# BIOFORTIFIED CROPS FOR IMPROVED HUMAN NUTRITION

## A CHALLENGE
## PROGRAM PROPOSAL PRESENTED BY

INTERNATIONAL CENTER FOR TROPICAL AGRICULTURE (CIAT)
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE (IFPRI)

ON BEHALF OF AN INTERNATIONAL CONSORTIUM OF COLLABORATIVE PARTNERS

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## Executive Summary

### A New Paradigm for Agriculture

The goal of the proposed program is to improve the health of poor people by breeding staple food crops that are rich in micronutrients, a process referred to here as "biofortification." The Biofortification Challenge Program seeks to bring the full potential of agricultural and nutrition science to bear on the persistent problem of micronutrient malnutrition. Micronutrient malnutrition, primarily the result of diets poor in bioavailable vitamins and minerals, affects more than half of the world's population, especially women and preschool children. The costs of these deficiencies in terms of lives lost, forgone economic growth, and poor quality of life are staggering. To reach the Millennium Development Goal's target of halving the proportion of undernourished people by 2015, new technologies and approaches are needed to help address the problem.

### An International, Interdisciplinary Collaborative Effort

Activities will be undertaken by an international alliance of Future Harvest centers, national agricultural research and extension systems (NARES), departments of human nutrition and plant science at universities in developing and developed countries, advanced research institutes (ARIs) with expertise in micronutrients in plants and animals, and genomics, nongovernmental organizations (NGOs), farmers' organizations in developing countries, and private-sector partnerships. The Future Harvest Centers involved in the Biofortification Challenge Program are world renowned for their plant breeding expertise and extensive germplasm banks, strong ties to national agricultural extension programs, and links to the human nutrition community. Thus, they are well placed to coordinate the proposed activities. However, close collaboration with institutions that offer complementary scientific expertise, skills, and experience not found within the Future Harvest Centers, is critical to a successful outcome. To achieve the goals and objectives of the Program, new ways of working together, both within the CGIAR system and with external partners, are needed. Such arrangements are possible under the Challenge Program framework but not under a Systemwide Initiative.

### Advantages of Biofortification

The biofortification strategy seeks to take advantage of the consistent daily consumption of large amounts of food staples by all family members, including women and children who are most at risk for micronutrient malnutrition. As a consequence of the predominance of food staples in the diets of the poor, this strategy implicitly targets low-income households.

After the one-time investment is made to develop seeds that fortify themselves, recurrent costs are low and germplasm may be shared internationally. It is this multiplier aspect of plant breeding across time and distance that makes it so cost-effective.

Once in place, the biofortified crop system is highly sustainable. Nutritionally improved varieties will continue to be grown and consumed year after year, even if government attention and international funding for micronutrient issues fades.

Biofortification provides a truly feasible means of reaching malnourished populations in relatively remote rural areas, delivering naturally fortified foods to people with limited access commercially-marketed fortified foods, which are more readily available in urban areas. Biofortification and commercial fortification, therefore, are highly complementary.

Breeding for higher trace mineral density in seeds will not incur a yield penalty. In fact, biofortification may have important spinoff effects for increasing farm productivity in developing countries in an environmentally-beneficial way. Mineral-packed seeds sell themselves to farmers because, as recent research has shown, these trace minerals are essential in helping plants resist disease and other environmental stresses. More seedlings survive and initial growth is more rapid. Ultimately, yields are higher, particularly in trace mineral "deficient" soils in arid regions.

## Feasibility Studies Support An Expanded Global Research Program

Since 1995, scientists from four Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR) and partner organizations have been evaluating the feasibility of using modern breeding techniques to produce new varieties of staple crops with high zinc, iron, and beta-carotene content. Results to date suggest that biofortification is highly feasible. For most crops, scientists will be able to increase micronutrient densities through conventional breeding by a multiple of two for iron and zinc and by higher multiples for beta-carotene (vitamin A). At the end of this six-year pilot study, scientists agree that the biofortification strategy is feasible[1] but that an expanded global research program is necessary to have the desired impact.

The Biofortification Program will focus on three micronutrients that are widely recognized by the World Health Organization (WHO) as limiting: iron, zinc, and vitamin A. Full-time breeding programs are proposed for six staple foods for which feasibility studies have already been completed and which are consumed by the majority of the world's poor in Africa, Asia, and Latin America: rice, wheat, maize, cassava, sweet potatoes, and common beans. Pre-breeding feasibility studies are proposed for eleven additional staples: bananas, barley, cowpeas, groundnuts, lentils, millet, pigeon peas, plantains, potatoes, sorghum, and yams.

Breeding, dissemination, and impact activities, outlined in the ten-year plan, are focused on development of conventionally-bred crops. No activities involving the release of nutritionally-improved transgenic crops to farmers and consumers are proposed here or are included in proposal budgets for the initial four years for which funding is being requested. Research and development activities with respect to transgenic crops are confined to agricultural research centers and research laboratories. Transgenic methods hold great promise for improving the nutrient content of staple foods and speeding up the breeding process over what can be achieved using conventional methods. High social benefit and lower risk applications, such as the incorporation of desirable traits from crop wild relatives, will be favored throughout the program whenever transgenic methods are considered.

## Program Governance and Oversight

A governance and oversight mechanism, led by CIAT and IFPRI, is intended to facilitate these more complex collaborative arrangements. A joint venture or similar agreement will clearly define how CIAT and IFPRI work together and how they will manage the Program. An external, inter-disciplinary Program Advisory Committee (PAC) of experts from developing and developed countries is being formed to recommend strategic research priorities, oversee project progress, and implement a transparent competitive grants process. Although the PAC will not be a legal entity, it will have the authority of the CIAT and IFPRI Boards to undertake its mandate as an independent body. A program leader, a breeding and biotechnology coordinator, and a nutrition coordinator, comprising a three-person Program Management Team (PMT), will coordinate the overall project and assist the PAC in carrying out its responsibilities. Program activities will be organized by crop, under crop team leaders responsible for coordination. Regional and cross-crop coordination will be facilitated by the PMT and the relevant crop team leaders.

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[1] Proceedings of an international conference that reviewed the findings of the CGIAR Micronutrients Project are published in the *Food and Nutrition Bulletin*, Vol. 21, No. 4, December 2000.

# 1. Extent and Underlying Cause of Micronutrient Malnutrition

Billions of people in developing countries suffer from an insidious form of hunger known as micronutrient malnutrition. Even mild levels of micronutrient malnutrition may damage cognitive development, lower disease resistance in children, and reduce the likelihood that mothers survive childbirth. The costs of these deficiencies in terms of lives lost and poor quality of life are staggering (Table 1).

***Table 1: Extent and consequences of micronutrient malnutrition***

| Deficiency | Prevalence in developing countries | Groups most affected | Consequences |
|---|---|---|---|
| Iron | 2 billion people | All, but especially women and children | Reduced cognitive ability; childbirth complications; reduced physical capacity and productivity |
| Vitamin A | 250 million children | Children and pregnant women | Increased child and maternal mortality; blindness |
| Zinc | May be as widespread as iron deficiency | Women and children | Illness from infectious diseases, poor child growth; pregnancy and childbirth complications; reduced birth weight |

**Source: ACC/SCN 2000.**

It is important to identify who the malnourished are, where they are located, and what they eat in order to develop an effective strategy to reduce micronutrient malnutrition. We know, for example, that they are mostly women and children whose nutritional requirements are highest due to reproduction and rapid growth, who reside in developing countries where dietary quality is often poor.

## 1.1 Extent of Micronutrient Malnutrition

More than 2 billion people worldwide are iron-deficient (ACC/SCN 2000; Stoltzfus 2001). Iron deficiency anemia is by far the most common micronutrient deficiency in the world. Iron deficiency during childhood and adolescence impairs physical growth, mental development, and learning capacity. In adults, iron deficiency anemia reduces the capacity to do physical labor. Iron deficiency increases the risk of women dying during delivery or in the postpartum period.

Table 2 shows estimates of prevalence of anemia by region for 1980. Though these figures also represent anemia brought on by infections, illness, and genetic factors, iron deficiency is by far the most important cause of anemia. Prevalence among children exceeds 50 percent in South and Southeast Asia, where 1.8 billion out of the approximately 4.5 billion people in developing countries live.[2] Prevalence is equally high in Africa, although the number of persons affected is smaller. Prevalence is consistently highest for pregnant women and consistently lowest for adult males. Table 3 suggests a lack of progress in reducing the prevalence of anemia over the past two to three decades, a lack of progress that is consistent across regions.

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[2] Published information on micronutrient deficiencies that is disaggregated by region is difficult to find because data are missing for several countries in any region, and, for countries where data are available, the cross-country time point comparisons may vary widely. It is not thought that indicated prevalences have changed dramatically since 1980. However, it is advantageous to present the data by region so that prevalence estimates can be matched (see Tables 5 and 6) with regional estimates of increases in nutrient intakes that could be accomplished through biofortification.

*Table 2: Prevalence of anemia among children in the world, 1980*

| | % of children with anemia | |
|---|---|---|
| | 0–4 years | 5–12 years |
| North America | 8 | 13 |
| Europe | 14 | 5 |
| Oceania | 18 | 15 |
| East Asia[a] | 20 | 22 |
| Africa | 56 | 49 |
| South and Southeast Asia | 56 | 50 |
| Latin America | 26 | 26 |
| Developed regions | 12 | 7 |
| Developing regions[a] | 51 | 46 |
| World | **43** | **37** |

**Source: DeMaeyer and Adiels-Tegman 1985.**

[a] Excluding China; regions are selected according to United Nations criteria.

*Table 3: Trends in prevalence of anemia among women*

| | Pregnant women | | Nonpregnant women | |
|---|---|---|---|---|
| Region | Average for 1975–1997 | 1995 | Average for 1975–1997 | 1995 |
| South Asia | 59.7 | 53.9 | 56.0 | 53.4 |
| Southeast Asia | 52.1 | 52.7 | 44.7 | 42.5 |
| Middle America and Caribbean | 38.0 | 34.8 | 28.3 | 27.6 |
| South America | 34.0 | 27.2 | 22.8 | 25.0 |
| Sub-Saharan Africa | 46.4 | 48.5 | 40.8 | 36.0 |
| Near East and Northern Africa | 37.7 | 34.1 | 25.4 | 24.3 |
| China | 30.3 | n.a. | 23.2 | n.a. |
| Pacific Islands | 20.8 | n.a. | 33.6 | n.a. |

**Source: Mason et al. 2001.**

n.a. = not available.

Zinc deficiencies have equally serious consequences for health. For example, meta-analyses of recent randomized controlled trials show that zinc supplementation can reduce morbidity from a number of common childhood infections, especially diarrhea, pneumonia, and possibly malaria, by one-third (Bhutta et al. 1999, 2000; Black 1998; Roy et al. 1999; Shankar et al. 2000). In addition, zinc deficiency is an important cause of stunting (Brown and Wuehler 2000; Roy et al. 1999; Umeta et al. 2000).

Billions of people are also ***at risk for*** zinc deficiency (Table 4). As for anemia, prevalence is highest for South and Southeast Asia and Africa. Because there is no widely accepted method for measuring of zinc deficiency, no estimates are available of numbers of people who are zinc deficient.

Globally, approximately 3 million preschool-age children have visible eye damage owing to vitamin A deficiency. Annually, an estimated 250,000 to 500,000 preschool children go blind from this deficiency, and about two-thirds of these children die within months of going blind. Even more importantly, the last two decades have brought an awareness that vitamin A is essential for immune function. Estimates of the prevalence of subclinical vitamin A deficiency range between 100 million and 250 million for preschool

*Table 4: Estimated population at risk of low zinc intake, by region*

| Region | Population (millions) | Percentage of population at risk of low zinc intake |
|---|---|---|
| Asia | 3,063 | 61 |
| South Asia | 1,297 | 95 |
| Southeast Asia | 504 | 71 |
| China | 1,262 | 21 |
| Africa and Eastern Mediterranean | 923 | 70 |
| Sub-Saharan Africa | 581 | 68 |
| North Africa/Eastern Mediterranean | 342 | 74 |
| Latin America/Caribbean | 498 | 46 |
| **Developing countries** | **4,484** | **61** |
| USA/Canada | 305 | 1 |
| Western Europe | 457 | 8 |
| Eastern Europe | 413 | 13 |
| Western Pacific | 223 | 19 |
| **Developed countries** | **1,398** | **10** |
| **All regions** | **5,882** | **49** |

**Source: Modified from Brown and Wuehler 2000.**

children. People with subclinical vitamin A deficiency more often experience anemia, impaired linear growth (Villamor et al. 2000), and morbidity from common childhood infections such as respiratory and diarrheal diseases (Sommer and West 1996), measles (West 2000), and malaria (Shankar et al. 1999). Most importantly, a number of randomized controlled trials in developing countries have shown that administration of vitamin A capsules among infants and preschool children helps reduce mortality rates from all causes by 23 percent (Beaton et al. 1993, Sommer and West 1996), and that administration of capsules with vitamin A and beta-carotene among women during childbearing years can reduce maternal mortality related to pregnancy by 40 percent and 49 percent, respectively.

Prevalence of vitamin A deficiencies by region is available only for preschool children. Again, similar to iron and zinc, prevalence is highest in South and Southeast Asia and Sub-Saharan Africa (Table 5).

*Table 5: Vitamin A deficiency in preschool children, 1995*

|  | Serum retinol <0.70 μmol/L |  |
|---|---|---|
| Region | Prevalence (%) | No. (mllions) |
| South and Southeast Asia | 35.6 | 59.5 |
| East Asia and Pacific | 18.2 | 29.6 |
| Latin American and Caribbean | 19.6 | 10.2 |
| Eastern and Southern Africa | 37.1 | 18.6 |
| Western and Central Africa | 33.5 | 17.4 |
| Middle East and Northern Africa | 9.8 | 4.2 |
| **Total** | **26.5** | **139.5** |

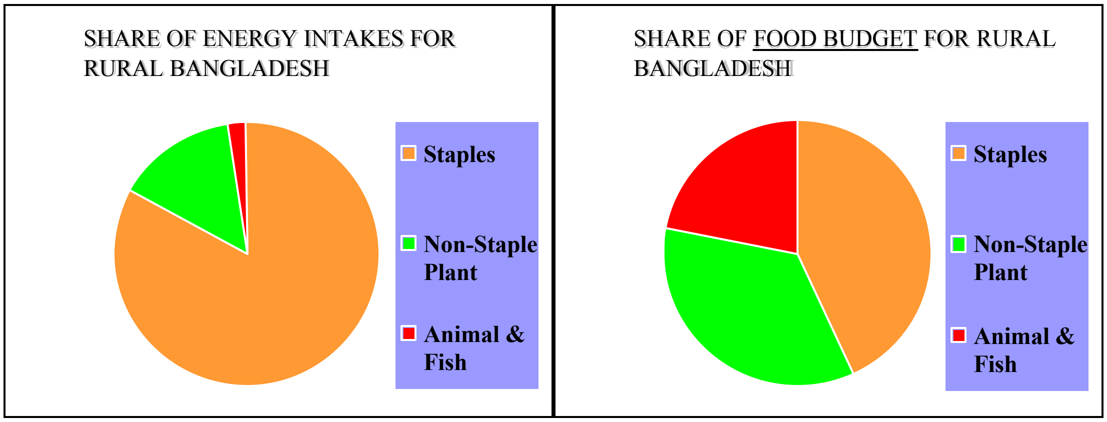
**Source: Mason et al. 2001.**

### 1.2 Underlying Cause of Micronutrient Malnutrition

The primary underlying cause of micronutrient malnutrition is poor quality diets, characterized by high intakes of food staples, but low consumption of animal and fish products, fruits, lentils, and vegetables, which are rich sources of bioavailable minerals and vitamins. As such, most of the malnourished are those who cannot afford to purchase high-quality, micronutrient-rich foods or who cannot obtain these foods from their own production.

The data shown in Figure 1 for rural Bangladesh are typical of diets and food expenditures for those who suffer from micronutrient malnutrition. Staple foods (overwhelmingly rice in this example) account for 80 percent of total per capita energy intakes. Animal and fish products are dense sources of bioavailable micronutrients that the poor wish to eat but cannot afford in large quantities. They account for 25 percent of total food expenditures but only 3 percent of total energy. Nonstaple plant foods such as fruits, vegetables, and lentils are also rich sources of vitamins and minerals. Together, nonstaple plant foods and animal and fish products account for only 20 percent of total energy intakes but 60 percent of food expenditures.

***Figure 1: Shares of energy intake and food budget for rural Bangladesh***



**Source: Bouis et al. 1998.**

What is perhaps most alarming, however, is the upward trend in nonstaple food prices. Cereal prices have fallen by 40 percent since the early 1970s. The Green Revolution can rightly take credit for its crucial contribution to this tremendous achievement. Falling cereal prices have not only led to increased food security in terms of energy, but also allowed greater purchases of nonstaples by freeing up cash. Unfortunately, however, the rate of production of nonstaple foods (e.g. fruits, vegetables, lentils) has not kept pace with demand, so that these micronutrient-rich food sources have become increasingly expensive for the poor.

## 2. Challenge Program Scope and Objectives

The ultimate goal of the biofortification strategy is to reduce mortality and morbidity rates related to micronutrient malnutrition and to increase food security, productivity, and the quality of life for poor populations of developing countries by breeding staple crops that provide, at low cost, improved levels of bioavailable micronutrients in a fashion sustainable over time. Developing plant breeding tools, crossing, testing various lines for nutritional effects, eventual dissemination of nutritionally improved varieties, and measuring their effectiveness in reducing malnutrition, indeed putting in place a new paradigm for agriculture and nutrition—is a process that will take a decade. Some intermediate outputs, however, can be made available in a 3- to 5-year time period.

Funding is being sought for a 4-year project that is part of a 10-year plan. At the end of 4 years, it will be possible to evaluate progress and the viability of further investments in the 10-year plan. The 10-year plan is described below, and outputs of the first 4-year project are identified within that plan.

The primary objectives of the 10-year plan are to:

- Select and breed nutritionally improved varieties of six major staple food crops with superior agronomic properties that make them attractive to farmers to grow;
- Demonstrate convincingly in the short to medium term the nutritional efficacy of the biofortification strategy;
- Develop efficient, accelerated mechanisms for testing materials on farms, including in areas among the most nutritionally disadvantaged, in order to identify varieties with superior agronomic, socioeconomic, and farmer-acceptable traits;
- Undertake activities to promote the adoption and dissemination of these varieties efficiently and rapidly in selected developing countries in Africa, Asia, and Latin America among the nutritionally disadvantaged; and
- Measure the nutritional and other impacts of these nutritionally improved varieties in community-based studies where these varieties have been adopted.

Complementary objectives are to:

- Initiate prebreeding studies to determine the feasibility of undertaking full-scale breeding programs for an additional eleven food staple crops;
- Understand better how dietary factors determine the bioavailability of micronutrients in malnourished populations in developing countries, especially interactions among micronutrients, anti-nutrients such as phytates, promoter compounds, and physiological status; and
- Inform decisionmakers in developing countries about cost-effective strategies to reduce micronutrient malnutrition through food-based approaches and policies to improve dietary quality among the poor.

Staple food crops under the project are classified into two groups[3]:

- Phase 1 crops, for which the knowledge base already exists to breed for improved micronutritional quality: wheat, maize, rice, sweet potatoes, common beans, and cassava; and
- Phase 2 crops, for which the knowledge base must be established: sorghum, millet, groundnuts, pigeon peas, lentils, barley, cowpeas, yams, potatoes, bananas, and plantains.

The primary target micronutrient deficiencies are iron, zinc, and vitamin A.

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[3] A planning workshop was held at CIAT headquarters in March 2001, with support from the Micronutrient Initiative/International Development Research Centre (IDRC), to identify geographic, breeding, and nutritional priorities and coordinate the process of activity planning for this proposed project. See the discussion in Appendix 2.

Delivery of improved, biofortified varieties to end-users will be assured through an alliance of international centers, NARES, ARIs, NGOs, and farmers' organizations and the use of participatory breeding techniques. As already stated, the biofortification breeding strategy is envisioned as a complement to other successful ongoing approaches, including supplementation and fortification.

### 2.1 Why a Challenge Program?

The Biofortification Challenge Program pushes the boundaries of agricultural research beyond the traditional limits of food security and sustainability and makes direct linkages with the human health and nutrition sectors. By making a formal connection between what people grow and consume and how healthy they are as a result, the program marries the often separate agendas of the international nutrition and agricultural research communities in the context of working concertedly to address a specific problem of global concern: micronutrient malnutrition.

This linkage of agricultural research and human health goals raises the profile of the international agricultural research system and gives new relevance to the often unheralded work being done throughout the CGIAR-supported Future Harvest centers and our partners in the developing and developed world. Building on a solid foundation of research results, the program will develop, deploy, and measure the nutritional impact of micronutrient-improved varieties of staple crops consumed by the poorest of the poor in Africa, Asia, and Latin America.

Activities will be undertaken by an international alliance of Future Harvest Centers, national agricultural research and extension systems (NARES), departments of human nutrition and plant science at universities in developing and developed countries, advanced research institutes (ARIs) with expertise in micronutrients in plants and animals, and genomics, nongovernmental organizations (NGOs), farmers' organizations in developing countries, and private-sector partnerships. The Future Harvest Centers involved in the Biofortification Challenge Program are world renowned for their plant breeding expertise and extensive germplasm banks, strong ties to national agricultural extension programs, and links to the human nutrition community. Thus, they are well placed to coordinate the proposed activities. However, close collaboration with institutions that offer complementary scientific expertise, skills, and experience not found within the Future Harvest Centers is critical to a successful outcome. To achieve the goals and objectives of the Program, new ways of working together, both within the CGIAR system and with external partners, are needed. Such arrangements are possible under the Challenge Program framework but not under a Systemwide Initiative.

There are significant advantages to working together in a coordinated fashion, under the rubric of a challenge program:

- Program success depends critically on the alignment of objectives and the coordinated efforts of institutions with diverse disciplinary perspectives, experience, and skills.

- These multiple partnerships, many formed with nontraditional collaborators of the CGIAR system, require strong central coordination to avoid loss of program focus.

- Interdisciplinary communication within single crop activities and common experiences across these crop activities will stimulate fresh insights and discovery of novel solutions.

- Standardization of methodologies (such as sample analyses) will lead to greater acceptance and applicability of results.

- Program-coordinated work in nutritional genomics, identification of breeding objectives, and other core research applicable across crops or nutrients will avoid duplication of efforts and result in cost savings.

