies in specific settings.

In summary, nutritionists perceive a great opportunity, for which new and compelling scientific evidence is rapidly accumulating, for improving nutrition and health in developing countries by reducing micronutrient malnutrition. Nevertheless, there is some frustration at not having well-developed tools appropriate for the context of a developing country, with which to solve the problem of micronutrient deficiencies quickly at reasonable cost.

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Biographical Sketch

Howarth E. Bouis is a senior research fellow at the International Food Policy Research Institute in Washington, D.C. where he has worked since 1982. He currently directs the micronutrients project of the Consultative Group on International Agricultural Research, a collaborative effort among a number of research centers to breed for micronutrient-dense staple food crops and to understand how programs and policies can be modified to improve the quality of diets among the poor in developing countries. His past research has concentrated on understanding how economic factors affect food demand and nutrition outcomes, particularly in Asia. He received his B.A. in economics from Stanford University and his M.A. and Ph.D. from Stanford University's Food Research Institute.