### Box 1: Pathways through which biofortification can contribute to the Millennium Development Goals

| Goals and Indicators | | How Biofortification Can Contribute |
|---|---|---|
| Goal 4 | Reduce child mortality<br>•Under-five mortality rate<br>•Infant mortality rate | Improved micronutrient status has been shown to reduce under-five mortality and morbidity; infant mortality rates may be benefited from improved micronutrient status of mothers during pregnancy. |
| Goal 5 | Improve maternal health<br>•Maternal mortality ratio | Improved micronutrient status has been shown to reduce mortality and morbidity. |
| Goal 1 | Eradicate extreme poverty and hunger<br>•Proportion of population below $1 a day<br>•Poverty gap ratio (*incidence x depth of poverty*)<br>•Share of poorest quintile in national consumption<br>•Prevalence of underweight in children (under five years of age)<br>•Proportion of population below minimum level of dietary energy consumption | Improved micronutrient status has been shown to improve work productivity, mental and psychomotor performance, and appetite, and to promote faster growth. Biofortification targets the rural poor, in particular, who consume large amounts of food staples and little else. |
| Goal 2 | Achieve universal primary education<br>•Net enrollment ratio in primary education<br>•Proportion of pupils starting grade 1 who reach grade 5<br>•Literacy rate of 15-to-24-year-olds | Improved micronutrient status has been shown to improve cognitive and psychomotor abilities. Children who do well in school are more likely to want to stay in school and their parents are more likely to support their education. |
| Goal 6 | Combat HIV/AIDS, malaria, and other diseases<br>•HIV prevalence among 15- to 24-year-old pregnant women<br>•Number of children orphaned by HIV/AIDS<br>•Prevalence and death rates associated with malaria<br>•Prevalence and death rates associated with tuberculosis. | The severity, mortality from, and perhaps incidence of HIV-AIDS, malaria, tuberculosis and other diseases are exacerbated by poor micronutrient status. |
| Goal 7 | Ensure environmental sustainability<br>•Change in land area covered by forest<br>•Proportion of population with access to secure tenure [rural areas] | When topsoil dries, roots in the dry soil zone (which are easiest to fertilize) are largely deactivated and the plant must rely on deep roots for further nutrition. Roots of plant genotypes that are efficient in mobilizing surrounding, external trace minerals, are not only more disease resistant, but also better able to penetrate deficient **subsoils,** and so make use of the moisture and minerals contained in subsoils. This reduces the need for fertilizers and improves drought tolerance.<br>In addition, fewer herbicides and pesticides would have to be used because micronutrient-efficient genotypes should have greater resistance to plant pathogens.<br>These characteristics benefit those whose soils are deficient in trace minerals on rainfed land and who are thus among the poorest farmers. |

- Consolidation of the main advocacy, fund-raising, communications, and other administrative burdens will permit the individual partners to focus on the core research, development, deployment, and impact analysis activities.

- Attraction of new sources of funding is best handled through centralized coordination.

The program will heighten the profile of the CGIAR system as an important world body addressing pressing global concerns.

## 3. Biofortification: A New Tool to Reduce Micronutrient Malnutrition

Modern agriculture has had reasonable success in meeting the energy needs of developing countries. In the past 40 years, agricultural research in developing countries has met Malthus' challenge by placing increased cereal production at its center. However, agriculture must now focus on a new paradigm that will not only produce more food, but bring us better quality food as well.[4]

By producing staple foods whose edible portions are more dense in bioavailable minerals and vitamins, a process referred to here as "biofortification," scientists can provide farmers with crop varieties that naturally reduce anemia, cognitive impairment, and other nutritionally related health problems in hundreds of millions of people. Biofortification can provide an additional instrument in the fight to reduce micronutrient malnutrition, one that uses food as a mechanism to improve human health.

The CGIAR Biofortification Challenge Program will focus on improving the nutritional content of the staple foods poor people already eat, providing a comparatively inexpensive, cost-effective, sustainable, long-term means of delivering micronutrients to the poor. This approach will not only lower the number of severely malnourished people who require treatment by complementary interventions, but also will help maintain an improved nutritional status. Moreover, biofortification provides a feasible means of reaching malnourished populations, especially in rural areas, with limited access to supplements or commercially marketed fortified foods.

Unlike the continual financial outlays required for traditional supplementation and fortification programs, a one-time investment in breeding-based solutions can yield micronutrient-rich plants for farmers to grow around the world for years to come. It is this multiplier aspect of biofortification across time and distance that makes it so cost-effective.

### 3.1 The Potential Impact of Biofortification on Micronutrient Malnutrition

No single type of intervention can by itself solve the micronutrient malnutrition problem. A comprehensive strategy involving multiple types of interventions adapted to conditions in specific countries and regions is required. The final, permanent solution to micronutrient malnutrition in developing countries is a substantial improvement in dietary quality—higher consumption of pulses, fruits, vegetables, fish, and animal products, which the poor already desire but cannot presently afford. Meanwhile, breeding staple foods that are dense in minerals and vitamins provides a low-cost, sustainable strategy for reducing levels of micronutrient malnutrition. Biofortification complements existing strategies and has its own unique "niche," as conditioned by the comparative advantages outlined above and technical characteristics, most importantly the level of the "dose" that biofortification can be expected

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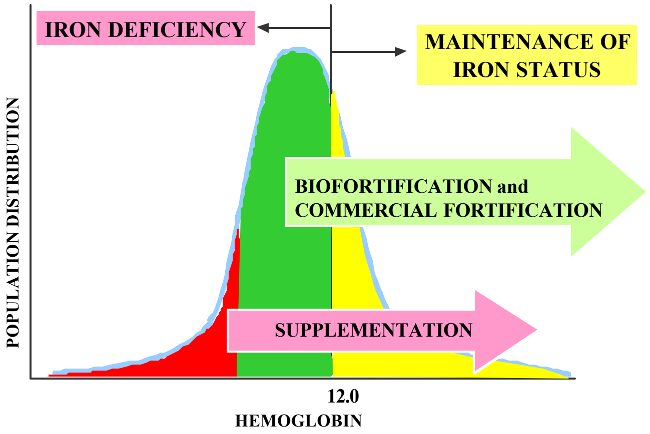
[4] An important part of the overall solution is to improve the productivity of a long list of nonstaple food crops. Because of the large number of foods involved, achieving this goal requires a very large investment, the dimensions of which are not addressed here.

to deliver. Biofortified crops do not need to provide the entire recommended daily allowance (RDA) to be effective in substantially reducing micronutrient deficiencies.

On any given day, biofortified staple foods cannot deliver as high a level of minerals and vitamins as supplements or industrially fortified foods, but they can help to bring millions over the threshold from malnourishment to micronutrient sufficiency. This potential is shown schematically in Figure 2, in which a high percentage of the iron-deficient population is shown to be relatively mildly deficient. For those who are severely deficient, supplements (the highest-cost intervention) are required.

Commercial fortification and biofortification (lower-cost, lower-"dose" strategies) then are highly complementary, in at least two ways, in treating the bulk of the iron-deficient population. First, there is a time dimension. Commercial fortification is a proven intervention and already being implemented. If the activities under the Biofortification Challenge Program proceed successfully, gradually those being reached by biofortified crops will reduce the need for commercial fortification. Second, there is a geographic dimension. Biofortification will reach rural populations most effectively, and commercial fortification will reach urban populations most effectively.

***Figure 2: Biofortification improves status for those less deficient and maintains status for all at low cost***



### *3.1.1 Potential to Reduce Iron and Zinc Deficiency*

Poor consumers in developing countries acquire roughly one-half of their total iron intake (and a higher percentage of zinc intake) from staple foods. Results from germplasm screening suggest that the iron and zinc content of staple foods can be doubled through conventional breeding. This result, in turn, implies that iron and zinc intakes in poor people's diets can be increased by 50 percent. This should result in an appreciable improvement in nutrition and health even for those whose intakes remain below recommended daily intakes.[5]

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[5] There are concerns that iron interventions might induce iron overload in some individuals (toxicity). For most individuals, homeostatic mechanisms increase non-heme iron (that found in plants) absorption when iron stores and iron status are low and reduce iron absorption as iron stores and iron status improve. In a consensus statement (UNICEF/UNU/WHO/MI 1999), an expert group concluded that "iron overload disorders and haemochromatosis are rare, even in those populations of European origin most susceptible to them"(sic). The expert group recommended that "the use of fortification and supplementation as public health interventions for preventing and

Table 6 provides conservative estimates of the amounts of ***iron*** that may be added through biofortification to diets for selected food staples for the indicated subregions. These ***minimum*** increments are based on average levels of consumption of these food staples (data available from the Food and Agriculture Organization of the United Nations) and conservative estimates of the extent to which conventional breeding might increase iron content in the consumed portions of these staple foods (Gregorio et al. 2000; Beebe et al. 2000; Monasterio et al. 2000, Banziger et al. 2000; Chavez et al. 2000).[6]

***Table 6: Estimated increments in iron intakes due to biofortification***

| | **Iron increment (mg/day)** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Region/subregion** | **Rice** | **Wheat** | **Maize** | **Beans** | **Sorghum** | **Millet** | **Total** |
| **Latin America** | **0.7** | **1.7** | **1.2** | **0.9** | **0.0** | **0.0** | **3.6** |
| Central America | 0.2 | 1.3 | 3.1 | 1.0 | 0.1 | 0.0 | 4.7 |
| Caribbean | 0.9 | 1.5 | 0.3 | 0.4 | 0.1 | 0.0 | 2.8 |
| South America | 0.8 | 1.8 | 0.6 | 0.8 | 0 | 0.0 | 3.2 |
| **Africa/Near East Asia** | **0.5** | **2.7** | **0.9** | **0.2** | **0.6** | **0.4** | **5.1** |
| North, Northwest Africa | 0.4 | 5.2 | 0.8 | 0.1 | 0.8 | 0.1 | 7.4 |
| Near East Asia | 0.5 | 5.7 | 0.2 | 0.1 | 0.1 | 0.0 | 6.5 |
| Western Africa | 0.7 | 0.3 | 0.8 | 0.0 | 1.4 | 1.3 | 4.6 |
| Central Africa | 0.2 | 0.4 | 0.7 | 0.4 | 0.4 | 0.2 | 1.8 |
| Eastern Africa | 0.4 | 0.4 | 1.8 | 0.6 | 0.3 | 0.2 | 3.0 |
| Southern Africa | 0.2 | 2.1 | 2.7 | 0.2 | 0.3 | 0.1 | 5.4 |
| **Asia** | **2.3** | **2.1** | **0.3** | **0.2** | **0.2** | **0.2** | **5.1** |
| South Asia | 2.0 | 2.4 | 0.2 | 0.3 | 0.4 | 0.3 | 5.2 |
| Southeast Asia | 3.5 | 0.5 | 0.4 | 0.2 | 0.0 | 0.0 | 4.4 |

Note: Calculated increments are the result of multiplying the average consumption levels of the indicated food crops (FAO database) times the assumed increment (milligrams/kilogram [mg/kg], or parts per million [ppm]), after milling and cooking, over presently consumed varieties that could be obtained through plant breeding. The following are the assumed increments: rice, 9 ppm; wheat, 16 ppm; maize, 11 ppm; beans, 32 ppm; sorghum, 18 ppm; millet, 18 ppm.

Note from Table 6 that with the exception of the heavy maize-eating populations of some subregions in Latin America and Africa, iron intakes are estimated to be increased by 4-6 milligrams of iron per day. Conservatively, based on the only study available linking diets and hemoglobin levels for a developing-

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controlling iron deficiency should not be constrained" (sic). It is safe to assume that the same conclusions apply to biofortification. For an authoritative and comprehensive review of toxicity issues see Gillespie (1998).

No adverse effects other than carotenodermia (a harmless yellow coloration of the skin) have been reported from very high consumption of beta-carotene or other carotenoids in foods. Beta-carotene is used therapeutically, at extremely high doses (approximately 180 mg per day), for the treatment of erythropoietic protoporphyria, a photosensitivity disorder. No toxic side effects have been observed at these doses. There is no evidence that beta-carotene or other carotenoids are teratogenic, mutagenic, or carcinogenic in long-term bioassays in experimental animals. In addition, long-term supplementation with beta-carotene to persons with adequate vitamin A status does not increase the concentration of serum retinol. (Institute of Medicine 2000).

[6] It would be desirable to disaggregate food staple consumption by urban and rural populations by income group and to match micronutrient prevalences with these socioeconomic groups. However, such data are not available. For example, the prevalence of anemia in a particular country typically will be available only from one survey in one year for a particular population group (such as pregnant women or preschool children). Only one study has been undertaken for rural Bangladesh, which matches detailed information on food intakes with anemia prevalence for adult women. This permitted calculation of a ***lower bound*** estimate (due to measurement error) of the effect of biofortification of rice on reductions in iron deficiency (Bhargava, Bouis, and Scrimshaw 2001). Roughly, each additional one milligram of nonheme iron added to rice (or to any other food in the diet) was estimated to reduce the anemia prevalence by 1 percent. To see that this is a ***lower bound*** estimate, consider that at this rate, an additional 36 milligrams of iron, or twice the recommended daily allowance for women, would be required to lower prevalence by 36 percent, say from 50 percent to 14 percent.

country population, this increased iron intake would reduce anemia prevalence by about 5 percent among populations consuming iron-biofortified food staples, say from 50 percent to 45 percent (see also footnote 6).[7]

As more is learned, for example, about genes that control iron transport in plants and iron-loading into seeds and about compounds that promote mineral bioavailability, it should be possible in the future to substantially upgrade these conservative estimates of the drop in iron-deficiency prevalences that could be effected through biofortification. A more reasonable expectation might be a 10–20 percent reduction in prevalence (say from 40 percent prevalence to a 20–30 percent prevalence) among consuming populations.

Consider a future scenario in which iron-biofortified crops are being consumed by 25 percent of the population in developing countries and where anemia prevalences fall by 10 percent among consuming populations. More than 100 million cases of iron-deficiency could be averted each year.[8]

As compared with analysis undertaken above for iron, far less is known about levels of zinc intakes, prevalence of zinc deficiency, and the relationship between zinc intakes and zinc deficiency. As for iron, germplasm screening under the CGIAR Micronutrients Project suggests that zinc density can be increased substantially through conventional breeding, perhaps by 100% in rice and wheat and by 75% in beans (Gregorio et al. 2000; Monasterio et al. 2000; Beebe et al. 2000). The data in Box 2 for rural Bangladesh for which some information is available on zinc intakes, indicate that rice is an even more predominant source of zinc than of iron in the low quality diets of the poor. This, in turn, suggests that a larger impact might be made on zinc intakes than on iron intakes.

**Box 2: Potential Impact of Zinc-dense Food Staples on Zinc Intakes**

The table below shows the high contribution of rice to total zinc intakes in rural Bangladesh compared with the contribution of rice to total iron intakes. If the zinc density of milled rice can be doubled from 11 to 22 mg/kg, this would result in a 70 percent increase in zinc intakes. An increment of 8 mg/kg of iron in milled rice would add 4 milligrams of iron per day to the intakes of females. See Gregorio (2001) for estimates of the range of genetic variation available for iron and zinc in rice.

***Daily rice and iron and zinc intakes of women ages 16–50 and children under age 7 in rural Bangladesh***

| Food and iron/zinc source | Adult females | Children |
|---|---|---|
| Rice intake (grams/day) | 502 | 234 |
| Total iron from all foods (mg/day) | 7.8 | 3.7 |
| Iron from rice (mg/day) | 2.9 | 1.4 |
| Total zinc from all foods (mg/day) | 8.1 | 4.0 |
| Zinc from rice (mg/day) | 5.7 | 2.7 |

### *3.1.2 The Potential to Reduce Vitamin A Deficiency*

Table 7 shows the increment in beta-carotene intakes that could be accomplished through biofortification. The geographic areas of largest potential impact are those subregions of Africa and Latin America where

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[7] Due to the presence in staple grains of anti-nutrient compounds, only a fraction of this iron will be absorbed and become available for physiological processes in the human body. Evaluation of the bioavailability of minerals and vitamins is discussed in more detail in supporting documents which are described in Appendix 1.

[8] A 10 percent reduction in prevalence rates potentially affects 450 million people out of a developing-country population of 4.5 billion. If one-quarter of this population ate iron-biofortified food staples, in one year, 112.5 million cases could be averted.

maize consumption is high and where projected increases in beta-carotene consumption could be 250 retinol activity equivalents, assuming 50 percent losses of beta-carotene due to processing and cooking.

*Table 7: Estimated increments in beta carotene intakes due to biofortification*

| | Increment in beta-carotene (mg/day) | | | | | Retinol activity equivalents | |
|---|---|---|---|---|---|---|---|
| | Wheat | Maize | Cassava | Sweet potato | Total | 12 to 1 conversion | 6 to 1 conversion |
| **Latin America** | **0.6** | **1.2** | **0.2** | **0** | **1.9** | **80** | **159** |
| Central America | 0.4 | 3 | 0 | 0 | 3.4 | 142 | 283 |
| Caribbean | 0.5 | 0.3 | 0.1 | 0.1 | 1 | 42 | 83 |
| South America | 0.6 | 0.6 | 0.2 | 0 | 1.4 | 60 | 119 |
| **Africa/Near East Asia** | **0.9** | **0.9** | **0.6** | **0.1** | **2.4** | **99** | **198** |
| North, Northwest Africa | 1.7 | 0.8 | 0 | 0 | 2.5 | 104 | 209 |
| Near East-Asia | 1.9 | 0.2 | 0 | 0 | 2.1 | 135 | 171 |
| Western Africa | 0.1 | 0.8 | 1 | 0 | 1.9 | 77 | 154 |
| Central Africa | 0.1 | 0.7 | 2.2 | 0.1 | 3.1 | 128 | 255 |
| Eastern Africa | 0.1 | 1.7 | 0.7 | 0.2 | 2.8 | 117 | 233 |
| Southern Africa | 0.7 | 2.6 | 0 | 0 | 3.3 | 136 | 272 |
| **Asia** | **0.7** | **0.3** | **0.1** | **0.2** | **1.2** | **50** | **100** |
| South Asia | 0.8 | 0.2 | 0 | 0 | 1 | 42 | 88 |
| Southeast Asia | 0.2 | 0.4 | 0.2 | 0.1 | 0.9 | 37 | 73 |

Note: Calculated increments are the result of multiplying the average consumption levels of the indicated food crops (FAO database) times the assumed increment (mg/kg, or parts per million [ppm]), over presently consumed varieties that could be obtained through plant breeding. The following are the assumed increments: wheat, 5 mg/kg; maize, 10.5 mg/kg; cassava, 10.5 mg/kg; sweet potato, 10.5 mg/kg. The RDA for a (nonpregnant, nonlacting) female adult is 700 RAE and the EAR is 500 RAE. These aggregate regional figures in both Tables 6 and 7 can conceal the fact that certain crops can increase micronutrient intakes of sub-populations, e.g., cassava in Northeast Brazil. Please see crop appendixes for a more detailed discussion of specific advantages for each crop. Calculation of Retinol Activity Equivalents assumes a 50 percent loss of beta-carotene for the Total column due to processing and cooking.

This is equivalent to 35 percent of the Recommended Daily Allowance (RDA) for an adult woman, or 50 percent of her Estimated Average Requirement (EAR). The EAR measures the average requirement over all persons in a particular age/gender group. The RDA is set so as to provide 97 percent of all individuals with a sufficient intake. The RDA is higher than the EAR due to interpersonal differences in requirements in a particular age/gender group.

No studies are available similar to Bhargava, Bouis, and Scrimshaw (2001) for iron to estimate the extent to which the prevalence of vitamin A deficiency might decline as beta-carotene intakes increase. However, it may be presumed that such high increments in intakes by consuming populations as suggested in Table 7 for subregions of Africa and Latin America would substantially reduce the prevalences of vitamin A deficiencies. Beta-carotene is already available from various sources in the diet so that those presently consuming only 40–50 percent of the EAR might well reach sufficiency.

Two key issues still to be researched under the project are the extent to which beta-carotene levels shown in Table 7 are lost during processing and cooking, and the proportion of pro-vitamin A carotenoids that is absorbed and converted to retinol. There is some evidence that for cassava high beta-carotene levels reduce the rate of postharvest root deterioration (Chavez et. al. 2000).

### *3.1.3 Potential Impact of Biofortification on Agronomic Productivity and Farm Costs*

Good nutrition balance is as important to disease resistance and stress tolerance in plants as it is in humans. Micronutrient deficiency in plants greatly increases their susceptibility to diseases, especially fungal root diseases of the major food crops. Efficiency in the uptake of mineral micronutrients from the soil is associated with disease resistance in plants, which leads to decreased use of fungicides. Breeding for micronutrient efficiency can confer resistance to root diseases that had previously been unattainable.

Micronutrient-efficient varieties grow deeper roots in mineral-deficient soils and are better at tapping subsoil water and minerals. When topsoil dries, roots in the dry soil zone (which are the easiest to fertilize) are largely deactivated and the plant must rely on deeper roots for further nutrition. Roots of plant genotypes that are efficient in mobilizing surrounding external minerals not only are more disease resistant, but are better able to penetrate deficient subsoils and so make use of the moisture and minerals contained in subsoils. This reduces the need for fertilizers and irrigation. Plants with deeper root systems are more drought resistant.

## Box 3: Trace Minerals in Soils Far Exceed What Plants Require

A soil is said to be deficient in a given nutrient when the addition of fertilizer produces better growth—even though the amount of nutrient in the fertilizer added may be small compared with the total amount of the nutrient in the soil. This seeming paradox can occur when only a small part of the nutrient in the soil is available to plants, owing, for example, to the chemical properties of the soil. Alternatively, the view can be taken that there is a genetic deficiency in the plant rather than a deficiency in the soil. Rather than adapting the soil to the plant, breeding can adapt the plant to the soil.

The table below gives an analysis of both total and extractable micronutrients in one trace element-deficient sandy soil in comparison with the nutrients removed in the grain of an average crop grown on that soil. The picture presented for nitrogen is quite different from that for trace minerals. Few soils of the world can sustain high yields for long periods without additional supplies of nitrogen, either by rotation of the crop with nitrogen-fixing legumes or from mineral fertilizer additions. Thus, it is pointless to breed for greater tolerance to nitrogen-deficient soils. Trace minerals are present in much greater concentrations (compared with plant needs) even in a nutrient-impoverished soil such as that below. It is logical, then, to concentrate breeding efforts on these elements with low requirements or low availability, but large reserves in the soil.

***Nutrient balances in a wheat-growing soil of South Australia***

| Element | Amount removed in grain | | Total amount in deficient soil | | Equivalent crops | Amount extracted from deficient soil | | Equivalent crops |
|---|---|---|---|---|---|---|---|---|
| | (milligrams per kilogram) | (grams per hectare) | (milligrams per kilogram) | (grams per hectare) | (number) | (milligrams per kilogram) | (grams per hectare) | (number) |
| Nitrogen | 20,000 | 30,000 | 1,200 | $2 \times 10^6$ | 67 | 12 | 20,000 | 0.67 |
| Phosphorus | 2,000 | 3,000 | 250 | $3.8 \times 10^6$ | 1,250 | 5 | 75,000 | 25 |
| Copper | 2 | 3 | 3 | 45,000 | 15,000 | 0.3 | 4,500 | 1,500 |
| Zinc | 20 | 30 | 5 | 75,000 | 2,500 | 0.3 | 4,500 | 150 |
| Manganese | 33 | 50 | 10 | 150,000 | 3,000 | 1 | 15,000 | 300 |
| Molybdenum | 0.1 | 0.15 | 1 | 15,000 | 100,000 | 0.05 | 750 | 5,000 |

Source: Graham 1978.

Micronutrient-dense seeds are associated with greater seedling vigor, which, in turn, is associated with higher plant yield (see Graham and Welch 1996; Marschner 1995; Welch 1986, 1995, 1999; Yang and Römheld 1999).

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, enough for hundreds or thousands of crops (see Box 3). However, because of chemical binding to other compounds, these trace minerals are "unavailable" to staple crop varieties presently used.

Depletion of soils of trace minerals may never occur at all, owing to various inadvertent additions such as windblown dust.

Therefore, the traits of efficient uptake of trace minerals from the soil and of loading of those trace minerals into the seed are compatible with breeding for high yields. Farmers can be expected to adopt genotypes with trace mineral-dense seeds out of a profit motive. High-mineral seed density is compatible with high yields; this trait can be incorporated into the best-yielding varieties.

In Bangladesh and India, approximately 80 million hectares are sown to rice and wheat each year. Suppose that 25 percent of this land (20 million hectares) is sown to iron- and zinc-dense varieties and that the seed zinc density imparts an increase in yield of 250 kg/hectare of unmilled rice and wheat on 8 million hectares (40 percent of the 20 million hectares). This increase in yield, with a value of perhaps US$35 per hectare, times 8 million hectares, would give a benefit of US$280 million per year.

In addition, Cakmak et al. (2000) has estimated that seeding rates for zinc-efficient wheat genotypes on 5 million hectares of zinc-"deficient" soils in Turkey can be lowered from 250 kg/hectares to 170 kg/hectares thanks to greater seedling vigor and vitality. This change would save farmers US$16 per hectare in input costs. On 5 million hectares of land, this represents a savings of US$80 million ***per year*** to farmers in Turkey—not including the value of increased wheat yields or improved human nutrition.

## 3.2 Comparative Advantages of Biofortification

Eliminating micronutrient malnutrition in any one country will require bringing to bear an array of interventions including supplementation, commercial fortification, and greater dietary diversity through nutrition education and higher incomes. Biofortification must have some comparative advantages relative to existing interventions to justify investments in this approach. These comparative advantages are discussed below.

### *3.2.1 Reaching the Malnourished in Rural Areas*

Modern varieties of crops developed by the CGIAR and NARES and disseminated by NGOs and government extension agencies are grown extensively by poor farmers, even in relatively remote regions. The biofortification strategy seeks to put the micronutrient-dense seed trait in the most profitable, highest-yielding varieties being released to farmers by agricultural research systems—as many released lines as future research and experience indicates are feasible. Thus, nutritionally improved varieties would reach into relatively remote rural areas not presently well covered by commercial fortification and supplementation programs. Moreover, marketed surpluses of these crops would make their way into retail outlets, reaching consumers in both rural and urban areas. The direction of the flow, as it were, is from rural to urban. Often commercial fortification works best for imported foods (such as wheat flour) that are processed at a few central industrial establishments. These foods flow from urban to rural locations. This situation clearly shows the complementarity of biofortification and commercial fortification.

The example of the New Plant Type (NPT), currently being developed by the International Rice Research Institute (IRRI) and several NARES, provides a concrete example. If the NPTs boost rice yields as significantly as expected, eventually NPTs will be grown widely all over Asia. Recent evaluation of 43 NPT lines at IRRI showed a wide range in iron and zinc concentrations in seeds. If rice breeders consciously incorporate a high-iron, high-zinc trait, this could appreciably increase iron and zinc intakes in those areas where NPTs are grown and consumed.

### *3.2.2 Cost-Effectiveness and Low Cost*

Unlike the continual financial outlays required for supplementation and fortification programs, a one-time investment in breeding-based solutions can yield micronutrient-rich plants for farmers to grow around the world for years to come. It is this multiplier aspect of biofortification across time and distance that makes it so cost-effective (Table 8).

***Table 8: How much nutrition an US$80 million investment can buy, by intervention***

| **Supplementation** | **Fortification** | **Plant breeding/Biofortification** |
|---|---|---|
| Provides vitamin A supplementation to 80 million women and children in South Asia ***for two years***, 1 in 15 persons in the total population, at a cost of 25 cents for delivery of each pill, each effective for 6 months. | Provides iron fortification to 33 percent of the population in South Asia ***for two years.*** Costs of fortification are estimated to be 10 cents per person per year. | Develops 6 nutrient-dense staple crops for dissemination to ***all the world's*** people for consumption ***year after year***. This includes dissemination and evaluation of nutritional impact in selected countries. |

In an analysis of commercial fortification, Horton and Ross (1998) estimate that the present value of each annual case of iron deficiency averted in South Asia is approximately US$20.[9] Consider the value of 1 billion cases of iron deficiency averted (this number of cases was derived in section 3.1.1) in years 16–25 after a biofortification research and development project was initiated. The nominal value of US$20 billion (1 billion cases times a value of US$20 per case) must be discounted because of the lags involved between the time that investments are made in biofortification and when benefits are realized. At a 3 percent discount rate, the present value would be approximately US$10 billion, and at a 12 percent discount rate, the present value would be approximately US$2 billion.

These calculations count no benefit to those with anemia whose iron status improves, as indicated by hemoglobin concentrations, but without crossing the threshold of anemia. Iron-biofortified crops would reach more than 1 billion such iron-deficient people each year, under an assumption of a 25 percent spread of these biofortified varieties in developing countries, or more than 10 billion iron-deficient people over a decade. Biofortified crops would also reach those who are iron-sufficient but whose iron stores would be increased.

If US$150 million in discounted investments were spent on developing, testing, disseminating, and maintaining iron-biofortified food staples, under the above scenario the cost would be 15 cents for each case of iron-deficiency averted (US$150 million divided by 100 million cases averted) and 1.5 cents for each ***iron-deficient*** person reached (US$150 million divided by 1 billion iron-deficient people reached).[10] As a basis of comparison, the cost of commercial fortification is 10 cents per person reached, whether the

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[9] A World Bank study (1994) assigns a present value benefit of US$45 to each annual case of iron deficiency averted through fortification (a mix of age-gender groups). The same study gives a present value of US$96 for each annual case of vitamin A deficiency averted for preschoolers.

[10] The costs of implementing biofortification are detailed later in the proposal. It is estimated that US$12.5 million would need to be spent over a 10-year period for each staple food crop. This would include the costs of developing breeding tools, a series of nutritional evaluations of promising lines, and breeding and dissemination costs in limited areas in a small number of countries.

Because these research and development expenditures are incurred over a decade, these costs need to be discounted as well, say US$10 million in discounted costs per crop. Multiplying by six major staple foods gives US$60 million in discounted costs. Ninety million dollars in discounted costs for extension/education are added to give the total figure of US$150 million in discounted costs.

person is iron-deficient or not, which is equivalent to about 20 cents per iron-deficient person reached. The cost of iron supplementation is US$2 per iron-deficient person reached.[11]

High-iron and high-zinc traits appear to be genetically linked. Thus, it should be relatively easy to breed high-iron and high-zinc varieties simultaneously. The calculations above count no benefit to human nutrition of increased zinc intakes (see Box 2) or to improved productivity due to higher loading of zinc into seeds (see section 2.1.3). And, of course, the calculations do not count any benefits prior to year 16 or after year 25, even though biofortified varieties would be available before and after these years.

### *3.2.3 Sustainability of Biofortification*

Once in place, the system described in the previous section is highly sustainable. The major, fixed costs of developing the varieties and convincing the nutrition and plant science communities of their importance and effectiveness will have already been borne. Government attention to micronutrient issues may fade. International funding for micronutrient interventions may be substantially reduced. But the nutritionally improved varieties will continue to be grown and consumed year after year. To be sure, recurrent expenditures are required for monitoring and maintaining these traits in crops. But these recurrent costs are low compared with the cost of the initial development of the nutritionally improved crops and the establishment, institutionally speaking, of nutrient content as a bona fide breeding objective.

### *3.2.4 Behavioral Change*

Mineral micronutrients make up a tiny fraction of the physical mass of a seed, 5–10 parts per million in milled rice. Dense bean seeds may contain as many as 100 parts per million. Whether such small amounts will alter the appearance, taste, texture, or cooking quality of foods will need be investigated. If increased densities in iron and zinc are not noticeable by consumers, the dissemination strategy for trace minerals, then, could rely on ***existing*** producer and consumer behavior. Analogous to the addition of fluoride to drinking water in some developed countries, successful implementation would not require that farmers and consumers know that they are producing and eating more nutritious varieties, although this information would be publicly advertised and publicly available.

In contrast, higher levels of beta-carotene will turn varieties from white or light colors of yellow to dark yellow and orange. Often, consumers much prefer white varieties of, for example, milled rice, wheat flour, maize, and cassava. Major nutrition education programs will have to be mounted to encourage consumers to switch to more nutritious varieties (and incorporated in benefit-cost calculations such as in the previous section). If these nutrition education programs are successful, however, the yellow-orange color will distinguish the more nutritious varieties from the less nutritious and a disadvantage will have been turned into an advantage (Hagenimana and Low 2000).

## 3.3 Feasibility of Breeding for Nutritious Crops Demonstrated

The CGIAR Micronutrients Project is an ongoing interdisciplinary effort of plant scientists, human nutritionists, and social scientists. The overall objective of the project has been to evaluate the feasibility of using modern breeding techniques to produce new varieties of staple crops that are eaten by the poor with high micronutrient content. The search for promising germplasm has been conducted in the seed banks of IRRI in the Philippines, the International Center for Tropical Agriculture (CIAT) in Colombia,

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[11] Commercial fortification delivers a higher dose of iron than biofortification under what is currently thought possible using conventional breeding. Supplements, of course, deliver an even higher dose than commercial fortification.

and the International Center for the Improvement of Maize and Wheat (CIMMYT) in Mexico. This research, coordinated by the International Food Policy Research Institute (IFPRI), has been carried out in collaboration with scientists at the University of Adelaide in Australia and research labs of the United States Department of Agriculture (USDA) located at Cornell University in Ithaca, New York, and the University of California at Davis.

During its initial six years (1995–2000), the CGIAR Micronutrients Project has undertaken research on five crops identified as being staples primarily consumed by the poor (rice, wheat, maize, cassava, and common beans) and three nutrients (iron, zinc, and beta-carotene) that the international nutrition community has recognized as target nutrients in the fight to reduce malnutrition. Thus far, three donors have provided the bulk of the funding: Danish International Development Assistance (DANIDA), the United States Agency for International Development (USAID), and the Australian Centre for International Agricultural Research (ACIAR). Recently, the Asian Development Bank (ADB) has contributed to help step up the pace of research on rice for 2001–2003, with additional support from USAID. DANIDA and ACIAR have renewed funding commitments for research on the other four crops.

During the past six years three scientists among the proposed collaborators in nutritional genomics have obtained significant funding from competitively awarded scientific funds to study molecular and genetic aspects of carotenoids (pro-vitamin A) and vitamin E synthesis and iron and zinc accumulation mechanisms in plants. This knowledge and expertise will be leveraged in the course of this proposed technology development and deployment project.

Results thus far indicate that biofortification is highly feasible. For most crops, there is adequate genetic variation in concentrations of beta-carotene, other functional carotenoids, iron, zinc, and other trace minerals in varieties available in CGIAR germplasm banks to increase micronutrient densities through conventional breeding by a multiple of two for trace minerals and by higher multiples for beta-carotene. Results also show that:

- Micronutrient density traits are stable across growing environments;
- It is possible to combine the high micronutrient density trait with high yield, unlike protein content and yield, which are negatively correlated;
- Genetic control of target nutritional traits is simple enough to make breeding economical;
- It is possible to improve the content of several micronutrients together in a single variety; and
- Bioavailability of the extra trace minerals in elite breeding lines is high in *in vitro* and animal tests; tests on human populations are now a high priority.

At the end of the pilot phase, scientists agree that the biofortification strategy is feasible[12] but that an expanded global research program is necessary.

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[12] Proceedings of an international conference that reviewed the findings of the CGIAR Micronutrients Project are published in the *Food and Nutrition Bulletin*, Vol. 21, No. 4, December 2000.

## Box 4: The Importance of Investing in Phase 2 Crops

There are several reasons for investing in Phase 2 crops. First, large numbers of people who do not consume Phase 1 crops depend on Phase 2 crops as their primary food staple. These populations often depend on rainfed agriculture and so are highly vulnerable.

Second, benefits (including benefits for agricultural productivity) are still sufficiently high for these crops, that their benefit-cost ratios provide strong justification for these investments. Each hectare planted to a biofortified staple crop can feed perhaps 10 people per year (a three-ton yield times a 50 percent milling rate divided by 10 people gives an annual per capita consumption rate of 150 kilograms of the milled staple food). If consumption of this biofortified staple averts anemia for one of these 10 people, the present value at a 3 percent discount rate is US$10 for this one person for each year. Analogous to the arguments made in section 3.2.2, over 10 years, the discounted value of improved nutrition is US$100. Thus, the biofortified crop need only be grown on 200,000 hectares over a 10-year period to exactly cover ***discounted*** investment and extension costs of US$20 million (see also footnote 11). Again, this counts no potential benefits to (1) agricultural productivity, (2) improved zinc nutrition, and (3) those other 9 people reached per hectare who get more iron and zinc in their diets, 3 of whom may be iron- and zinc-deficient.

Third, there are expected to be important synergies in research across crops. It may be that an important discovery for one crop will inform work on other crops as well. Fourth, ignoring dietary diversity and focusing research investments on a small number of widely grown staple foods is arguably responsible in part for the present situation of poor dietary quality. The micronutrient density of as many foods as possible should be increased, starting with the broad range of food staples. In any event, the requested funds for the Phase 2 crops are relatively modest to support studies of the feasibility of undertaking full-scale nutrition breeding programs for these crops.

# 4. Research Activities and Methods

The 10-year plan objectives will be accomplished through a series of interdisciplinary activities. The major activities to be undertaken are:

- Plant breeding based at Future Harvest centers and national agricultural research systems (NARES) for six Phase 1 crops, using a dual approach: early development of "fast-track" varieties that will convincingly demonstrate the validity of the biofortification strategy; and a more lengthy parallel development of varieties combining the best nutritional and agronomic traits in each crop, using adaptive/decentralized breeding methods and seed production where feasible;
- Prebreeding feasibility studies based at Future Harvest centers for 10 Phase 2 crops important in the diets of those suffering from micronutrient deficiencies but for which the knowledge base for biofortification has yet to be developed;
- Initial screening of promising lines for micronutrient bioavailability using *in vitro* and animal models and subsequent efficacy studies involving human subjects to evaluate nutritional impact of the most promising lines intended for release;
- Dissemination of nutritionally improved varieties through collaboration with farmers, NARES, and NGOs, and evaluation of effectiveness of the biofortification strategy after adoption;
- Application of novel advances in genomics, genetics, and molecular biology to identify and understand plant biosynthetic genes and pathways of nutritional importance; use of this knowledge (1) in marker-assisted selection for conventional breeding of Phase 1 crops and (2) in initial development (but not release) of transgenic lines;

- Research to understand economic and social factors that determine the dietary quality of the poor and their micronutrient status, and policy advocacy based on that research; and
- Coordinated communication activities designed to provide support to internal project constituents and external audiences, including donors, the academic and development communities, public officials, and the general media.

## 4.1 Human Nutrition Activities

University partners will help identify nutritionally optimal breeding strategies and conduct nutrition efficacy trials. Impact studies will involve collaboration among these university partners, social scientists at the relevant Future Harvest centers, and local partners. Analyses related to human nutrition will be conducted in four areas:

- Basic studies will investigate optimal strategies (that is, identifying breeding objectives) for maximizing nutrient bioavailability through increasing micronutrient density, reducing anti-nutrients, and/or increasing promoter compounds. This work will be initiated by Robin Graham and James Stangoulis at the University of Adelaide and Ross Welch at PSNL on the Cornell University campus.
- The PSNL will undertake *in vitro* and animal studies to provide initial screening of bioavailability for promising genotypes for each crop.
- Midproject efficacy trials involving human subjects to test nutritionally improved lines for each crop will be undertaken in developing countries under the direction of nutritionists from developed-country universities in collaboration with developing-country nutritionists. Areas will be selected in which the prevalent diets are representative of wide geographic regions and in which two or more of the crops under study are staples, thus incorporating the food-system approach.
- In the final phase of the project, once nutritionally improved varieties have been adopted, community-based impact studies will be undertaken by these same teams of nutritionists in selected countries, including an evaluation of the effectiveness of the nutritionally improved varieties in reducing micronutrient malnutrition.

## 4.2 Plant Breeding Activities

### *4.2.1 Conventional*

A recommendation for initiating a full-scale breeding program for the six Phase 1 target crops is based on favorable previous findings summarized in section 2.1. The target micronutrients to be improved are iron, zinc, and beta-carotene. Breeding activities include:

## Box 5: Micronutrient Bioavailability and Determination of Optimal Breeding Strategies

There is evidence that micronutrients may interact with each other and with other nutrients in their absorption and conversion to biologically active compounds in the human body. Such interaction may be either synergistic (for example, fat may possibly increase absorption of beta-carotene) or antagonistic (for example, iron from supplements appears less effectively absorbed when these supplements are concurrently taken with zinc supplements). The most convincing evidence for such interactions comes from physiological studies, but there is insufficient knowledge whether the mechanisms involved are important under real-life conditions. Most importantly, randomized controlled trials have conclusively shown that improved health can be achieved by increasing intake using single nutrients.

Many other factors influence the degree to which ingested micronutrients are absorbed (bioavailability) and utilized (bioefficacy), including a person's micronutrient and health status. Given this complexity, three breeding sub-strategies may be applied individually or in various combinations. These are (1) increasing the mineral and vitamin content, (2) reducing the level of anti-nutrients in food staples that inhibit the bioavailability of minerals and vitamins, and (3) increasing the levels of nutrients and compounds that promote the bioavailability of minerals and vitamins.

For example, phytates and tannins inhibit iron and zinc absorption. Proposed in vitro and animal studies and efficacy feeding trials will evaluate effects of these inhibiting compounds. With respect to compounds that promote bioavailability, certain amino acids (such as cysteine) enhance iron and/or zinc bioavailability (Hallberg 1981). These amino acids occur in many staple foods, but their concentrations are lower than those found in meat products. A modest increase in the concentrations of promoter amino acids in plant foods may have a positive effect on iron and zinc bioavailability in humans. Iron and zinc occur only in micromolar amounts in plant foods, so only micromolar increases in the amounts of these amino acids may be required to compensate for the negative effects of anti-nutrients on iron and zinc bioavailability. These amino acids are essential nutrients for plants as well as for humans, so relatively small increases of their concentrations in plant tissues should not have adverse consequences on plant growth (Graham and Welch 1996).

While the Biofortification Challenge Program pursues breeding for higher micronutrient content as its initial breeding objective, at the same time an effort will be made to investigate the possibly large nutritional impacts of the extended breeding strategies suggested above. This component of the project explores genetic variation in nutrient content in staple crop plants and the interactions among nutrients in animals and humans that can dictate improved strategies of plant breeding for nutritional quality. The idea is to exploit potential synergies in the human body to simplify the breeding objectives by decreasing the number of genes needed in a breeding program, thereby optimizing the cost-effectiveness of the strategy. The results of the research from this component of the project will inform breeding strategies for all crops.

For a fuller discussion of these topics, see supporting documents on activities to be undertaken in the area of human nutrition which are described in Appendix 1.

- Additional germplasm evaluation of materials with potential for short-term impact;
- Implementation of molecular markers for large-scale selection programs;
- Genetic and QTL analyses to determine loci involved in micronutrient content; and
- Development of varieties with high micronutrient concentration and superior agronomic traits, in collaboration with NARES and farmers' groups.

Breeding has been the strength of the CGIAR centers since their inception, as a logical extension of the gene banks that are held in the centers. For every crop listed in this project, significant success has been obtained in the areas of disease resistance, tolerance to abiotic stresses and/or yield potential. Productivity of several crops has been increased dramatically, and these objectives continue to be important as breeders look to the future.

From this perspective, can breeders assume still another breeding objective? Breeders involved in this project do not feel that this is unrealistic. The experience in IRRI's rice program suggests that a moderate level of iron was achieved even without directed screening in a few modern varieties. This modest success can be greatly amplified by breeding consciously and systematically for higher micronutrients, thus exploiting opportunities that have been observed in the germplasm where much greater levels are to be found.

"Conventional" breeding is made even more efficient by integrating a set of tools such as: marker-assisted selection for key agronomic and nutritional traits; molecular biology for gene discovery of relevant traits; and transgenics to increase existing levels or provide opportunities that are lacking within the respective crop species.

In the final analysis, the requirement is that 3-4 genes be added to the suite of genes that breeders successfully work with in their breeding programs. This is totally feasible with the tools described above, and breeders feel comfortable that they can increase levels of micronutrients while continuing to make gains in agronomic breeding objectives. Materials to be released will have superior agronomic traits to facilitate adoption by farmers. QPM maize is now fully competitive with standard maize varieties and often out yields these, making them attractive to producers. Biofortified maize will build on progress in QPM and expand these successes to higher levels of iron and zinc. Progress has been registered in beans for superior drought tolerance and this in turn will be the basis for new varieties with better nutritional quality. Results for several crops show that there is no penalty in yield or other traits from increasing micronutrient content.

Table 9 below gives an indication of the genetic variation in the micronutrient content that breeders have available to them.

More detailed discussions of breeding activities for each specific crop are provided in supporting documents described in Appendix 1. Each crop proposal and budget includes activities to be undertaken with collaborating institutions. For most crops, selection of specific sub-regions for which initial nutritionally improved varieties will be developed and disseminated, is still to be refined based on levels of malnutrition, diets, prospects for successful breeding, and opportunities for establishing effective partnerships. These decisions will be taken after start-up of the Program in full consultation.

For the eleven Phase 2 crops, prebreeding studies will be undertaken over three to four years to determine the feasibility and desirability of pursuing full-scale breeding activities for these crops. Analyses of the mineral and vitamin content of crop samples will be processed at a central collaborating partner facility to

***Table 9: Genetic variation in concentrations of iron, zinc, beta-carotene, and ascorbic acid found in germplasm of five staples, (mg/kg) DW basis***

| | Fe Conc. range (mg/kg) | Zn Conc range (mg/kg) | Beta-carotene*** range (mg/kg) | Ascorbic Acid range (mg/kg) |
|---|---|---|---|---|
| **Rice, brown** | 6 – 25 | 14 – 59 | 0 – 1 | – |
| **milled** | 1 – 14 | 14 – 38 | | – |
| **Cassava, root** | 4 – 76 | 3 – 38 | 1 – 24* | 0 – 380* |
| **leaves** | 39 – 236 | 15 – 109 | 180 – 960* | 17 – 4200* |
| **Bean** | 34 – 111** | 21 – 54 | 0 | – |
| **Maize** | 10 – 63 | 12 – 58 | 0 – 10 | – |
| **Wheat** | 10 – 99** | 8 – 177** | 0 – 20 | – |

Notes: * FW basis; ** including wild relatives; ***range for total carotenoids is much greater.

ensure quality control and comparability of measurements among crops. Based on rigorous peer review of the results of the prebreeding studies, additional funding may be sought to pursue a full breeding program for those crops with demonstrated potential for significant impact.

The University of Adelaide's Plant Nutrition Group members (Robin Graham and James Stangoulis) will provide micronutrient expertise to crop leaders, particularly those of the Tier 2 crops, through regular visits, newsletters, relevant literature, and a laboratory and fieldwork handbook for micronutrient research in plant breeding and agronomy. Additionally they will provide support in data evaluation and interpretation, as well as provide strategic research essential to strategy development. Waite Analytical Services (WAS) will provide, at cost, analysis of grain and other food crop products involved in the Challenge Program, maintaining quality assurance standards certified by ASPAC. These analyses include all essential minerals, and fat-soluble vitamins.

### *4.2.2 Nutritional Genomics Activities*

Nutritional genomics is a new approach to the study of complex biochemical pathways in plants. It seeks to elucidate the basic, underlying mechanisms involved in the synthesis and accumulation of essential vitamins and minerals in plant tissues. Because of the metabolic unity among organisms through evolution, the knowledge obtained in one organism by using this approach can be readily applied to many organisms. As a component of the overall biofortification research program, nutritional genomics will leverage the massive knowledge base resulting from the enormous investment of the developed world in DNA sequencing of entire organisms (plants, bacteria, fungi, and animals). This knowledge base will be used to increase specific micronutrient levels in crops that will be of most benefit to the needs of the developing world. Once the genes of interest are identified, they are moved into a crop species to demonstrate proof of concept to effect the desired change in nutritional content of the target tissues. This process can provide novel traits for breeding that are not available in the existing germplasm (beta-carotene in rice endosperm, for example). The expanding ability to manipulate pro-vitamin A carotenoid synthesis (such as in Golden Rice), vitamin E synthesis, and mineral composition in plants can be directly traced to advancements in nutritional genomics and exemplifies the power and potential benefits of the approach.

Activities to be undertaken in this project area aim to:

- Leverage and integrate new methods in genomics, genetics, and molecular biology to identify and understand plant biosynthetic genes of nutritional importance, specifically those related to zinc, iron, and vitamin A;
- Demonstrate proof of concept nutritional enhancements by engineering genes involved in the biosynthesis of essential vitamins and accumulation of essential minerals;
- Analyze the consequences of proof of concept enhancements on nutrients and bioavailability;
- Transfer proven materials to partner breeding centers for implementation in Phase 1 and 2 crops;
- Assist with analysis of micronutrient composition and agronomic traits; and
- Aid breeders in identifying molecular markers to nutritionally important genes for incorporation into molecular breeding programs.

### *4.2.3 On-Farm Testing and Adaptation*

The on-farm testing phase is crucial, especially in regions and for crops for which adoption rates of modern varieties have been low. Simply, if the varieties are not grown or appreciated by farmers (widely and by large numbers), the positive impacts will not be achieved.

The on-farm testing phase will have three basic aims: to assess whether varieties grow under farmer conditions and management; to get precise feedback from the range of potential producers on the acceptability of materials; and to give farmers exposure to what, in some cases, may be quite novel materials (e.g., yellow varieties where white varieties are preferred).

## Box 6: The Scope of Research on Transgenic Crops

Breeding, dissemination, and impact activities, outlined in the ten-year plan, are focused on development of conventionally-bred crops. No activities involving the release of nutritionally-improved transgenic crops to farmers and consumers are proposed here or are included in proposal budgets for the initial four years for which funding is being requested. Research and development activities with respect to transgenic crops are confined to agricultural research centers and research laboratories. Transgenic methods hold great promise for improving the nutrient content of staple foods and speeding up the breeding process over what can be achieved using conventional methods. High social benefit and lower risk applications, such as the incorporation of desirable traits from crop wild relatives, will be favored throughout the program whenever transgenic methods are considered.

The biofortification challenge program will implement a wide range of technologies including germplasm characterization, breeding, molecular marker assisted breeding and genetic transformation technologies. The mix and extent to which each of these technologies is used will vary by crop (see crop appendixes for further information). The first phase of the project will mainly involve germplasm deployment of land races and breeding genotypes. Genetic transformation technologies will be used in the first phase for research purposes to a better understanding of the targeted nutritional pathways resulting in better screening and to develop efficient genomic tools for marker assisted selection and breeding; and in the second and third phases for potential seed deployment by increasing the level of a trait beyond what is available in the gene pool and by providing traits not present in the gene pool.

The project participating institutions have established strict regulations to develop and deploy genetically modified organisms consistent with the CGIAR policy. All institutions involved have well-established guidelines for biosafety related issues and will pursue rigorous scientific processes to ensure the safe use of transgenic plants when there is a high social benefit. Components of the project that involve genetically transformed plants will strictly adhere to international safety standards and the national regulations of the partner countries. As part of their research agenda, several institutions involved in the project are conducting gene flow, risk assessment project and food safety studies. Results from such studies will be incorporated during the implementation of the program. The Centers will distribute with caution and consultation/approval of civil society transgenic materials for experimental purposes with advanced informed consent only to countries where national biosafety legislations are in place.

Development of Golden Rice is much further ahead of any other nutritionally-improved transgenic crop. Research activities related to Golden Rice will be undertaken under the purview of the Biofortification Challenge Program and will adhere to the guidelines set forth above. Research will be undertaken during Phase 1 at IRRI and other collaborating research institutions to evaluate the agronomic and nutritional properties of various existing lines, and to develop experimental lines with even higher levels of beta-carotene. Initial evaluations of the bioavailability of beta-carotene in Golden Rice using human subjects is not expected to be undertaken until 2004. Decisions concerning possible release to farmers and consumers, therefore, can only be taken well after the first four years for which funding is being sought, pending results of an array of agronomic, nutritional, and safety tests.

Rigorous designs for Participatory Plant Breeding (PPB) and Participatory Varietal Selection (PVS) are well known among the groups' IARC and select NARs collaborators (for example, see the PRGA 2002 inventories at the following website: *www.prgraprogram.org.*). These will be employed if deemed technically useful and of interest to the potential stakeholders involved. It may be that on-farm and extensive community-based collaboration could be beneficial quite early in the breeding process, with early stabilized or segregating materials. This will greatly depend on the local context, the challenges adaptation, the stringency of producer/consumer requirements, and the diversity of materials on offer.

On-farm research and development (R&D) remains a program component of many NARS' partners in this proposal and is supported by their collaborating commodity networks (for example, the African bean, cassava, and sweet potato networks). However, staffing and operating costs constraints have been progressively reducing the scale of on-farm research, particularly in some of the key Latin American and African target countries of this biofortification work. While there is a growing body of experience to work with and through these resource constraints, we aim to stimulate further creative on-farm R& D relationships, starting from the strengths of NARS and moving to joint work with, inter alia, civil society groups, farmers' organizations, agricultural schools, and even churches (when technically appropriate and mutually beneficial).

### *4.2.4 Multiplication and Diffusion of Biofortified Varieties*

Explicit attention to seed multiplication and diffusion will also be key for the success of the project. Field studies are increasingly showing that certified seed, sold and promoted through formal channels (e.g., seed parastatals) delivers solid results among the more progressive farmers but often bypasses much of the rural poor (the cases of Asian rices and African maize hybrids being important exceptions). Hence, a range of channels will be brought into action to ensure that seeds (and ultimately the food itself) are distributed to the targeted communities where micronutrient deficiencies are widespread. One effective channel used by all of the Future Harvest Centers to distribute improved varieties has been the NARES. In many instances, commodity-based regional research networks also have helped in the exchange and coordination of research, knowledge and germplasm distribution. Action-oriented research has also shown that local and private companies, civil society groups, farmers organizations, women's cooperatives, and specially-formed seed producer groups have proven effective in reaching remote and micro-niche areas, which otherwise might be overlooked by routine seed sector production and diffusion paths. A mix of centralized and decentralized seed production and diffusion arrangements will be supported to ensure a steady supply of the new germplasm, which meets farmer-desired quality standards. Proposal collaborators together have significant and innovative experience to bring to bear here.

## 4.3 Policy Analysis

The CGIAR can be given much of the credit for the fall in staple food prices over the past three decades, which has increased food security among the poor in terms of energy intake. This decline has also freed up resources that would have been spent for food staples. Nonetheless, the growth in supply of some foods, such as pulses, has not kept pace with growth in population and demand, resulting in higher prices for these foods. In the past, economists have most often equated food security with energy security. Consumption of food staples and energy intakes have been the focus of many studies, but relatively little is known about trends in the dietary quality of the poor.

Biofortified crops, if successfully developed, can have a large positive impact on micronutrient status. Rigorous cost-effectiveness studies of biofortified crops will need to be undertaken, especially in the context of other food-based interventions. The realized impact of biofortified crops on the micronutrient status of those most deficient in micronutrients will depend on a number of factors:

1. Will there be an income effect in micronutrient-deficient rural areas via improved yields and off-farm linkages? If so, the ability to diversify diets and improve micronutrient status will be enhanced.

2. Will the price of micronutrient-rich foods be reduced for the micronutrient-deficient? This will only happen if market infrastructure is extensive or, when it is not, if farmers in micronutrient-deficient areas can get access to the new seeds.
3. How will rapid urbanization change the demand for biofortified crops and micronutrient-rich foods in general? In terms of the demand for dietary diversity, urbanization can be a positive force (for example, through better access to nutrition information and a variety of foods) or a negative force (such as through greater influence of advertising toward more processed foods that often are expensive sources of micronutrients).
4. How important are non-economic factors in determining consumption of biofortified crops? The organoleptic qualities of food are not expected to change dramatically as a result of biofortification. However, the perceptions of the developers of the crop about what is "dramatic" may differ a great deal from the perceptions of the consumer. Even if there is no sensory difference from the consumer's perspective, will there be an effect on consumption simply from knowing that the crop is biofortified?

The following need to be undertaken and are described more fully in supporting documents described in Appendix 1:

- Document changes in the diets of the poor over time, and calculate nutrient intakes from diets. This mapping of diet quality does not exist currently and will be crucial if the biofortified crops are to be targeted to certain regions and households or if we are to understand the barriers to access of certain groups.
- Estimate the impacts of price, income, education, urbanization, and perceptions on the demand for micronutrients from different food sources. These estimates exist only for a small handful of countries and then only at a very aggregated level.
- Estimate the effects of changes in diet and nutrient intakes on changes in nutritional status. This is important for estimating cost-benefit ratios for biofortified crops and for linking diet and food security to the global burden of disease estimates.
- Define and assess the costs of various food-based interventions, including a selection of biofortified crop interventions. Recalibrate the extent and pattern of food insecurity using an operational measure (such as the source of the calories consumed in addition to the total amount) that is a truer reflection of the conceptual basis for food security (that is, one that is more consistent with the notion of good health). In this way one can get a truer picture of food insecurity, and one can communicate the importance of diet quality to policymakers, NGO administrators, and international organizations.

## 5. Partnerships

In simple terms, the biofortification strategy involves adding nutritional quality to an already long list of breeding objectives primarily concerned with improving crop productivity. From this perspective, it is the ultimate responsibility of plant breeders to develop varieties that farmers will want to grow and that have the desired nutritional characteristics. This adaptive breeding work will be carried out primarily by NARES on a country-by-country basis, with assistance from Future Harvest centers in developing breeding tools and in coordinating this work across countries.

To be successful, however, this plant breeding work cannot be done in isolation. Plant breeders will need to pay close attention to human nutritionists for advice on what breeding objectives to pursue—levels of nutrients and compounds that inhibit and promote bioavailability and how these are affected by various steps in processing and cooking. Human nutritionists must evaluate the potential of various crop lines to improve nutrition at various points in the breeding process and provide feedback to the breeders.

Research in the area of nutritional genomics will provide new ideas for breeding strategies and will make the breeding process more efficient through marker-assisted selection. Use of participatory plant breeding will ensure that, once developed, nutritionally enhanced varieties are acceptable to farmers. This is shown schematically in Figure 3.

The CGIAR biofortification project has built up strong partnerships to accomplish the basic, applied, and adaptive research and outreach that will be necessary for the adoption of this new technology. A consortium of partner organizations and institutions brought into the project through competitive bidding will undertake the individual components of project activities as described below. Each member of the project team has been selected based on their unique comparative advantage to contribute to the goals of the project.

### 5.1 CGIAR

In taking the lead on this project, the CGIAR has an obvious comparative advantage in terms of (1) access to material available for screening from its extensive germplasm banks, (2) undertaking the tasks of developing breeding tools and incorporating promising nutritional characteristics into existing elite lines through breeding, (3) genomic capacity and its integration with breeding programs, and (4) disseminating the nutritionally improved elite material to a large number of countries through long-established research and development networks. Close collaboration with institutions outside the CGIAR that can provide necessary scientific expertise, skills, and experience not found within the system strengthen the project's ability to deliver the biofortified varieties that will have a positive impact on the micronutrient status of hundreds of millions of poor people around the world.

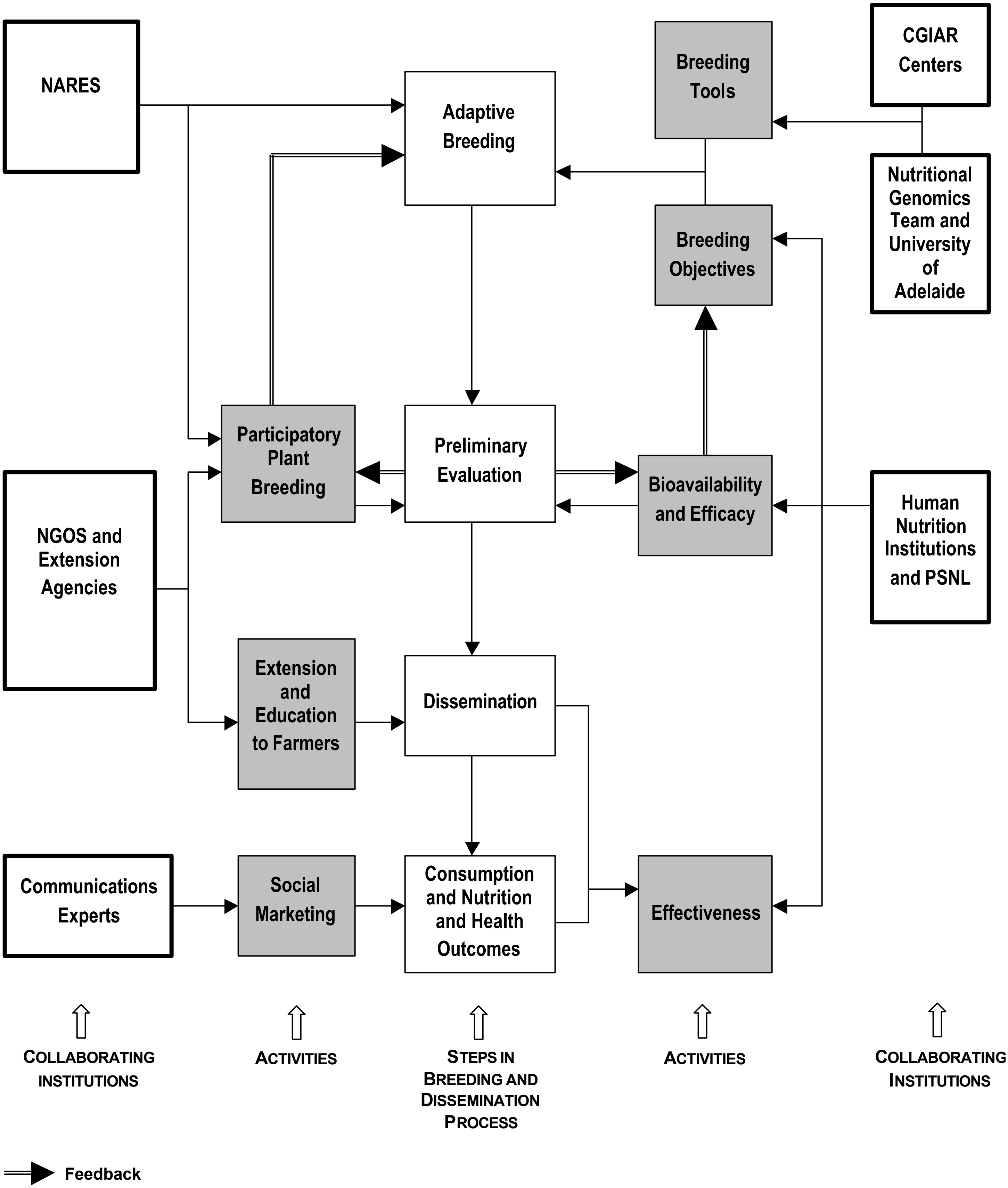
### 5.2 NARES

As shown in Figure 3, NARES are the focal point of development and dissemination of biofortified crops, with the Future Harvest centers, University of Adelaide, and the nutritional genomics team providing technical assistance, for example, in the development of breeding tools. Table 11, presented later in section 6 of the proposal, lists NARES partners who are currently working on or have indicated their willingness to collaborate with the biofortification program. Examples are discussed below of key collaborating NARES in each of three broad geographic regions for which biofortified crops will be developed and, in some cases, ongoing collaborative activities are emphasized.

***Latin America***. The Brazilian Agricultural Research Corporation, EMBRAPA, is one of the largest agricultural R&D organizations in the world. Its mission is to develop technology that helps increase agricultural yields, at lower costs and without damaging the environment. EMBRAPA coordinates the Brazilian National Agricultural Research System, which consists of universities, research institutes, and state research corporations. The organization has ongoing technical and scientific cooperation programs with more than 150 institutions from 56 countries. Ongoing collaborations with several African countries will provide the opportunities for training and establishing collaborative research as part of the overall project.

EMBRAPA expertise covers most of the core pillars of the biofortified crops project (breeding, nutrition, and genomics). Its current approaches to nutritional quality of maize, beans, cassava, and vegetables target the poorest people and involve development of delivery mechanisms that are feasible and cost-

*Figure 3: Schematic representation of primary responsibilities and collaborative linkages*



effective. In addition to its breeding programs, EMBRAPA's Food Technology Research Center has facilities and personnel conducting research on human nutrition. Facilities are available for analysis of Fe, Zn, and beta-carotene content of target crops. In vitro and animal studies for the biovailability of Fe, Zn, and beta-carotene in promising lines and bioefficacy studies to determine effects on micronutrient status of human subjects could be conducted with two leading universities with world-wide reputations, the University of São Paulo (USP) and the University of Campinas (UNICAMP).

***Africa.*** The mission of the Kenya Agricultural Research Institute (KARI) is to develop and disseminate appropriate agricultural technologies to farmers and processors in collaboration with stakeholders. KARI contributes to improving sustainable livelihoods by increasing agricultural productivity, raising the postharvest value of agricultural and livestock products, and conserving the environment. Current goals are to improve the nutritive value of foods (e.g. vitamins, iron, zinc, calcium, and protein) as well as reducing the anti-nutrients. Planned outputs will be biofortified food crop varieties resistant/tolerant to pests and diseases or drought, biofortified industrial and fodder crop varieties resistant to pests, vaccines against priority livestock diseases, diagnostics against priority livestock and plant diseases, and inoculants for improved soil nitrogen and phosphorus in acid soils. KARI has a total of 29 research stations in various agroecological zones of the country, working in the areas of food crop production, livestock management, soil and water management, biotechnology, and business development.

***Asia.*** Ongoing activities to develop high-iron rices funded by the Asian Development Bank would be incorporated under the Biofortification Challenge Program and would provide valuable lessons in organizing collaborative activities related to biofortification. The project currently involves the NARES of Bangladesh, Indonesia, the Philippines, and Viet Nam (see Table 11 for formal names of these institutions). IRRI, IFPRI, and the University of Adelaide are also participating institutes.

An inception meeting was held in late 2000 at which annual work plans for the collaborating partners were discussed and agreed upon. The principal investigators for each NARES consists of a team of two people: a plant breeder and a human nutritionist or grain quality expert. The first annual work plan for the NARES involved germplasm screening, among other activities. Some crosses were initiated with high-iron material supplied by IRRI (based on previous research at IRRI). In general, NARES were not familiar with the handling of rice samples to avoid trace mineral contamination, so training was provided by the University of Adelaide, where rice samples were sent for analysis of trace mineral content on the Adelaide ICP. Subsequently, standardized dehulling and milling equipment that does not contaminate samples has been identified and purchased by each of the four NARES, so that milled samples are comparable across countries.

The group met again after 15 months to discuss initial results and to jointly develop work plans for year two of the project. These work plans involve studies of genotype by environment interaction and of the effects of milling and cooking on iron content for rice lines from the respective countries. Eventually, each NARES will determine its own breeding strategy for incorporating the high-iron (and high-zinc) trait into its releases.

Observers from Thailand—a nutritionist from Mahidol University and a rice breeder from Kasetsart University—attended this first annual meeting hosted by the Cuu Long Delta Rice Research Institute in Viet Nam. Based on what was learned at that meeting and a subsequent seminar presentation by IFPRI and other follow-up activities in Thailand, researchers from these two institutions are currently writing a multi-year, joint proposal for (1) development of high-iron rices for low-income areas in rural Thailand and for export to Africa and (2) development of institutional capabilities in Cambodia, Laos, and Myanmar (human nutrition and rice research) so that these countries may also develop and evaluate biofortified rice varieties.

### Box 7. Early Stakeholder Consultation with NGOs, Farmer Organizations, and Other Civil Society Groups

As outlined in sections 4.2.3 and 4.2.4, NGOs, farmer organizations, and other civil society groups will be importantly involved in the development of farmer-acceptable varieties and seed multiplication and diffusion. Although seed multiplication and diffusion will take place in the latter stages of the ten-year plan, it will be important to consult with these groups in the initial stages of the planning process. Fundamentally, mutual expectations will need to be clarified early.

Stakeholders (both direct and indirect) need to be involved at different levels, *inter alia* a) to ensure that the research itself, from the beginning, sets desired, targeted, and ultimately usable goals; b) to help create a facilitating environment (e.g., for policy development promoting decentralized seed multiplication/ diffusion channels) and c) to encourage extensive collaboration on-the-ground, so that partners share the practical challenges of meeting the needs of the poor in quite diverse, and often, remote geographic areas.

Current strong relationships with higher management structures (e.g., high level regional groups in Africa such as ASARECA or CORAF, steering committees of commodity networks, and NARS directors in Africa, Asia, and Latin America) can be built on to move the agenda forward. However, we will need to find ways to reach out to regional, national, and grassroots civil society groups, including those that represent small farmer and urban poor interests. We will have to bring into the discussion the policy-oriented and advocacy groups, as well as those which actually effect the work on the ground. Stakeholders focusing on nutritional policy and improvement, most often do not overlap with those working the agricultural domains—and we will need to engage both. Finally, experience has also taught us that many of the poorest, whether rural or urban, have few organized bodies that speak for them at all (although this varies greatly by continent and region, with much of Africa among the more ‘organizationally disadvantaged’). A process of stakeholder analysis and consultation, needs to be *explicitly programmed and budgeted*, by region, and at different decision-making levels—from poor woman farmer up to national ministry, and beyond.

Eventual success will depend on the formation and endurance of range relationships with key organizations. This commitment to extensive and authentic stakeholder consultation has already been tested in the elaboration of this document, which emerges from some eight separate face-to-face meetings, bringing together IARC, NARS, private sector, university scientists, NGO representatives from three different continents. Such consultation has brought fundamental changes in program design. For instance, feedback during the May 2002 meeting in Washington, D.C., led to significant modifications in the proposed structure and process of governance for this Challenge Program.

## 5.3 Human Nutrition Research

Proposals will be solicited for undertaking efficacy trials (and, much later, effectiveness studies) in developing countries. It is anticipated that the proposals selected will involve collaborative partnerships between nutritionists from developing- and developed-country institutions. These studies would necessarily be carried out under the leadership or co-leadership of local institutions.

An ongoing efficacy trial for high-iron rice being undertaken in the Philippines provides an example of how the collaboration will work.[13] The three principal investigators are based at the University of the Philippines at Los Baños (UPLB), Cornell University (CU), and Pennsylvania State University (PSU) in the United States. The trial, using religious sisters in convents as subjects, was originally conceived by the principal investigator from UPLB, who initiated a pilot study in collaboration with staff at IRRI. After the pilot study was completed, the principal investigators from Cornell and PSU were brought in to provide complementary technical expertise and experience in designing a rigorous feeding trial. Contact with all

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[13] This feeding trial is being co-financed by Micronutrient Initiative and DANIDA trust funds administered by the Asian Development Bank.

the convents involved in the trial has been conducted exclusively through UPLB staff. Obviously, then, UPLB has primary responsibility for accomplishing the logistics of the trial over a nine-month period. Several planning meetings took place in Los Baños involving the principal investigators, staff and graduate students from UPLB and PSU, IRRI staff who are responsible for the production, milling, and delivery of the rice to the convents, staff from Waite, where rice samples are being analyzed for iron and zinc content, and an IFPRI staff person in a coordinating and funding administration role. Analysis and publication of the feeding trial data will be undertaken by all three collaborating human nutrition institutions. Specific sub-studies also have been identified in which IRRI, Waite, and IFPRI staff will participate in analysis and publication of the results.

Waite and PSNL staff provided comments and technical advice throughout the planning process. Rice samples were also analyzed at PSNL for iron and zinc as a check against the Waite results, and *in vitro* tests of the high-iron and control rices were screened to determine if there might be gross differences in the bioavailability of the iron between the two rices.

Nutritionists and food scientists from CU, Dhaka University (Bangladesh), EMPRAPA (Brazil), Emory University (USA), Kenyatta University (Kenya), Mahidol University (Thailand), Makarere University (Uganda), PSU, the Royal Veterinary and Agricultural University (Denmark), UPLB, and Wageningen University (Netherlands) have assisted in the writing of this proposal, have attended interdisciplinary technical meetings to plan how the research will be structured, and/or have participated in research cited in this proposal. However, none of these institutions are named as specific collaborating partners in that they will be required to submit proposals under a competitive bidding process.

Effectivness studies, which are the primary program activities related to impact analysis, will also be led or co-led by local nutrition institutions. However, these studies are envisioned as more broadly interdisciplinary, including, for example, impacts on crop productivity, cropping patterns, and household income. The study teams would also include local institutions involved in extension (e.g., NGOs) and the social science departments of the Future Harvest Centers. Any finalized plan for effectiveness studies/impact analysis will be conditioned by program research findings in the initial years. For now, we feel that it is sufficient to state the intention to do impact analysis, provide a budget line item (termed "effectiveness studies"), and state some basic principles (see the discussion on impact analysis in Section 6.2).

## 5.4 Advanced Research Institutions

### *The University of Adelaide, Waite Campus*

The University of Adelaide has a long-standing reputation in research on micronutrients in plants and animals, dating from the formation of the Waite Agricultural Research Institute in 1924.

The Micronutrients Group, led by Robin Graham, operates an analytical laboratory staffed by a manager, an analyst, and two technicians, who together conduct about 40,000 analyses a year to support research in the group and the current CGIAR Micronutrients Project. This laboratory is based on an Inductively Coupled Plasma Optical Emission Spectrometer and an Inductively Coupled Plasma Mass Spectrometer, state-of-the-art new instruments capable of analyzing plant, animal, and human samples for micronutrient elements at the required detection limits with quality assurance certified by the Australian Soil and Plant Analysis Council.

The expertise of the Micronutrients Group lies heavily in the area of the genetics and physiology of micronutrient uptake by plants and distribution to grain, the interaction of micronutrients and disease resistance, the flow of micronutrients in food systems, and the bioavailability of micronutrients in animal models. For this range of interests, the group has established collaborations with geneticists, plant breeders, and molecular biologists in their own department, and with animal and human nutritionists in Animal Science, CSIRO Human Nutrition, the Women's and Children's Hospital, and most importantly, the PSNL at Cornell University for the bioavailability studies. For micronutrient research on plants, the group has the unique advantage of local soils severely deficient in each of several micronutrients. This allows screening of genetic resources for micronutrient efficiency under practical field conditions. This association of expertise, outstanding facilities, and soils that mimic those in Africa, Asia, and elsewhere in the developing world puts the University of Adelaide in a unique position to support the Biofortification Challenge Program. As the Scientific Coordinator of the CGIAR Micronutrients Project from the beginning, Robin Graham has provided field-based micronutrient expertise to the crop leaders in the Micronutrient Project as well as contributing to the strategic development of the program. James Stangoulis has provided similar advice to the NARS in the ADB project that is integrated into the Biofortification Challenge Program, and both will continue to provide this expertise to the Challenge Program, especially to the Tier 2 crop leaders. Additionally, they will continue to provide research leading to the strategic development of the Program in collaboration with Ross Welch (PSNL).

### *The Plant Soil and Nutritional Laboratory (PSNL), USDA-ARS*

For 63 years, the USDA-ARS's Plant, Soil, and Nutrition Laboratory (PSNL), located on the Cornell University campus, has had a mission to improve the nutritional quality of plant foods in sustainable ways through understanding and improving the linkages between agriculture and human health. A primary focus of its mission has been developing bioavailability technologies to test plant foods as sources of micronutrients for people.

From the inception of the CGIAR Micronutrients Project, scientists at the PSNL have played a critical role in directing the bioavailability activities related to the breeding efforts of cooperating Future Harvest centers. The PSNL will continue to lead activities related to testing select genotypes for bioavailable iron, zinc, and pro-vitamin A carotenoid content using the most advanced technologies and methods available. Both an *in vitro* human cell culture model (that is, the Caco-2 cell model) and animal models (pigs and rats) will be employed to screen large numbers of select micronutrient-dense lines of staple food crops for bioavailable levels of iron, zinc, and pro-vitamin A carotenoids using, when appropriate, intrinsically isotope-labeled plant foods. Additionally, to enhance the breeding effort, some research will be conducted to identify ways to reduce the negative effects of anti-nutrients on micronutrient bioavailability, including experiments to identify promoter substances and prebiotic factors in meals that negate anti-nutrient effects on micronutrient bioavailability. Some small-scale human feeding trials are also planned to substantiate findings obtained using the bioavailability models. These bioavailability tests are essential to the project in order to identify promising lines for further advancement in the breeding programs.

### *The Nutritional Genomics Team*

The group from Michigan State University (USA), the University of Freiburg (Germany), and the USDA-ARS Children's Nutrition Research Center, Baylor College of Medicine (USA) will perform research to identify and understand the underlying molecular and biochemical mechanisms of specific genes and loci affecting the nutritional traits of interest in model systems. It will then apply this knowledge, with the assistance and close collaboration of the CGIAR and NARES scientists, to improving micronutrient status in staple crops. Ten years of research by the three labs has already yielded an impressive knowledge base about the pathways and compounds of interest and has been largely responsible for a series of initial high-priority targets in the current proposal. The work plan will use and build upon this knowledge base to put the development and testing of genomic/genetic/molecular-based solutions to problems in micronutrient composition on a fast track. Their efforts will not only enable the development of micronutrient-improved transgenic crops, but also provide needed insights into marker-assisted selection strategies to enhance micronutrient levels in various crops. Transgenic crops will be an important approach when classical breeding approaches alone cannot achieve the target levels of micronutrients. Both approaches will be needed, however, and the nutritional genomics team will provide tools, knowledge, and direction for both types of effort.

### 5.5 Deliverables

Table 10 provides an indicative list of deliverables by time period, encompassing the activities presented in section 4, to be accomplished by the collaborative partners just discussed.

***Table 10: Generic deliverables for six Phase 1 crops (timing and activities vary by crop)***

| **Deliverable** | **Primary institution(s)** | **Period 1 (Years 1-4)** | **Period 2 (Years 5-7)** | **Period 3 (Years 8-10)** |
|---|---|---|---|---|
| **Nutrition** | | | | |
| 1. Optimal breeding objectives determined (relative importance of nutrient interactions, anti-nutrients, and promoters of bioavailability; this is not a crop-specific activity) | University of Adelaide and PSNL (core); Developed- and developing-country nutrition collaborators(competitive) | X | | |
| 2. *In vitro* and animal studies of the bioavailability of Fe, Zn, and beta-carotene in promising lines | PSNL | X | | |
| 3. Bioefficacy studies conducted to determine effects on micronutrient status of human subjects | Developing and developedcountry nutrition collaborators (competitive) | | X | |
| 4. Nutritional effectiveness studies, including identification of factors affecting adoption, impacts on household resource allocation, and welfare of individuals | Developing and developed-country collaborators and Future Harvest centers (competitive) | | | X |
| **Plant breeding** | | | | |
| 1. Germplasm screened for high Fe, Zn, and beta-carotene levels | Future Harvest centers and NARES | X | | |
| 2. Genetically diverse sources of high Fe, Zn, and beta-carotene levels identified in germplasm | Future Harvest centers and NARES | X | | |
| 3. Genotype by environment interactions understood, including effects of cultural practices and processing on micronutrient content | Future Harvest centers and NARES | X | | |
| 4. Genetics of high Fe, Zn, and beta-carotene levels determined and markers made available to transfer these traits to other lines | Developed-country collaborators and Future Harvest centers | X | | |
| 5. Initial crosses of high-yielding, adapted germplasm with high Fe, Zn, and beta-carotene lines; for selected crops (such as sweet potatoes, rice, and beans), promising varieties, identified from initial screening and crosses, released to farmers | Future Harvest centers and NARES | X | | |
| 6. Farmer participatory breeding initiated | Future Harvest centers, NGOs, and NARES | | X | |
| 7. Using marker-assisted selection, high-yielding, conventionally bred, micronutrient-dense lines developed that are well adapted to South Asia, East Africa, Central America, Brazil | Future Harvest centers and NARES | | X | |
| 8. Several gene systems identified with potential for increasing nutritional value (Fe, Zn, and beta-carotene) beyond limits posed by conventional breeding (not a crop-specific activity; | Primarily developed-country collaborators | | X | |

| Deliverable | Primary institution(s) | Period 1 (Years 1-4) | Period 2 (Years 5-7) | Period 3 (Years 8-10) |
|---|---|---|---|---|
| commissioned and competitive) | | | | |
| 9. Transgenic lines produced at experimental level and screened for high Fe, Zn, and beta-carotene levels | Future Harvest centers and NARES | X (Golden Rice only) | X | X |
| 10. Transgenic lines crossed with high-yielding, adapted lines | Future Harvest centers and NARES | | X | X |
| 11. Adapted, nutritious, transgenic cultivars field tested to determine if they meet biosafety regulations (costs of tests not included in budget) | NARES and Future Harvest centers | | X | X |
| 12. Certified seed produced (conventional breeding for deliverables 12-15) | Future Harvest centers and NARES | | X | X |
| 13. Seed multiplied and distributed to farmers | NGOs and NARES | | X | X |
| 14. Social marketing programs undertaken to promote consumption of nutritionally improved varieties | NGOs and developing-country collaborators | | X | X |
| 15. Nutritionally improved varieties adopted on 1.5 million hectares (each crop) | NGOs and NARES | | | X |
| **Policy analysis** | | | | |
| 1. Trends in dietary quality of the poor and factors affecting these trends analyzed; projections of food consumption by the poor undertaken | IFPRI, other Future Harvest centers, developing- and developed-country collaborators | X | X | |
| 2. Analysis undertaken relating food/dietary intakes to changes in levels of micronutrient malnutrition | IFPRI, other Future Harvest centers, developing- and developed-country collaborators | X | X | |
| 3. Benefit-cost analysis undertaken of plant breeding for improved nutrition and of other food-based interventions | IFPRI, other Future Harvest centers, developing- and developed-country collaborators | | X | X |

## 6. Business Plan

The business of achieving the objectives of the Biofortification Challenge Program calls for new ways of working together, both within the CGIAR system and with external partners. A particularly new aspect central to this program is the linkage of agricultural and nutritional objectives. For example, nutritionists play a key role identifying plant breeding objectives for this challenge program. This section presents the justification for this new program, the manner in which it will be managed and governed for optimum impact, communication and outreach efforts, the program's collaborating participants and their roles, program financing and disbursement structure, and fund-raising strategy and activities.

### 6.1 Program Management, Oversight, and Operations

#### *6.1.1 Program Governance and Oversight*

An external Project Advisory Committee (PAC) of experts is being formed to recommend strategic research priorities to the core parties (CIAT and IFPRI), oversee program progress and recommend a transparent competitive grants process to the core parties. The PAC will not be organized as a legal entity but will have delegated authority from the CIAT and IFPRI boards (via electronic resolution, since both bodies meet physically in December) to undertake its mandate as an independent expert body. The initial PAC members will be nominated by CIAT and IFPRI, but subsequent members will be nominated by the PAC itself and approved by the Boards of CIAT and IFPRI. The PAC chair will be expected to maintain close communication with the directors general of CIAT and IFPRI, who in turn will report to their respective boards. The PAC director will make an annual progress report to the CGIAR Science Council.

The directors general of CIAT and IFPRI will report progress to the CGIAR Executive Council annually. Should the Executive Council develop different guidelines for reporting, the program will make any necessary adjustments to comply with such new requirements.

The membership of the PAC will consist of 12 individuals with widely recognized expertise in the following disciplines:

| Members | Backgrounds |
|---|---|
| 2 | Agriculture |
| 2 | Nutrition |
| 2 | Social science/economics |
| 1 | Public health |
| 1 | Ethics |
| 4 | Combination of the above expertise with strong communication and outreach/advocacy skills |

Members will represent a balance of gender and developing- and developed-country citizenship. Membership tenure will be for a four-year, non-renewable term. To stagger the membership terms, the inaugural group's members will have two-, three-, and four-year appointments. Members will be paid an honorarium (based on standard CGIAR rates) and receive reimbursement for expenses related to their participation. The PAC will meet at least two times each year, one of which may be a virtual meeting.

Each year, the program team will present the program's work plan priorities to the PAC for review and approval. The PAC can approve the priorities as they stand or request that the program team make modifications. Funding priorities for both commissioned research and competitive grants for the coming year will be driven by the approved strategic priorities.

The PAC will determine the process for establishing a competitive grants scheme for a portion of the program's funding, with input from the program management team. It is expected that at least 25 percent of program funds over the life of the program will be awarded through a competitive grants mechanism, with a principal focus on identifying breeding objectives and nutrition effectiveness and efficacy studies, as well as some components of the nutritional genomics work. These competitions will be widely announced and open to all organizations, with the exception of the regional collaboration funds, specifically earmarked for developing countries (see description in Program Financing section below). The PAC will establish peer review committees to ensure independent and transparent selection of competitively-awarded grants within the challenge program. The PAC will then make funding recommendations to the core parties for the negotiation and execution of collaborative agreements and include these competitively funded components in its annual progress reviews.

The PAC will also play an advocacy and communications role on behalf of the program. The program leader and communications team will work with the PAC to facilitate the outreach objectives of the program and to facilitate fund-raising activities

In the event of an irresolvable conflict within the PAC or within the program management team, the mediation services of a qualified, independent agent will be sought. Should such mediation not resolve the dispute within an agreed-upon time frame, the core parties agree to seek arbitration services and abide by the final decision of the arbitrator.

### *6.1.2 Operating Framework*

CIAT and IFPRI will enter into a joint venture or similar agreement to jointly manage this challenge program. Each of these core parties will, in turn, enter into agreements or formal understandings with other collaborating organizations to complete the specific program activities and deliver the desired outputs. Many of the proposed collaborating organizations have been working together to develop this program for two to six years already.

Among the issues to be treated in the joint venture or similar agreement between CIAT and IFPRI are:

- Clear definition of the areas of responsibility of the core parties. CIAT will be responsible for coordination of the breeding and genomics components and IFPRI for the nutrition and policy components. Joint efforts to mobilize resources for the program will be conducted by the core parties and seek to involve collaborating organizations as well whenever warranted.
- The handling of funds for all collaborating organizations involved in the program, including those held in trust for other collaborating organizations.
- Human resource management arrangements for program staff, including staff locations, reporting relationships, and terms of employment.
- Arrangements for coordination of program and budget oversight.
- Stipulation of the arrangements for conflict resolution among the parties.

Among the issues to be treated in the agreements between the core parties and other collaborating organizations are:

- Clear definition of the collaborating organization’s responsibilities for delivering specific outputs within a specific time frame.
- Agreed-upon budgets for collaborators, bookkeeping and audit responsibilities.
- Mechanisms for coordination of fund-raising activities for program objectives.
- Adherence to program and CGIAR intellectual property rights policies and international/national biosafety regulatory mechanisms.
- For pertinent collaborators, treatment of the role of institutional review boards in issues such as the involvement of human subjects in studies.
- Principles guiding program research, including a focus on participatory research methods, gender, and equity issues.

These agreements between the core and collaborating parties are necessary because the program's governing body will not have a separate legal identity and fiduciary responsibility will reside with the boards of the individual organizations.

### *6.1.3 Intellectual Property Rights*

The proponents recognize that the management of intellectual property is a critically important issue to the success of the Biofortification Challenge Program. However, intellectual property owners in the private and public sectors cannot enter into licensing agreements with the challenge program itself, due to its lack of legal status. Experience among program collaborators has shown a preference on the part of IP owners to negotiate separate and specific agreements with legally established institutions. Therefore, collaborators in the challenge program will negotiate individual agreements that seek sufficient freedom to operate within the objectives of the program and favorable licensing within the existing and any future CGIAR-approved guidelines. The CGIAR's Central Advisory Service will be consulted for support throughout this process.

Additionally,

1. Results will be published in the public interest as stipulated by collaborating organizations in their formal agreements with the core program parties.
2. Results will be published jointly by contributing scientists.
3. All background intellectual property rights over the materials owned by each collaborator shall remain with that party.
4. If the IPR-protected research outcome as a result of this program is jointly owned by all collaborating parties, each party will have free access to the outcomes of the joint research through a non-exclusive, non-transferable, irrevocable, and royalty-free worldwide license.
5. If the IPR-protected research outcome as a result of this program is wholly owned by one party, the other collaborating parties will have access to the outcomes of the joint research through a non-exclusive, non-transferable, irrevocable, and royalty-free worldwide license.

Should the CGIAR's policies on intellectual property rights change, the core parties to the Biofortification Challenge Program will coordinate the updating of the program's IPR policy to be reflected in any future agreements entered into among partners in the program.

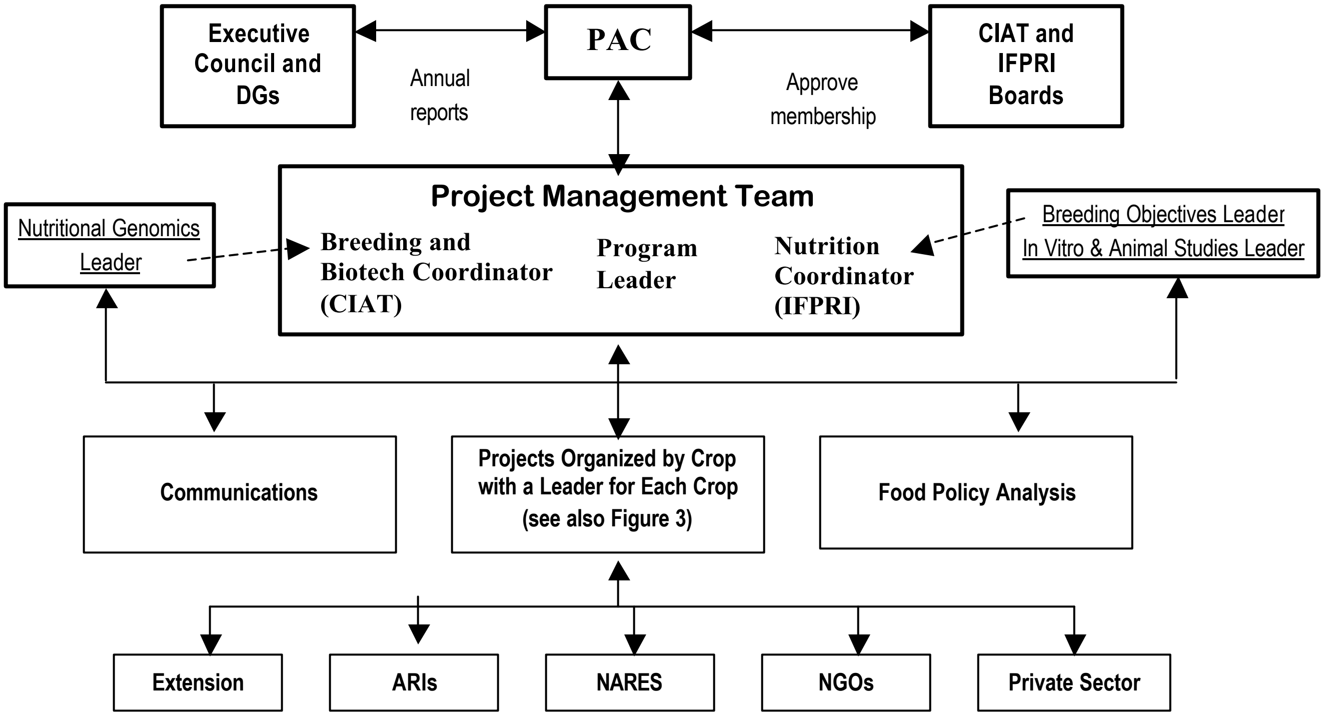
### *6.1.4 Program Staff*

The following professionals will be hired to fill central program positions:

- Program team leader, hired by the core parties, full time;
- Breeding and biotechnology coordinator, hired by CIAT, full time;
- Nutrition coordinator, hired by IFPRI, half time;
- Communications specialist, hired by the center housing the program team leader, full time; and
- Administrative coordinator, hired by the center housing the program team leader, full time.

The program team leader will hold a joint appointment to CIAT and IFPRI. CIAT and IFPRI will be responsible for hiring the program team leader based on the recommendation of the Program Advisory Committee. As one of its initial priorities, this committee will conduct the review of candidates for this position. The PAC will analyze the cost and other benefits of the location of the program team leader, communications specialist, and administrative coordinator and make a recommendation to the core parties that also considers the location preferences of the principal candidate(s) for the program leadership. A breeding coordinator hired by and based at CIAT will coordinate all breeding, nutritional genomics, and dissemination activities with collaborating organizations. Similarly, a human nutrition coordinator hired by and based at IFPRI will oversee the work of partners involved in the bioavailability and nutrition studies, as well as the impact evaluation activities. A communications specialist will coordinate the program's internal and external communications efforts, described in more depth below. The administrative coordinator will oversee the budget and subcontract performance, coordinate travel and meeting arrangements, and provide general clerical support to the program.

***Figure 4: Overview of the program governance structure***



The program's operations will be coordinated by a three-person program management team (PMT) consisting of the breeding and biotech coordinator and the human nutrition coordinator who will report to the program team leader. The PMT, in consultation with program collaborators, will prepare annual work plans for the various components of the program, for review and approval by the PAC. The PMT will evaluate solicited proposals under the competitive grant mechanism and provide recommendations to the PAC. The PAC will have final authority and approval over the annual work plans and selection of competitive proposals to be funded.

Robin Graham (University of Adelaide) will be designated as the leader of the breeding objectives research (reporting to the nutrition coordinator); Ross Welch (Plant, Soil, and Nutrition Laboratory) will be designated as the leader of the animal and *in vitro* studies (reporting to the nutrition coordinator); Dean DellaPenna (Michigan State University) will be designated as the leader of the nutritional genomics activities (reporting to the breeding and biotech coordinator). This formalizes responsibilities for developing annual work plans and reporting on progress for activities in these core areas. As part of his responsibility as leader of the breeding objectives research, Robin Graham produce reports on strategic directions for the project, based on project research, input from other project participants, and contacts and literature gathered from outside of the project.

### *6.1.5 Coordination activities*

***Meetings.*** An annual coordination meeting will be held to bring together the entire group of collaborating organizations and review progress on work plans, align and coordinate goals and objectives for the coming year's work, identify obstacles, and suggest solutions or course corrections. The PAC will meet during or following this annual meeting to review the results and make recommendations on strategic priorities and directions for the coming year, assessing the scientific rigor of the planned and executed program work.

It is expected that program component satellite meetings will be arranged around significant global or regional meetings attended by numbers of program collaborators in order to keep travel costs under control. These meetings will also serve an outreach purpose as they represent opportunities to involve and inform a broader scientific and development community in the program's progress. This model has been successfully employed in the past six years to raise awareness about the potential of a biofortification approach to address problems of micronutrient malnutrition.

***Program Inreach.*** The Biofortification Challenge Program is a multi-national, multi-sectoral, multi-disciplinary, multi-crop, multi-nutrient, and multi-partnered undertaking. For this reason an information web is envisioned with a communications hub at its center but with independent communication activities taking place among the partners.

Program communications will benefit by taking full advantage of the latest collaborative technologies. Through Virtual Private Networking (VPN) the program will use broadband technologies now available in many collaborating organizations to assist in the sharing of information across the research program and to provide secure access to networked applications by remote users on a round-the-clock basis. Such a network will enable real time communication and improved information exchange. The linking with other existing networks, such as the World Bank's Global Development Learning Network, will be explored to add value and versatility to the program's internal communications.

A communication resource library will be established to provide communications tools for the research team. Publications, slide presentations, photo libraries, and contact databases will be made available to all members of the program. These services will be housed with the communications specialist. Because program coordinators, the program leader, researchers, and members of the PAC will serve as ambassadors for the program, media training will also be made available to sharpen their communications and advocacy skills.

### 6.2 Impact Evaluation Strategy

Of necessity this program is long-term in nature with several types of research involved: diagnostic, basic, strategic, participatory, applied, and adaptive. These are not necessarily conducted in a sequential manner but sometimes in unison. As a result impact assessment will of necessity rely on a range of indicators of progress and success.

In carrying out proposed effectiveness studies, essential to this process will be careful attention to the initiation of benchmark or baseline studies in representative households, villages, environments, and countries where the challenges of micronutrient deficiencies are perceived to be most acute. Diagnostic and participatory components can be undertaken in the same sites. By selecting a set of "control" and "treatment" sites, appropriate "with-and-without" comparisons can be made. Studying the same households and villages over an extended period of time provides a set of panel data that also allows "before-and-after" assessments. Both dimensions are required to properly evaluate causes and effects.

The benchmark sites should feature:

- the major cropping systems using typologies;
- the major micronutritionally deprived regions;
- regions with both high and negligible adoption of existing high-yielding-varieties (HYVs) of the target crops;
- the range of typical processing/cooking systems for the target crops; and

- a willingness on the part of participants to be involved for 10 years or more in the studies.

The indicators that would be assembled over time in the benchmark sites and from other sources would comprise five primary categories.

***Outputs:*** Publications refereed and otherwise; documentation of benefits/trade-offs in yields and other desired traits from increased micronutrient contents;

***Outcomes:*** Derived demand by NARES and others for collaboration in the program and supply of genes/breeding lines/elite materials; invitations to present papers to key fora;

***Influence:*** Increased government and donor support; inclusion of genetic materials in R&D projects;

***Nutrition and Health Impacts****:* Reduction in prevalence of micronutrient deficiencies among various age and gender groups and improvements in selected health indicators

***Socioeconomic Impacts****:* (1) *Intermediate:* Number and extent of trials, breeding lines and releases; (2) *Final:* Seed production, demand, and adoption; benefits of micronutrient-dense cultivars for nutrition and income compared with "control" households and villages, traditional landraces, and existing HYVs; spillovers to other villages and urban areas.

### 6.3 Program Communication and Outreach Efforts

Unlike traditional communication strategies within the CGIAR, the Biofortification Challenge Program must develop complementary communications strategies for two sectors: agriculture and human nutrition. Just as those who are interested in agriculture are fed information that meet their needs, so must nutrition stakeholders be fed the research findings to inform their choices. Without this dual-discipline approach to communications, biofortified crops will have difficulty thriving as a tool for public health.

Beginning with the program's research staff, the communications specialist will work to assist the scientists in the placement, design, and presentation of their material for a variety of audiences. The communications specialist in collaboration with the research staff will work to layer the peer-reviewed research findings—each layer differing in its level of complexity and emphasis—to meet the needs of multiple audiences, encompassing the full range from expert to uninformed public. All audiences are important to the success of the program, but each audience needs tailored information.

Different stakeholders rely on different sources of information. Experts regularly review professional journals for methodologies and research findings. The informed look toward summaries, research briefs,

#### Box 8: Communications for Biofortification

Public relations strategies are especially important when novel and complex technological methods are involved. Given the global implications of this multisectoral research project, it will require a sustained communications effort to enhance the academic credibility of the project and to educate professionals, policymakers, and the general public in the fields of both agriculture and nutrition. The project will design and disseminate information for all audiences, translating highly technical information into compelling, easy-to-assimilate material for the general public. Research publications for experts will also serve as the foundation for many spin-off products, including newsletters, policy briefs, and donor summaries. List-serves, websites, and other Internet communications gateways will be exploited as fora for generating interest in research findings, which will be made available in English, French, Spanish, and Portuguese. See Appendix for detailed communication strategy.

newsletters, workshops, and conferences for information. The general public turns to the news media for information. All audiences rely on the Internet.

The collective network of communications resources across the collaborating organization centers will constitute an extensive web of information channels. While the program will continue to make use of the traditional communication channels for distributing publications, the Biofortification Challenge Program will also use more pioneering channels and mechanisms for communication brought about by the Internet and other forms of information technology. Radio, television, and news media will be regularly tapped to give the general public and decision-makers access to the program findings.

Social marketing is a concept developed in the 1970s that channels the same principles developed to sell products into selling ideas, attitudes, and behaviors. This technique has been used extensively in international health programs, especially for contraceptives and oral rehydration therapy (ORT). The extent to which the Biofortification Challenge Program will need to employ up-to-date social marketing techniques will vary depending on the crop and the introduced nutrient. An effective social marketing strategy will need to determine whether there is a perceived price to pay for nutritionally enhanced crops—what are the opportunities and the threats to farmer and, ultimately, consumer acceptance? Strong partnerships will need to be established to aid in promoting the varieties. Here the NGOs, national health networks, and NARES will be at the center of activity. Local women's organizations, community nutrition programs, private sector partners, and civic organizations will be the program's allies. Useful vehicles may include public service announcements, mass mailings, media events, and community outreach efforts appropriate to the local cultural context.

### 6.4 Parties and Roles

CIAT and IFPRI will be the core parties responsible for the managing and executing the Biofortification Challenge Program. Additionally, a large number of collaborating organizations from developing and developed countries will play a coordinated role in achieving the program's objectives. The list of collaborating organizations is expected to expand significantly as the program matures and makes linkages with more regional and national partners and donors.

***Table 11: Collaborating organizations***

| TYPE OF ACTIVITY | **PROGRAM PARTICIPANTS** (listed alphabetically by crop/area) |
|---|---|
| **Plant breeding/biotechnology** | |
| Central coordination | International Center for Tropical Agriculture (CIAT), Colombia |
| ***Phase 1** crops* | |
| Rice | Bangladesh Rice Research Institute<br>Central Research Institute for Food Crops (Indonesia)<br>Cu Long Delta Rice Research Institute (Viet Nam)<br>International Rice Research Institute (IRRI), Philippines<br>Kaesetsart University (Thailand)<br>Philippine Rice Research Institute<br>Research Institute for Rice (Indonesia)<br>University of the Philippines at Los Banos |
| Wheat | International Maize and Wheat Improvement Center (CIMMYT), Mexico<br>Selected NARES, including Ethiopia, India and Pakistan |
| Maize | Brazilian Agricultural Research Corporation (EMBRAPA), Brazil<br>CIMMYT, Mexico<br>International Institute of Tropical Agriculture (IITA), Nigeria<br>Selected NARES in Sub-Saharan Africa and Latin America, including Ghana, Zambia, Brazil and Guatemala |
| Cassava | Brazilian Agricultural Research Corporation (EMBRAPA), Brazil<br>CIAT, Colombia<br>IITA, Nigeria |

| TYPE OF ACTIVITY | PROGRAM PARTICIPANTS (listed alphabetically by crop/area) |
|---|---|
| | Selected NARES partners in Africa, Asia and Latin America/Caribbean |
| Common bean | Brazilian Agricultural Research Corporation (EMBRAPA), Brazil |
| | CIAT, Colombia |
| | Selected NARES/University partners in Africa and Latin America, including Brazil, Colombia, Haiti, and the bean research networks PROFRIJOL (Central America), ECABREN (eastern Africa), SABRN(southern Africa) |
| Sweet potato | International Potato Center (CIP), Peru |
| | Selected NARES partners in Africa, including Ethiopia, Kenya, South Africa, Tanzania, Uganda, and the regional research network PRAPACE |
| *Phase 2 Crops* | |
| Barley | International Center for Agriculture in Dry Areas (ICARDA), Syrian Arab Republic |
| Banana | IITA, Nigeria |
| | International Network for the Improvement of Banana and Plantain (INIBAP), France |
| Cowpea | IITA, Nigeria |
| Groundnuts | International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India |
| Lentils | ICARDA, Syrian Arab Republic |
| Millet | ICRISAT, India |
| Pigeon peas | ICRISAT, India |
| Plantain | IITA, Nigeria |
| | INIBAP, France |
| Potato | CIP, Peru |
| Sorghum | ICRISAT, India |
| Yams | IITA, Nigeria |
| Sample analyses and other technical support | Waite Agricultural Research Institute, University of Adelaide, Australia |
| | Other partners as identified |
| Adaptive breeding and dissemination | Selected NARES as specified above by crop |
| Dissemination | Selected NGOs and communications and extension specialists from NARES |
| | Institutions expressing support/willingness to participate to date: |
| | CARE |
| | Helen Keller International |
| **Nutritional genomics** | ***Components of this work will be subject to a competitive grants process*** |
| Iron | USDA-Agricultural Research Service, Children's Nutrition Research Center, Baylor College of Medicine, Houston, Texas, USA; University of Freiburg, Germany, and others as selected |
| Zinc | USDA-ARS, Children's Nutrition Research Center, Baylor College of Medicine, Houston, Texas, USA, and others |
| Carotenoids, Vitamin A | University of Freiburg, Germany; Michigan State University, USA, and others |
| **Human nutrition** | ***Components of this work will be subject to a competitive grants process*** |
| Overall coordination | International Food Policy Research Institute (IFPRI), USA |
| Identifying optimal breeding objectives | Selected developed- and/or developing-country institutions |
| *In vitro*, animal studies | USDA-ARS Plant Soil Nutrition Laboratory (PSNL), USA |
| Efficacy studies | Selected developed- and developing-country universities/institutes |
| Effectiveness/Impact studies (impact subcomponent) | Selected developed- and developing-country universities/institutes in collaboration with social science departments of relevant Future Harvest centers |
| **Policy analysis** | IFPRI, USA and developed- and developing-country institutions |

## 6.5 Program Financing

### *6.5.1 Funding Mechanisms*

Program funds are being raised to finance activities through three mechanisms: commissioned activities, competitively awarded grants, and central program management functions. Additionally, the program will encourage the linking of complementary efforts with closely-aligned objectives under the umbrella of crop biofortification.

***Commissioned activities*** include those undertaken by collaborators in areas central to the core program pillars of nutrition, nutritional genomics, breeding, and policy analysis. Some central program services, such as sample analyses and plant nutritional pathway elucidation, will also be commissioned by the program to ensure consistency of results and obtain efficiencies of scale.

***Competitive grants*** will be awarded in open competitions. An important aim of these competitive grants will be to widen the pool of developing-country institutions and networks participating in the challenge program, thus building national and regional capacity in the target regions for the program. The PAC will determine a process for administering these open competitions, including peer review mechanisms, to ensure independence and transparency in the awarding of grants within the challenge program.

***Central program activities*** include the administration, coordination, outreach, and fund-raising activities needed to manage the overall program. These have been described in detail in the management and oversight section above.

***Complementary efforts*** include those present and future projects whose objectives are closely aligned with those of the challenge program, but not receiving direct funding from the program. Under this mechanism, institutions may seek formal endorsement from the program to assist in leveraging funding for projects whose outcomes broadly fall under the umbrella of biofortification. This endorsement could be particularly helpful to national and regional institutions seeking to tap bilateral funding for projects addressing particular needs outside the challenge program's target geographic regions, crop or micronutrient focus. Similarly, advanced research institutes could seek to align their projects with the challenge program to attract new financing while advancing common goals.

### *6.5.2 Strengthening Regional Collaboration*

The program budget includes US$3.2 million in centrally administered funds specifically earmarked for developing countries in the first 4-year period, in addition to the collaborative and institutional development activities budgeted at US$15.3 million within the different program areas for all types of non-CGIAR partners. These US$3.2 million will be available on a competitive basis to national & regional programs/institutions in Africa, Asia and Latin America with proven capacity in core program pillar areas of nutrition, breeding/biotechnology, policy analysis, and in consortium leadership. These strong institutions can help build the capacity of others in the regions and serve as models of what can be accomplished in the developing tropics. Brazil, China, South Africa, and Thailand are examples of countries with institutions of demonstrated strength in core program pillar areas and could assume such a role in regional collaborative efforts. Even trans-regional programs may be possible. For example, research on cassava in Brazil may be applicable to Africa, experience with adoption of yellow/orange sweet potato varieties in Africa may be shared with Asian and Latin American institutions, and expertise in human nutrition may be applied in all three of these regions.

Implementation of such national and regional biofortification programs for specific crops under complementary funding managed by selected NARES is envisioned as an additional type of collaborative activity. Under this scheme, scientifically- and institutionally-strong NARES, partnered with human nutrition institutes in the relevant country or region, would undertake projects not only to develop, test, and disseminate nutritionally-improved lines nationally or regionally, but also to build institutional capability (agricultural research and human nutrition) locally and in neighboring countries to themselves undertake biofortification-relevant activities.

Depending on the level of interest among various NARES across many countries in pursuing multi-year projects for several staple food crops, funding requirements for these national and regional biofortification projects potentially could be quite substantial. These programs, therefore, will likely depend primarily on bilateral or regional funding targeted for that country or region. NARES wishing to develop proposals to secure such funding can find support from the Biofortification Challenge Program in these efforts by linking their work to the challenge program. The Biofortification Challenge Program will increase the probability of securing funds for these national and regional programs in four important ways:

- Counterpart funding is provided in a program budget line to partially support three initial such programs, one in Asia, one in Africa, and one in Latin America;
- The proposals will be evaluated and endorsed to donors by the PMT and PAC;
- The projects will operate under the umbrella of the challenge program; representatives of the national and regional programs will attend annual program meetings and report on progress; this progress will be evaluated by the PMT and PAC; and
- Core technical assistance (such as by the relevant CGIAR center, University of Adelaide, PSNL, and/or the nutritional genomics team) will be made available as requested; this core technical assistance will be funded centrally without charge to the national or regional biofortification program.

### *6.6.3 Designation of Funding*

Donors are encouraged to provide the least restrictive support possible to the challenge program. Broad support is critical to allowing all of the program's components to proceed according to an efficient work plan. However, many donors opt to target their funding for a particular component of a larger program that may be more aligned with internal donor goals than others. Recognizing this reality, the Biofortification Challenge Program will accept donor-designated funds and will ensure that the funding is directed for its intended use.

It is expected that central program activities will be funded with a portion of the funding made available to challenge programs from the World Bank. It may prove necessary to scale some central program activity budget lines to reflect actual funds available. Any remaining World Bank funds will then be disbursed through the competitive grants and commissioned program activity mechanisms with a strong preference for supporting collaborators in key underfunded strategic priority areas and national organizations in target regions of program operations. The PAC will approve the priorities for allocating these funds, based on the recommendation of the PMT.

## 6.6 Fund-Raising Strategy and Activities

The Biofortification Challenge Program has been in development for several years and elements of the program are already underway. A logical continuation of the feasibility research begun under the CGIAR Micronutrients Project in 1995, this program aims to take the research out of the labs and develop and deliver improved biofortified crops to raise the nutrition status of the poor in the developing world.

Research on the feasibility of the biofortification strategy (1995-2001) was funded primarily by DANIDA (US$1.2 million) with contributions also from USAID and ACIAR. An inception - planning meeting for this work was held in 1994, supported by USAID and USDA-ARS. The results of this work to date were reported at a CGIAR-wide conference on human nutrition in 1999, organized by IFPRI and hosted by IRRI, which was funded by USAID, Norway, and USDA-ARS. Funding from the Asian Development Bank (US$1.3 million) and USAID for further development of high-iron rice was approved approximately one year after this conference. DANIDA trust funds administered by the ADB and funding from Micronutrient Initiative are supporting the high-iron rice feeding trial.

Apart from the CGIAR Micronutrients Project, the Rockefeller Foundation and USAID have supported and are continuing to support the further development of Golden Rice.

Detailed crop and nutrition work plans for this proposed program have been developed by scientists from collaborating organizations following a planning meeting held at CIAT in March 2000. Prospective donor consultations and the incorporation of feedback of external experts into the proposal have been ongoing since then. Presentations on the proposed program have been made at a number of donor agencies, and resource mobilization efforts are underway to translate the positive reception the proposal has received into concrete funding commitments. Active cultivation of donor interest has been ongoing with the following donors: DANIDA, ADB, USAID, CIDA, the Rockefeller Foundation, the Bill and Melinda Gates Foundation, and Japan.

CIAT and IFPRI are partnering on these efforts on behalf of all collaborating organizations in the program. Additionally, all partners are contributing to the resource mobilization efforts through their contacts in the donor community, particularly among private foundations with international development and health interests. Presentations made at numerous scientific and donor meetings have generated a high level of confidence among the program participants that full funding of the program will be possible.

Since donors operate on funding cycles that are shorter than the envisioned 10-year life of the program, all work plans have been structured into three phases of 4, 3 and 3 years with specific deliverable milestones identified in each area work plan. These milestones will allow donors to assess the impact of their support and consider renewal for subsequent phases of activity.

Because this program represents a bridge between agricultural research and development action for improved health status, there is a good possibility of mobilizing resources from funding windows not traditionally available to strictly agricultural research projects, even within the community of CGIAR member governments. USAID has made an initial commitment of US$1 million to this program for 2002, recently expanded to an additional $1 million for the following year, with half of the funding from non-traditional windows. High vitamin A sweet potato development is being supported in Africa by a number of donors. Organizations already working in the field of improving the micronutrient content of crops have joined the program in recognition of the value of presenting a coordinated, unified agenda to donors interested in significant impact that will advance the Millenium Development Goals.

In the first half of 2002 proposal development and refinement activities have included a meeting of potential and committed stakeholders in May to gather input for the design of the program, to agree upon the specific governance and oversight mechanisms, and to formulate a funding strategy.

An additional meeting of program scientists, including external partners and representatives of NARES and NGOs active in the program's target regions was held in April to discuss (1) the iSC comments on the proposal and make adjustments to the document; (2), program management and governance to ensure transparency; and (3) revisions to the proposal and a work plan for its completion. The group also discussed the allocation of USAID funds for implementing a biofortification strategy in Africa.

This planning activity within the program and its larger stakeholder community will help ensure that as donor funding comes on stream initially there is a clear and agreed-upon agenda for implementing elements of the overall work plan. It has been particularly useful during this period to incorporate input from regional NARES, NGOs, and health/nutrition agencies to ensure effective implementation of the program and good communication among interested parties. For example, CARE and Helen Keller International have expressed a strong interest in joining the program, and will bring significant strengths in dissemination, adoption and resource mobilization to the effort.

The Micronutrient Initiative has provided advice and financial support to the development of this program in the form of participation of its executive director and a senior scientist in program development meetings and with a program development grant. The convening power of the Bill and Melinda Gates Foundation has assured excellent representation of potential donors and stakeholders throughout the process of developing this program. The Executive Committee of the CGIAR has generously supported the development of the challenge program proposal, permitting more extensive consultation and involvement of NGOs and health and agricultural systems representatives from Africa, Asia, and Latin America.

The core parties are confident that the timing is right for this proposal within a range of donor groups, including traditional CGIAR donors, some non-traditional windows within those donor governments (for example, health and nutrition), and new prospective donors. The logic of applying CGIAR-supported expertise to address problems of micronutrient malnutrition has sounded a fresh note with many donors, some of whom were once skeptics of the value of such an approach. Of particular note has been the growing acceptance within the nutrition science community of a biofortification approach as a complement to existing interventions that offers hope to improve the health status of those groups that suffer most from the effects of micronutrient malnutrition -- pregnant women and children under the age of five. The marriage of the agricultural and nutrition sciences represented by this proposed challenge program holds the promise of bearing fruits that will change the way agricultural research is viewed as a tool for development throughout the world for years to come.

## 6.7 Program Budget

The indicative budget on the following pages summarizes the details contained in each of the crop and area budgets included in the Appendixes. The individual crop and area budgets will be updated and formalized in the individual agreements between the core parties and collaborating partners, including those chosen through a competitive process.

***Table 12 Percentage of Program Funds to NARES and Other Non-CGIAR Partners by Area and Period***

| | Period I | Period 2 | Period 3 | Total |
|---|---|---|---|---|
| **Phase I Crops** | 19% | 28% | 32% | **25%** |
| **Nutr. Genomics** | 90% | 90% | 90% | **90%** |
| **Nutrition** | 100% | 100% | 100% | **100%** |
| **Policy Analysis** | 0% | 0% | 0% | **0%** |
| **Communications** | 0% | 0% | 0% | **0%** |
| **Program Management** | 0% | 0% | 0% | **0%** |
| **Phase II Crops** | 11% | | | **11%** |
| **Regional Collaboration** | 100% | 100% | 100% | **100%** |
| **Total** | **39%** | **44%** | **42%** | **40%** |

## *Table 13: Indicative budget*

| (thousands of US$) | BASE | | | | | OPTIMISTIC | | |
|---|---|---|---|---|---|---|---|---|
| **Base Budget Phase 1 Crops** | Year 1 | **Year 2** | **Year 3** | **Year 4** | **Period 1 (yr. 1-40) Total** | **Period 2 (yr. 8-10) Total** | **Period 3 Total** | **Grand Total** |
| **PHASE 1 PLANT BREEDING & BIOTECHNOLOGY[1]** | | | | | | | | |
| **Personnel** | 1,217 | 1,443 | 1,597 | 1,543 | **5,799** | 3,176 | 2,237 | **11,212** |
| **Operations** | 791 | 893 | 898 | 901 | **3,482** | 2,239 | 1,719 | **7,441** |
| **Institutional Development** | 285 | 300 | 295 | 210 | **1,090** | 643 | 620 | **2,353** |
| **Collaborative Activities** | 270 | 355 | 413 | 472 | **1,510** | 1,478 | 1,322 | **4,310** |
| **Other** | 250 | 253 | 201 | 175 | **879** | 393 | 255 | **1,527** |
| **Indirect Costs** | 574 | 665 | 694 | 704 | **2,636** | 1,697 | 1,302 | **5,635** |
| **CROP TOTALS** | | | | | 15,397 | | | |
| Beans | 444 | 434 | 535 | 562 | **1,975** | 1,701 | 1,325 | **5,000** |
| Cassava | 604 | 688 | 723 | 727 | **2,742** | 1,502 | 558 | **4,802** |
| Maize | 631 | 774 | 805 | 884 | **3,094** | 2,029 | 1,365 | **6,488** |
| Rice | 539 | 781 | 786 | 715 | **2,821** | 1,620 | 1,243 | **5,684** |
| Sweet Potato | 455 | 495 | 490 | 355 | **1,795** | 1,110 | 1,140 | **4,045** |
| Wheat | 480 | 495 | 510 | 525 | **2,010** | 1,665 | 1,825 | **5,500** |
| Crop Trace Mineral Assistance | 234 | 241 | 248 | 236 | **959** | | | **959** |
| **TOTAL PHASE 1 CROP BREEDING & BIOTECHNOLOGY** | **3,387** | **3,908** | **4,097** | **4,004** | **15,397** | **9,626** | **7,455** | **32,478** |
| **NUTRITIONAL GENOMICS[2]** | | | | | | | | |
| Personnel | 750 | 773 | 796 | 820 | **3,138** | 2,327 | 2,066 | **7,531** |
| Operations | 860 | 216 | 223 | 229 | **1,529** | 611 | 501 | **2,640** |
| Indirect Costs | 270 | 218 | 225 | 232 | **944** | 621 | 504 | **2,069** |
| **TOTAL NUTRITIONAL GENOMICS** | **1,880** | **1,207** | **1,243** | **1,281** | **5,611** | **3,558** | **3,072** | **12,241** |
| **NUTRITION** | | | | | | | | |
| Breeding Objectives | 635 | 651 | 667 | 683 | **2,636** | 0 | 0 | **2,636** |
| In Vitro & Animal Studies[3] | 854 | 560 | 617 | 732 | **2,763** | 575 | 0 | **3,338** |
| Efficacy Trials | 305 | 493 | 807 | 1,004 | **2,609** | 386 | 0 | **2,995** |
| Impact/Effectiveness | 356 | 359 | 131 | 167 | **1,013** | 2,768 | 2,698 | **6,479** |
| Indirect Costs | 388 | 397 | 401 | 509 | **1,695** | 707 | 574 | **2,975** |
| **TOTAL NUTRITION** | **2,537** | **2,459** | **2,623** | **3,096** | **10,715** | **4,436** | **3,272** | **18,423** |
| **POLICY ANALYSIS** | | | | | | | | |
| Personnel | 168 | 174 | 181 | 189 | **712** | 612 | 689 | **2,013** |
| Operations | 35 | 35 | 50 | 35 | **157** | 136 | 121 | **414** |
| Indirect Costs | 52 | 53 | 59 | 57 | **222** | 191 | 207 | **619** |
| **TOTAL POLICY ANALYSIS** | **255** | **263** | **291** | **281** | **1,090** | **939** | **1,017** | **3,046** |
| **COMMUNICATIONS** | 0 | 0 | 0 | 0 | **0** | 0 | 0 | **0** |
| Personnel | 95 | 99 | 103 | 107 | **404** | 347 | 391 | **1,142** |
| Communications Activities | 184 | 184 | 109 | 109 | **586** | 327 | 327 | **1,239** |
| Indirect Costs | 71 | 72 | 54 | 55 | **252** | 172 | 183 | **607** |
| **TOTAL COMMUNICATIONS** | **350** | **355** | **266** | **271** | **1,242** | **846** | **900** | **2,988** |
| **PROGRAM MANAGEMENT[4]** | | | | | | | | |
| Personnel | 453 | 470 | 488 | 507 | **1,918** | 1,641 | 1,838 | **5,398** |
| Operations | 345 | 345 | 345 | 345 | **1,379** | 1,034 | 1,034 | **3,448** |
| Project Director | 197 | 201 | 206 | 211 | **815** | 663 | 713 | **2,191** |
| **TOTAL PROGRAM MGMT** | **995** | **1,016** | **1,039** | **1,063** | **4,113** | **3,338** | **3,586** | **11,037** |
| | | | | | | | | |
| **TOTAL BASE BUDGET** | **9,403** | **9,209** | **9,559** | **9,996** | **38,167** | **22,744** | **19,302** | **80,213** |
| **TOTAL PHASE 2 DIVERSITY CROPS[5]** | **1,247** | **1,488** | **1,143** | **1,068** | **4,946** | | | **4,946** |
| **Strengthening Regional Collaboration[6]** | **800** | **800** | **800** | **800** | **3,200** | | | **3,200** |
| **GRAND TOTAL BUDGET** | **11,450** | **11,497** | **11,502** | **11,864** | **46,313** | **22,744** | **19,302** | **88,359** |

***Budget Notes:***

The Biofortification Challenge Program is seeking US$46,313,000 for an initial 4-year period. The complete vision for this program spans a 10-year time frame and includes six base crops, called *Phase 1 crops*, and 11 crops considered important for a diversified diet for the poor in the program's target regions in Africa, Asia, and Latin America, called *Phase 2 diversity crops* here. The absolute base budget is shown in the first period for the Phase 1 crops (US$38,167,000). The program proponents and stakeholders strongly believe that the extended base budget, including the Phase 2 diversity crops and the regional collaboration support funds, should be endorsed as the challenge program's base budget for an initial 4-year period.

1. **Crop Breeding and Biotechnology** – Includes breeding, genomics, seed multiplication and diffusion efforts, including collaborative activities with NARES and NGO partners as detailed in individual crop appendices.
2. **Nutritional Genomics** – Twenty percent of these funds will be awarded through a competitive grants process.
3. ***In vitro* and Animal Studies** – This represents commissioned work. The remainder of the nutrition budget will be awarded through a competitive grants process.
4. **Program Management** – Includes Program Leader, Communications, Administrative Coordinator, Program Advisory Committee, Breeding and Nutrition Coordinators. These last two positions hold research responsibilities in addition to their coordination functions.
5. **Phase 2 Crops** – Budgeted for Period 1 only at present. The PAC will evaluate progress and recommend for further development crops demonstrating high potential in later phases, with additional funding to be sought.
6. **Regional Collaboration** – These funds are earmarked only for developing country programs and institutions as described in section 6.6.2.

***Table 14: Detail of Phase 2 Diversity Crop Budgets (in thousands of US$)***

| **All Phase 2 Diversity Crops** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Total** |
|---|---|---|---|---|---|
| Personnel | 313 | 315 | 294 | 291 | 1,212 |
| Operations | 573 | 713 | 495 | 373 | 2,153 |
| Institutional development | 39 | 66 | 54 | 114 | 273 |
| Collaborative activities | 65 | 89 | 85 | 91 | 330 |
| Others | 49 | 54 | 24 | 24 | 150 |
| Indirect costs | 209 | 251 | 192 | 176 | 828 |
| **Total Extended Base** | **1,247** | **1,488** | **1,143** | **1,068** | **4,946** |
| | | | | | |
| **Sorghum, Groundnut, Millet, Pigeonpea** | 414 | 414 | 414 | 414 | 1,655 |
| **Barley, Lentil** | 200 | 228 | 193 | 219 | 839 |
| **Cowpea, Yam, Banana, Plantain** | 526 | 742 | 437 | 339 | 2,043 |
| **Potato** | 108 | 105 | 100 | 97 | 408 |
| **TOTAL** | **1,247** | **1,488** | **1,143** | **1,068** | **4,946** |

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# APPENDIXES

## Appendix 1 —Description of Supporting Documents Available Through the IFPRI FTP Site

### Instructions for Access

**Internet Address:** ftp://ftp.cgiar.org/ifpritemp/Biofortification_proposal

When clicking on a desired file, you will be prompted for a password (identical password for all files). If you have not been given the password, please contact Shellemiah Keya, Executive Secretary, iSC Secretariat (s.keya@cgiar.org) or Howarth Bouis, IFPRI (mailto:h.bouis@cgiar.org).

Where relevant, files contain detailed justifications, work plans, deliverables, and budgets by crop or program component area.

### List of PDF Files

### Files in Root Directory

1. Biofortification Challenge Program proposal
2. Nutritional Genomics
3. Food Policy
4. Communications Strategy
5. Letters of Endorsement

### Folder Name -- Nutrition

1. Identifying Long-Run Breeding Objectives
2. In vitro and Animal Models
3. Efficacy Trials

### Folder Name -- Phase 1 Crops

1. Beans
2. Cassava
3. Maize
4. Rice
5. Sweet Potatoes
6 Wheat

### Folder Name -- Phase 2 Crops

1. Barley and Lentils
2. Cowpeas, Yams, Plantains, Bananas
3. Groundnut

4. Millet
5. Pigeonpea
6. Potato
7. Sorghum

**Folder Name -- Meeting Participants**

1. Inception meeting, Annapolis, January, 1994
2. Agriculture-nutrition linkages, IRRI headquarters, October, 1999
3. High-iron rice inception meeting, IRRI headquarters, November, 2000
4. High-iron rice first annual meeting, Cantho, Viet Nam, February, 2002
5. Donor briefing, CIAT headquarters, January 2001
6. Expanded biofortification proposal, CIAT headquarters, March 2001
7. Revisions of biofortification proposal, Houston, Texas, April, 2002
8. Stakeholder meeting, World Bank headquarters, May, 2002

# Appendix 2 —Description of Meetings, Consultations, and Other Activities in Developing the Biofortification Challenge Program Proposal

This appendix briefly describes the major meetings and consultations which have been held in the development of the Biofortification Challenge Program proposal. Many of the proposed components of the Program and collaborative arrangements have evolved from the CGIAR Micronutrients Project, so that these activities are included in the discussion. During 1994-2002, several collaborators in the CGIAR Micronutrients project have presented the biofortification strategy at a large number of plant science and human nutrition forums throughout the world. These are not listed here but selected publications coming out this work are listed in Appendix 4. A list of participants, their titles and organizations, are provided in files at the IFPRI ftp site. See Appendix 1 for instructions on how to access these files.

## 1. CGIAR Micronutrients Project

### 1.1 Inception meeting, Annapolis, Maryland, USA, January, 1994

In 1993, USAID funding became available to IFPRI to consult with Future Harvest Centers to identify activities which could be undertaken within the CGIAR to help in the fight against micronutrient malnutrition. In the course of these consultations, initial contacts were made with the PSNL and the University of Adelaide. The idea of a micronutrients plant breeding project involving CGIAR and non-CGIAR institutions was formulated and a draft proposal discussed at an inception meeting held in Annapolis, Maryland in January, 1994. This meeting was attended by an inter-disciplinary group of proposed collaborators, other plant scientists, human nutritionists, and social scientists, donors, and persons from agencies implementing micronutrients programs, from developing and developed countries. DANIDA agreed to fund a part of the proposed activities, but involving all the proposed collaborators (CIAT, CIMMYT, IFPRI, IRRI, PSNL, and the University of Adelaide), and research was initiated in 1995. USAID and ACIAR also contributed funding to this research.

### 1.2 CGIAR-wide conference on agriculture -nutrition linkages, October, 1999, IRRI headquarters

A CGIAR-wide meeting on agriculture-nutrition linkages, organized by IFPRI, hosted by IRRI, and funded by USAID, Norway, and USDA-ARS, was convened primarily to discuss findings from the CGIAR Micronutrients project, but included other Future Harvest center activities related to human nutrition. A distinguishing characteristic of this meeting was that nearly half of the 100 participants were human nutritionists or implementing human nutrition programs. Other participants were primarily plant scientists, both from Future Harvest Centers and other institutions. The proceedings of the conference were published as a regular issue of the *Food and Nutrition Bulletin*.

## 2. High-iron rice project meetings, IRRI headquarters, November, 2000 and Cantho, Viet Nam, February, 2002

Funding from the ADB for accelerating development of high-iron rices resulted from the positive discussions at the CGIAR-wide meeting on agriculture-nutrition linkages. A distinguishing aspect of this project, as compared with the feasibility studies being undertaken during 1995-2000 for five crops, is the participation of four NARES from Bangladesh, Indonesia, the Philippines, and Viet Nam. Project meetings have involved the heavy participation of NARES, as well as plant scientists and human nutritionists from developed countries.

## 3. Donor briefing, CIAT headquarters, January, 2001

CIAT organized a meeting to brief representatives of the Bill and Melinda Gates Foundation and Micronutrient Initiative (MI) on aspects of the micronutrients plant breeding strategy. In addition to CIAT staff, the meeting was attended by other collaborators on the CGIAR micronutrients project and invited plant scientists and human nutritionists from developed and developing countries, with a particular emphasis on Africa and Latin America. At the end of the two-day meeting the donor representatives encouraged the group to develop a comprehensive proposal which included activities to disseminate nutritionally-improved varieties and to evaluate their impact on human nutrition. Micronutrient Initiative provided funding to CIAT to assist in developing such a proposal.

After the meeting, CIAT and IFPRI agreed to collaborate in developing the proposal and, once funding was obtained, to co-coordinate the project, with CIAT taking primary responsibility for the plant breeding and biotechnology activities and IFPRI taking primary responsibility for the human nutrition activities. The term “biofortification” was coined at this meeting and CIAT has since obtained a trademark for the term “biofortified” on behalf of the entire consortium.

## 4. Expanded biofortification proposal collaborator meeting, CIAT headquarters, March, 2001

A meeting was convened by CIAT and IFPRI, held at CIAT with the funding from MI, to discuss the elements of a comprehensive proposal and to assign responsibilities for writing the proposal. All interested CGIAR centers were invited to attend as were several potential collaborators from outside the CGIAR, including human nutritionists. The concept of Phase 1 and Phase 2 crops was developed at this meeting, and the agreement to include activities related to biotechnology.

The proposal was completed in time for presentation at an organizational meeting hosted by the Gates Foundation in July 2001, attended by a number of agencies involved in implementing the Global Alliance for Improved Nutrition (GAIN), a major initiative for funding strategies to reduce micronutrient malnutrition in developing countries, initially with a particular emphasis on commercial fortification. A modified version of this proposal was the basis for the submission to the Challenge Program process in December, 2001.

## 5. Challenge Program proposal revisions, Houston, Texas, USA, April, 2002

A meeting of proposed Program collaborators was hosted by a member institution of the nutritional genomics team, shortly after notification of selection of biofortification as one of three “fast-track” proposals. This was a meeting, the agenda subsequently modified, that was already planned to discuss how new funding from USAID ($2 million) for biofortification activities in Africa would be spent (thus stakeholders from Africa were already invited). Responses to the iSC comments on the December, 2001 version of the proposal were discussed, as well as governance and project management issues. A distinguishing characteristic of this meeting were comments and discussion on the use of biotechnology by participants from the private sector.

## 6. Stakeholder meeting, World Bank, May, 2002

This two-day meeting was convened primarily to receive input and suggestions on the proposal and the iSC comments, from a number of institutional perspectives, from those not initially collaborating in the project. A rather distinguished group was assembled representing NARES, NGOs, the private sector, donors, and scientists from a number of disciplines, in addition to a subgroup of proposed Biofortification Challenge Program collaborators. The tone of the meeting was quite positive and many constructive comments were received.

A new draft of the revised proposal was prepared after the stakeholder meeting incorporating these comments. It has now been shared by e-mail with the participants of both the stakeholder and Houston meetings. A fresh round of comments has been received and incorporated into the July 15, 2002 proposal submission.

## Appendix 3 —List of Institutions Submitting Letters of Support and Willingness to Collaborate

| | Organization | Country | Name | Designation |
|---|---|---|---|---|
| **Developing Countries** | | | | |
| 1 | University of Dhaka, Institute of Nutrition and Food Science | Bangladesh | Nazmul Hassan | Human Nutrition |
| 2 | Universidad del Valle, Nutrition, School of Medicine | Colombia | Alberto Pradilla | Human Nutrition |
| 3 | Ministry of Health, Nutrition Unit | Ghana | Rosanna Agble | Human Nutrition |
| 4 | University of the Philippines, Los Baños, Human Ecology | Philippines | Maria Antonia Tuazon | Human Nutrition |
| 5 | Mahidol University, Institute of Nutrition | Thailand | Songsak Srianujata | Human Nutrition |
| 6 | Makerere University, Child Health & Development Centre | Uganda | Jessica Jitta | Human Nutrition |
| 7 | Bangladesh Rice Research Institute | Bangladesh | Mahiul Haque | NARES |
| 8 | Pulses Research Center, Bangladesh Agricultural Research Institute | Bangladesh | Syed Ali Hussain | NARES |
| 9 | EMBRAPA — Brazilian Agricultural Research Corporation | Brazil | Marcio C.M. Porto | NARES |
| 10 | All India Coordinated Pearl Millet Improvement Project | India | S. K. Bhatnagar | NARES |
| 11 | National Research Centre for Sorghum & ICAR | India | N. Seetharama | NARES |
| 12 | Central Research Institute for Food Crops | Indonesia | A. Hasanuddin | NARES |
| 13 | Indonesian Institute for Rice Research | Indonesia | Irsal Las | NARES |
| 14 | Research Institute for Agric Biotechnology & Genetic Resource | Indonesia | Ida Hanarida Somantri | NARES |
| 15 | Research Institute for Legumes & Tuber Crops | Indonesia | Koas Hartojo | NARES |
| 16 | Kenya Agricultural Research Institute | Kenya | Romano M. Kiome | NARES |
| 17 | Institut National dela Recherche Agronomique, Morocco | Morocco | | NARES |
| 18 | Institut National dela Recherche Agronomiques du Niger | Niger | Guero Yadji | NARES |
| 19 | Philippine Rice Research Institute | Philippines | Leocadio Sebastian | NARES |
| 20 | National Agricultural Research Organisation | Uganda | J. K. Mukiibi | NARES |
| 21 | Programme Regional d'Amelioration de la Pomme de terre et de la Patate douce en Afrique Central et de I'Est (PRAPACE) | Uganda | Berga Lemaga | NARES |
| 22 | Cuu Long Delta Rice Research Institute | Viet Nam | Bui Chi Buu | NARES |
| 23 | Hung Loc Agricultural Research Center | Viet Nam | Hoang Kim | NARES |
| 24 | Ministry of Agriculture & Irrigation, Agric Research & Extension Authority | Yemen | Ismail Muharran | NARES |
| 25 | ARC-Roodeplaat Vegetable & Ornamental Plant Institute | South Africa | Christo Kok | NGO |
| 26 | Tanzania Home Economics Association (TAHEA) | Tanzania | Asia K. Kapanda | NGO |
| 27 | University of Nairobi | Kenya | Crispus M. Kiamba | Plant Science |
| 28 | University of the Philippines, Los Baños, Agriculture | Philippines | Candida Adalla | Plant Science |
| 29 | Thailand Rice Genomic Program at Kasetsart University | Thailand | Apichart Vanavichit | Plant Science |

continued

## Appendix 3 — continued

| Organization | | Country | Name | Designation |
|---|---|---|---|---|
| **Developed Countries** | | | | |
| 1 | Royal Veterinary & Agricultural University | Denmark | Flemming Frandsen | Human Nutrition |
| 2 | Wageningen University, Human Nutrition & Epidemiology | The Netherlands | Clive E. West | Human Nutrition |
| 3 | Emory University, Dept of International Health | USA | Reynaldo Martorell | Human Nutrition |
| 4 | Pennsylvania State University, Nutrition Dept | USA | John Beard | Human Nutrition |
| 5 | Helen Keller Worldwide | USA | W. Jeff Waller | NGO |

Note: The letter themselves may be read as PDF files which may be accessed at ftp://ftp.cgiar.org/ifpritemp/Biofortification_proposal. See also Appendix 1.

## Appendix 4 — References for Selected Biofortification-Related Publications — CGIAR Micronutrients Project

Listed in Chronological Order

Graham, R.D. and Welch, R.M. 1996. Breeding for staple food crops with high micronutrient density. Agricultural Strategies for Micronutrients. Working Paper 3. pp. 1-72. Washington, D.C.: International Food Policy Research Institute.

Bouis, H. 1996. Enrichment of food staples through plant breeding: A new strategy for fighting micronutrient malnutrition. *Nutrition Reviews* **54**(5): 131-137.

Iglesias, C., Mayer, J., Chavez, L. and Calle, F. 1997. Genetic potential and stability of carotene content of cassava roots. *Euphytica* **94**, 367-373.

Graham, R.D., Senadhira , D. and Ortiz-Monasterio, I. 1997. A strategy for breeding staple-food crops with high micronutrient density. *Soil Sci. Plant Nutr.* **43**, 1153-1157.

Ruel, M., and H. Bouis. 1998. Plant breeding: A long-term strategy for the control of zinc deficiency in vulnerable populations. *American Journal of Clinical Nutrition*. **68** (2S): 488S-494S.

Welch, R.M. and Graham, R.D. (eds.) 1999. Special issue on Sustainable Field Crop Systems for Enhancing Human Health: Agricultural Approaches to Balanced Micronutrient Nutrition. *Field Crops Research.* **60**.

Welch, R.M. and Graham, R.D. 1999. A new paradigm for world agriculture: Meeting human needs; productive, sustainable, nutritious. *Field Crops Res.* **60**, 1-10.

Graham, R.D., Senadhira, D., Beebe, S.E., Iglesias, C. and Ortiz-Monasterio, I. 1999. Breeding for micronutrient density in edible portions of staple food crops: Conventional approaches. *Field Crop Res*. **60**, 57-80.

Bouis, H. 1999. Economics of enhanced micronutrient density in food staples. *Field Crops Research* **60**: 165-173.

Welch, R.M., House, W.A., Beebe, S., and Cheng, Z. 2000. Genetic selection for enhanced bioavailable levels of iron in bean (*Phaseolus vulgaris* L.) seeds. J Agr Fd Chem **48**: 3576-3580.

Bouis, H. (ed.) 2000. Special issue on improving human nutrition through agriculture. *Food and Nutrition Bulletin* 21(4). [several CGIAR Micronutrient Project articles; not listed here]

Bhargava, A., H. Bouis, and N. Schrimshaw. 2001. Dietary intakes and socioeconomic factors are associated with the hemoglobin concentration of Bangladeshi women. *Journal of Nutrition* **131** (3): 758-764.

Graham, R. D., Welch, R. M., and Bouis, H. E. 2001. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: principles, perspectives and knowledge gaps. *Advances in Agronomy* **70**: 77-142.

Glahn, R.P., Cheng, Z., Welch, R.M. and Gregorio, G.B. 2002. Comparison of iron bioavailability from 15 rice genotypes: studies using an *in vitro* digestion/Caco-2 culture model. Journal of Agricultural and Food Chemistry. **50**: 3586-3591.

Bouis, H.; Welch, R.M.; Gregorio, G.B.; Raboy, V.; Beyer, P., et al.; King, J.C.; and Holm, P.B., et al. 2002. Symposium: Plant breeding: A new tool for fighting micronutrient malnutrition. Special issue. *Journal of Nutrition* 132: **3** (March) 491S-514S.

House, W.A., Welch, R.M., Beebe, S. and Cheng, Z. 2002. Potential for increasing the amounts of bioavailable zinc in dry beans (Phaseolus vulgaris L.) through plant breeding. Journal of the Science of Food and Agriculture 82: (In Press).

## Appendix 5 — Collaborator Biographical Sketches

The following is only a partial list of collaborators. It does not reflect many NARES and other non-CGIAR partners who contributed to the development of the proposal. No collaborators of competitively awarded grant components can be identified yet.

### Marianne Bänziger, International Maize and Wheat Improvement Center (CIMMYT)

**Marianne Bänziger** is a physiologist and senior scientist at the International Maize and Wheat Improvement Research Center (CIMMYT) and stationed in Zimbabwe. Her research on biofortified maize spans 8 years. She also coordinates CIMMYT's global program, "Maize for Sustainable Production in Stress Environments."

### Stephen Beebe, Centro Internacional de Agricultura Tropical (CIAT)

**Stephen Beebe** is senior bean breeder at CIAT with more than 25 years experience in working with Phaseolus beans. Prior to involvement in the biofortification effort his focus was improving common bean for disease and insect resistance and tolerance to low soil fertility and drought, with special emphasis on Central America and the Caribbean but with contacts in Brazil and in Africa as well. Several varieties bred by Dr. Beebe for resistance to bean golden yellow mosaic virus are widely used in Honduras, Nicaragua, Mexico, Guatemala, El Salvador, Cuba, and Argentina. Since the initiation of the biofortification effort in 1996, he supervised the initial studies to determine the feasibility of improving common bean for higher mineral content. He received his Ph.D. in 1978 from the University of Wisconsin in Plant Breeding-Plant Genetics.

### Peter Beyer, Albert-Ludwigs-Universität

**Peter Beyer** is a Cell Biologist at the Albert-Ludwigs-Universität in Freiburg, Germany, where he covers the position of a professor in Cell Biology, heading an independent research group. Being a member of the Humanitarian Board and a committee member of the Indo-Swiss Collaboration in Biotechnology (ISCB), he is active in organizing the GoldenRice technology transfer to developing countries. Peter Beyer´s background is in plant biochemistry and during his post doctoral training he began to focus on prenyllipid metabolism of bacteria and plant cells, then specializing further on plastid prenyllipid biosynthetic pathways. Starting with investigating their enzymology, he extended his work into exploring their molecular regulation. This field of research represents an ongoing effort in Dr. Beyer´s laboratory. To date, one of his main working areas is to employ of the accumulated basic-science-oriented experience in applied research, i.e., to generate plant GMOs with altered characteristics in prenyllipid composition of nutritional importance (provitamin A, vitamin K, vitamin E). He is one of the two inventors of GoldenRice, licensor for the noncommercial use of the technology. He is currently involved in improving the technology used in collaboration with National Research Institutes in Asia as well as CGIAR centers.

### Matthew Blair, Centro Internacional de Agricultura Tropical (CIAT)

**Matthew Blair**, Andean Bean Breeder and Bean Germplasm Specialist - Involved in analysis of genetic resources in Phaseolus and genetic improvement of large-seeded Andean beans for South America, the Caribbean, and support to Africa. Leader of laboratory based projects using molecular markers for basic research and for applied plant breeding goals in beans. Collaboration with national agricultural research programs and regional networks in Latin America, Africa, Europe and North America. Previously, breeding experience in maize, vegetables (Asgrow) and new crops (Rodale Research center) and post-doctoral research on a USDA project devoted to the map-based cloning of a recessive disease resistance gene from rice to the bacterial leaf blight pathogen. Degrees in Plant Breeding and Agronomy from Cornell University and the University of Puerto Rico. Awards or fellowships from CIAT (2001); Cold Spring Harbor (1998); USDA-National Research Initiative (1997) Organization of American States (1996) Plant Science Center, Cornell (1993-1995); Florida Phytopathological Society (1993), Carribbean Crop Society - SOPCA (1992) and Crop Science (1992). Authored or co-authored eighteen publications (1990 -2002).

### Tom Blake, International Center for Agricultural Research in the Dry Areas (ICARDA)

**Tom Blake** is Director, Germplasm Program, ICARDA. Dr. Blake received his B. Sc. in genetics from U.C. Davis in 1976, and his M.Sc. in Agronomy from SDSU in 1979, his Ph.D. in genetics and cell biology from WSU in 1983, was postdoctoral research associate with Dr. Fred Bliss at U. Wisconsin in 1983, and served as assistant professor, associate professor and professor of plant breeding and genetics at Montana State University from 1984 through 2001. He joined ICARDA January 1, 2002. Dr. Blake has published more than 90 refereed papers in the fields of plant breeding, agronomy and genetics. A founding member of the North American Barley Genome Mapping Project, Dr. Blake helped to develop and utilize the tools of genetic analysis and mapping to develop and release several barley cultivars for food, animal feed and malting. His current research emphasis revolves around the develop and deployment of cost- and time-effective microarray-based technologies for linkage map construction and gene expression analysis in each of ICARDA's mandate crops.

### Merideth Bonierbale, International Potato Center (CIP)

**Merideth Bonierbale** earned a Ph.D. degree from Cornell University in 1990, with specialization in Plant Breeding and Genetics. She is currently Senior Breeder and Commodity Improvement Leader at the International Potato Center (CIP) in Lima, Peru. She heads CIP's Crop Improvement and Genetic Resources Department and its project on Gene Discovery and Mobilization for Crop Improvement. Her breeding program seeks to build durable resistance to worldwide production constraints and improve the utilization of potato through conventional and biotechnological approaches. With 10 years of experience in two CGIAR centers, she is committed to the valorization and efficient use of genetic resources for the improvement of the sustainability and profitability of staple crops in less favorable environments. Her research accomplishments include collaborative development of the first molecular maps of potato (comparative with tomato) at Cornell University and cassava at the International Center for Tropical Agriculture (CIAT). Her research group is currently developing parental lines with multiple resistance and food quality traits in the context of a population improvement program aimed at the development of potato varieties that may impact favorably on developing country production and markets while reducing dependence agrochemical inputs. Expertise in Physiology, Biochemistry, Genetics and Molecular Biology will also be available for the Potato Micronutrient Project through commitment of the following internationally recruited staff of CIP: Drs. Mahesh Upadhya, Dapeng Zhang, William Roca, Enrique Chujoy and Marc Ghislain of CIP, as resource persons or collaborators.

### Howarth Bouis, International Food Policy Research Institute (IFPRI)

**Howarth Bouis**, an economist, is a Senior Research Fellow at the International Food Policy Research Institute (IFPRI), where he has been employed since receiving his Ph.D. from the Food Research Institute at Stanford University in 1982. His research at IFPRI has focused on the interface of economic factors which influence food consumption and nutrition outcomes, primarily in Asia with a particular interest in micronutrient malnutrition. He is presently coordinator the CGIAR Micronutrients Project, which seeks to develop nutritionally-improved (micronutrient-dense) staple food crops. This is a collaborative effort among plant scientists at CIAT, CIMMYT, and IRRI, and plant scientists and human nutritionists at the USDA-ARS, the University of Adelaide, and several developing country institutions. Since 1993, he has sought to promote biofortification activities both within the Future Harvest Centers, including their NARES partners, and in the human nutrition community -- through publications, seminars, workshops, symposiums, and fund-raising. Along with Joe Tohme of CIAT, he has been coordinating development of the Biofortification Challenge Program proposal.

**Hernán Ceballos, Centro Internacional de Agricultura Tropical (CIAT)**

**Hernán Ceballos** B.S. in Agronomy (1980, Argentina) and Ph.D. (1987, Cornell University, USA). Major in Plant Breeding, minors in Plant Pathology and International Agriculture. Experience in 1) Population improvement and development of inbred lines for good agronomic performance, disease and insect resistance and tolerance to acid soils and drought in maize and cassava, 2) Advising South American national research programs in their breeding activities, 3) Basic research on the inheritance of different traits, 4) Directing M.S. and Ph.D. student theses, 5) Teaching graduate courses on *Quantitative Genetics* and *Breeding for Biotic and Abiotic Stresses* at National University of Colombia, 6) Leader of a research project involving the management of about 25 people. 7) Interaction with private sector to better orient the cassava breeding project, 8) Research of cassava use and processing. Awards and scholarships: Universidad Nacional de Córdoba, Argentina (1980). Instituto Nacional de Tecnología Agropecuaria, Argentina. (1981). Organization of American States (1983). Cornell University (1986). Publication of 33 articles in refereed journals since 1986. Two technical manuals for Universities. Editor in two books of international relevance.

**Swapan Kumar Datta, International Rice Research Institute (IRRI)**

**Swapan Kumar Datta**, Ph.D., born in Bangladesh received a B.Sc. (Honors) at Presidency College, Calcutta, India (1972), and a M.Sc. (1974) and Ph.D. (1980) at Calcutta University, India. He served at Visva-Bharati University, Santiniketan, as associate professor (1979-1985). Since 1985, he worked in several leading institutions and universities such as the Institute of Resistance Genetics (Germany; as a DAAD Fellow, 1985-1986); Friedrich Miescher Institute (Switzerland; as a FMI Fellow, 1987); Swiss Federal Institute of Technology, ETH-Zurich (Switzerland; as a senior scientist and group leader of rice biotechnology, 1987-1993); University of California, Davis (USA; as a visiting associate professor, 1989); and the International Rice Research Institute (IRRI) (Philippines; 1993 to present). As plant biotechnologist at IRRI he leads the work on haploid and transgenic breeding for rice improvement. Coordinator of BMZ/GTZ funded research on plant protection and field evaluation of transgenic rice in Asia and Project leader of Golden Rice project at IRRI funded by USAID. He pioneered demonstrations of the first genetically engineered indica rice [Datta, S.K., et al. *Biotechnology* 8, 736-740 (1990)] in addition to contributions in cereal haploidy (barley, rice, maize, and wheat). He has authored around 100 research publications, mentored 14 Ph.D. students, and developed worldwide collaboration on gene technology for rice improvement including transgenic breeding for nutrition improvement.

**Dean DellaPenna, Michigan State University**

**Dean DellaPenna** is a Full Professor in the Department of Biochemistry and Molecular Biology at Michigan State University in East Lansing, Michigan. Dr. DellaPenna earned a B.S. in Cellular Biology at Ohio University in 1984 and a Ph.D. in Plant Physiology at the University of California at Davis in 1987. He was a faculty member in the Plant Sciences Department at the University of Arizona from 1990-1996, an Associate Professor at the University of Nevada, Reno, from 1996-2000 and has been in his current position at MSU since May 2000. For the past decade he has studied various aspects of plant biochemistry, especially compounds related to aspects of human health. His most recent work has focused on understanding and manipulating the synthesis of carotenoids (e.g., beta-carotene) and vitamin E in plants, the two major lipid soluble antioxidants in the human diet. His work in genetically dissecting these pathways using Arabidopsis as a model system has led to important insights into the synthesis and regulation of carotenoid and vitamin E in plants and has provided a significant knowledge base to engineer levels of these compounds in crops. He has also worked on topics as diverse as tomato fruit ripening, fungal resistance and plant cell walls. In recent years he has become a vocal proponent for engineering the nutritional content of agricultural crops to provide a more balanced and healthful diet both in developed and developing countries. The dire need for such research and possible approaches that can be taken were recently detailed (*Science* 285:375-79; *Ann. Rev. Plant Physiol. Plant Mol. Biol* 50:133-161).

### Emile Frison, International Network for the Improvement of Banana and Plantain

**Emile Frison** is Director of the International Network for the Improvement of Banana and Plantain, a programme of IPGRI, based in Montpellier, France. He is a Belgian national and has spent most of his career in international agricultural research, starting at IITA, Nigeria in 1979. A plant pathologist by training, Dr Frison obtained an MSc from the Catholic University of Louvain and a Ph.D. from the University of Gembloux, Belgium. He worked for six years in Africa, in Nigeria and Mauritania, and was Development Manager of an Agro-chemical company in Belgium for three year. In 1987, he joined IPGRI (then IBPGR) to coordinate research on the phytosanitary aspects of international germplasm movement. In collaboration with FAO, he initiated the series of 'FAO/IPGRI Technical Guidelines for the Safe Movement of Germplasm'. The first issue produced in 1988 was on Musa. He supervised several banana projects funded by IPGRI, including the collecting of wild Musa germplasm in Papua New Guinea, one of the first research project on molecular markers for banana and a project on the identification of the causal agent of banana bunchy top virus. In 1992 he became Regional Director for Europe within IPGRI and initiated a new phase of the European Cooperative Programme for Crop Genetic Resources Networks, which developed into the platform for the implementation of the Global Plan of Action on Genetic Resources for Food and Agriculture in Europe. He became the Director of INIBAP in 1995 and has been instrumental in strengthening the Programme, especially in Africa. He stimulated the re-launching of the regional networks of INIBAP established in the early 1990s as NARS-owned and NARS-lead networks operating under the auspices of the regional and sub-regional fora (APAARI, FORAGRO, ASARECA and CORAF). In 1997, he launched the Global Programme for Musa Improvement (PROMUSA), which now counts more than 120 members and became a model for the development Global Programmes on Commodity Chains in the context of the Global Forum for Agricultural Research. In 2001, he was instrumental in the establishment of the Global Consortium on Musa Genomics with 26 members from 13 countries, among which Brazil, India, Malaysia and Mexico. Dr Frison is author and co-author of over 120 scientific publications.

### Robin Graham, Waite Agricultural Research Institute, University of Adelaide

**Robin Graham** is Professor of Plant Science at Waite Agricultural Research Institute, the University of Adelaide. He is the current leader of the University's Micronutrient Research Group and Scientific Coordinator of the CGIAR Micronutrients Project. He has published more than 200 books and research papers on micronutrients. Together with Professor Welch of PSNL with whom he has worked for the past 20 years, he drafted, in 1993, the first position paper to detail the concept and breeding strategies for improving the micronutrient value of staple crops to impact on nutritional health of whole populations.

The expertise of the Micronutrients Group is heavily in the area of the genetics and physiology of micronutrient uptake by plants and distribution to grain, the interaction of micronutrients and disease resistance, the flow of micronutrients in food systems, and the bioavailability of micronutrients in animal models. For this range of interests, the Group has established collaborations with geneticists, plant breeders, and molecular biologists in their own department, in Animal Science, CSIRO Human Nutrition, The Women's and Children's Hospital, and most importantly, the PSNL at Cornell University for the bioavailability studies. For micronutrient research on plants, the Group has the unique advantage of local soils severely deficient in each of several micronutrients that allows screening of genetic resources for micronutrient efficiency under practical field conditions. This association of expertise, outstanding facilities, and soils that mimic those in Asia, Africa, and elsewhere in the developing world puts the University of Adelaide in a unique position to support the GCP.

### Stefania Grando, International Center for Agricultural Research in the Dry Areas (ICARDA)

**Stefania Grando**, an Italian Citizen, is currently Barley Breeder in the Germplasm Program at the International Center for Agricultural Research in the Dry Areas (ICARDA) in Aleppo, Syria. She holds a Ph. D. in Plant Breeding (1986) from the University of Perugia, Italy. She has more than twenty years of experience in barley breeding, of which the last 15 in an international breeding program. In her present position she is responsible for research and training on stabilizing and enhancing productivity of barley in developing countries with emphasis on breeding varieties for poor farming communities. She promoted and developed decentralized breeding programs in a number of countries, and ultimately, she gave a considerable contribution to the development of methodologies for participatory breeding programs, which are currently underway. She is author or co-author of several referee-journal articles, conference and non-referee papers, and chapters in books.

### Glenn B. Gregorio, International Rice Research Institute (IRRI)

**Glenn B. Gregorio** Ph.D. University of the Philippines, Los Baños, Philippines Joined IRRI's Plant Breeding, Genetics, and Biochemistry (PBGB) Division in 1986 and worked on rice breeding for tolerance for abiotic stresses such as salinity and problem soils. In 1997, served as consultant to a micronutrient dense rice project at IRRI and as consultant and expert to: The FAO/IAEA agriculture and biotechnology laboratory in Vienna, and the Nuclear Institute for Agriculture and Biology (NIAB) in Faisalabad, Pakistan. Appointed project scientist of the PBGB Division, IRRI in 1998 to 1999. As interim flood-prone breeder and project team leader on efficient selection techniques and novel germplasm for increasing the productivity of flood-prone rice lands, Dr. Gregorio's led the development of marker-assisted selection for tolerance for soil-related stresses. His research included genetic analysis of the high-Fe trait; developing breeding strategies and genes mapping on rice chromosomes. As affiliate scientist (plant breeder) from January 2000 up to the present, .he leads the following specially funded projects: 1) Breeding for micronutrient-dense rice to reduce micronutrient malnutrition, 2) Mapping salinity tolerance genes in japonica rice in collaboration with the Agricultural Research Center in Egypt and the U.S. Salinity Laboratory, and 3) Development of high yielding rice varieties for the coastal wetlands of Bangladesh. Serves as affiliate assistant professor at the University of the Philippines at Los Baños. Supervised four graduate students.

### Michael A. Grusak, USDA/ARS Children's Nutrition Research Center

**Michael A. Grusak** is a Plant Physiologist at the USDA/ARS Children's Nutrition Research Center, Houston, TX and an Associate Professor of Pediatrics, Baylor College of Medicine. He also serves as Director of the CNRC Plant Growth Facility. His educational and research background include undergraduate training in biology at Bates College in Lewiston, Maine, after which he earned both his M.S. and Ph.D. in botany at the University of California, Davis. Dr. Grusak received postdoctoral training in isotope technology and plant nutrient transport at the Physics and Engineering Laboratory in Lower Hutt, New Zealand, the Université de Poitiers, Poitiers, France, and the USDA/ARS US Plant, Soil and Nutrition Laboratory at Cornell University. Dr. Grusak joined the Children's Nutrition Research Center in 1990 to develop an interdisciplinary program that would link plant science/production agriculture with human nutrition concerns. He has designed and developed equipment and methodologies that enable the intrinsic labeling of plants with stable isotopes of various elements. These labeled foods are used in clinical investigations to study the bioavailability and subsequent metabolism of essential and/or health-promoting phytonutrients. Recent studies have focused on minerals, carotenoids, phylloquinone, and various phenolic compounds. In addition to these human nutrition efforts, Dr. Grusak's plant physiology laboratory is examining and identifying the molecular mechanisms which regulate mineral transport and partitioning within plants, such that strategies can be developed to enhance the nutritional quality of plant foods. The main focus of his group is on the whole-plant homeostasis of the micronutrient metals, iron and zinc; experimental tools include genomic analysis and gene discovery in model species, and the functional analysis of nutritionally relevant gene products.

**David A. Hoisington, International Maize and Wheat Improvement Center (CIMMYT)**

**David A Hoisington** Currently, Director of the Applied Biotechnology Center (ABC) and Bioinformatics at the International Maize and Wheat Improvement Center (CIMMYT) located near Mexico City, Mexico. I have been at CIMMYT for the past 12 years, when I joined the Center to establish the biotechnology program. Prior to working at CIMMYT, I was an Assistant Research Professor in the Agronomy Department at the University of Missouri. My current responsibilities include the oversight of all research activities within the ABC. On-going research activities of the group include the development and use of molecular markers in maize and wheat for genetic, cytogenetic and breeding applications; the use of molecular techniques to fingerprint various genomes including plants and fungi; the use of genetic engineering to enhance host-plant resistance to stresses; and the development of apomictic cereals. The ABC has major projects focused on Sub-Saharan Africa involving the development of national biotechnology capacity and insect resistant maize that combines conventional and transgenic-based mechanisms. In addition, CIMMYT's apomixis project involves a collaboration between two public institutes (CIMMYT and IRD) and three private sector agricultural companies (Limagrain, Pioneer Hi-Bred and Syngenta Seeds). As Director of Bioinformatics, I supervise the combined areas of biometrics, information management and information technology (computing and software support services. Major emphasis is focused on developing a crop information system to manage CIMMYT's breeding, biotechnology and related information on a global basis. As a member of the senior management teams (Research Coordinating Committee and Management Advisory Committee) at CIMMYT, I am involved in research priority setting, project development, resource allocation and administration of the institute. I also serve as the Chair of the Intellectual Property Committee and have considerable experience is evaluating and negotiating a number of agreements and collaborations between CIMMYT and public and private institutions. I hold a BS in Botany and Plant Pathology from Colorado State University, Ft. Collins and a Ph.D. in Plant Biology from Washington University, St. Louis.

**David J. Mackill, International Rice Research Institute (IRRI)**

**David J. Mackill** is Head, Plant Breeding, Genetics & Biochemistry Division, International Rice Reseach Institute (IRRI), Philippines. During 1991-2001, he was a research geneticist with USDA-ARS, and Adjunct Professor in the Department of Agronomy & Range Science, University of California, Davis, USA. From 1982 to 1991 he was a plant breeder at IRRI, Philippines, working on rainfed lowland rice. His special assignments include: Secretary-General, SABRAO - Society for the Advancement of Breeding Research in Asia and Oceania (from 2001), Associate Editor of Crop Science Journal (1998-2003), Editor of Theoretical and Applied Genetics Journal (form 2002). He has worked in rice research for 27 years. He has conducted research on breeding for rainfed rice environments, genetics of resistance to diseases (blast and stem rot) and tolerance to submergence and low temperature, genetic diversity studies and application of molecular marker technology to rice improvement programs. From his breeding program at IRRI, 17 rice cultivars were released in various countries. He has authored or coauthored 93 publications including refereed journal articles, book and symposium chapters and technical reports.

### Abebe Menkir, International Institute of Tropical Agriculture (IITA)

**Abebe Menkir** has worked at IITA as a maize breeder-geneticist since 1996, developing many open-pollinated varieties, inbred lines, and hybrids for midaltitude and savanna zones in West and Central Africa and making them available through regional trials and other means. Current breeding emphases include high yield potential, resistance to diseases and Striga, drought tolerance, and broadening the genetic base of adapted maize. He has taken part in work to develop maize whose grain possesses enhanced iron, zinc, and pro-vitamin A content, and in breeding for resistance to the fungus responsible for aflatoxins. As team leader for maize improvement research at IITA since 2001, Dr. Menkir supervises 5 Scientists and 30 support staff. He served as elected coordinator of the IITA multidisciplinary project on maize-grain legume production systems during 2000-2001. He has also been one of the principal investigators in six different projects funded by various agencies and implemented by IITA. Maize scientists in West and Central Africa elected him to WECAMAN's ad-hoc research committee, which manages and reviews the funding of projects through the network. Dr Menkir directed the development of a GIS-linked database for IITA maize international trials. Prior to his assignment at IITA, he worked as a sorghum breeder in the Institute of Agricultural Research in Ethiopia.

### Rodomiro Ortiz, International Institute of Tropical Agriculture (IITA)

**Rodomiro Ortiz** received his undergraduate and MSc training at National Agrarian University, La Molina, Peru and Ph.D. in Plant Breeding and Genetics, University of Wisconsin-Madison, USA. He works now as Director of Research of Development at IITA, Nigeria. His previous responsibilities include being Director of Crop Improvement Division, IITA; Director of Genetic Resources and Enhancement Program, ICRISAT, India; Nordic Associate Professor for Plant Genetic Resources, Royal Veterinary and Agricultural University, Denmark; Leader & Breeder/Geneticist Plantain & Banana Improvement Program, IITA; Blueberry and Cranberry Cytogeneticist, Rutgers University, USA; and Associate Geneticist, International Potato Center, Perú. Together with many colleagues he has employed conventional, modified, and novel techniques for germplasm enhancement, including bio-techniques that facilitate the genetic manipulation of plant species.

### J. Ivan Ortiz-Monasterio, International Maize and Wheat Improvement Center (CIMMYT)

**J. Ivan Ortiz-Monasterio** is a Senior Scientist, in the Wheat Program at CIMMYT. He earned the B.S. degree from the Monterrey Institute of Technology in Mexico and M.Sc. and Ph.D degrees from the University of Illinois at Urbana-Champaing. Dr. Ortiz-Monasterio has been working on ways to improve nutrient use efficiency in wheat, both from the breeding as well as the crop management perspective. He has published five chapters, 22 refereed journal articles, and 65 abstracts and conference papers. Dr. Ortiz-Monasterio has served as a consultant to the IAEA, International Atomic Energy Agency. He is a member of the Mexican Academy of Sciences as well as the National Academy of Agricultural Sciences. He is currently serving as Project Coordinator in Frontier Project 4 – Biofortified Grain for Human Health - at CIMMYT.

### Shivaji Pandey, International Maize and Wheat Improvement Center (CIMMYT)

**Shivaji Pandey** is Director of the Maize Program, International Maize and Wheat Improvement Center (CIMMYT). He obtained his B.S. from G.B. Pant University of Agriculture and Technology, Pantnagar, Uttar Pradesh, India, and his M.Sc. and Ph.D. from the University of Wisconsin, Madison. As leader of CIMMYT's South American Regional Maize Program during 1986-96, Dr. Pandey's research focused on developing high yielding varieties and hybrids that possessed tolerance to the acidic soils typical of the region. The Program he currently directs works with researchers worldwide to develop and promote improved varieties, hybrids, and farming systems for maize farmers in Africa, Asia, and Latin America.

### James Stangoulis, University of Adelaide

**James Stangoulis** is a Research Fellow in the Department of Plant Science at the University of Adelaide in South Australia. He obtained his B.Agr.Sc. and later (1996) his Ph.D. from Adelaide University. James has extensive experience in micronutrient research in developing countries, including involvement in ACIAR research in China and capacity building in Viet Nam. His experience crosses a number of disciplines from plant physiology to the more applied agronomy. He is currently the coordinator to the national programs in Indonesia, Bangladesh, Viet Nam, and the Philippines for the ADB-funded project that aims to breed high iron rice for Asia. James is also involved in teaching both undergraduate and post-graduate students, including the delivery of plant nutrition workshops to research institutions in developing countries of Asia.

### Joe Tohme, International Center for Tropical Agriculture (CIAT)

**Joe Tohme** is a plant geneticist at the International Center for Tropical Agriculture (CIAT) with Ph.D. from Michigan State University. He is currently the leader of the Agribiodiversity and Biotechnology project. He helped set up CIAT molecular markers lab, implement the molecular characterization of genetic diversity and mapping of agronomical traits in bean, cassava, rice and Brachiaria. His current research interest involves integrating molecular assisted selection in breeding and germplasm conservation programs, setting up a SNP facility for high throughput mapping and a microarray gene expression facility for plant pathogens interaction (rice blast, bean angular leaf spot) and aluminum stress studies. Since 2001, he has been assisting Howarth Bouis in the coordination of the Biofortification proposal with an emphasis on the breeding and biotechnology components of the project.

### Ross Welch, USDA-ARS

**Ross Welch** is a plant physiologist and lead scientist employed at the USDA-ARS, U.S. plant, soil and nutrition laboratory located on the Cornell University campus. He received his B.Sc. degree from California Polytechnic State University at San Luis Obispo, and his M.Sc. and Ph.D. degrees from the University of California at Davis. He has a faculty appointment courtesy professor of plant nutrition) within the department of crop and soil sciences at Cornell University. Dr. Welch's research is directed at improving the nutritional quality of food crops for humans using sustainable food-based system approaches. His laboratory's mission is to closely link agricultural production to improving human health. His current efforts focus on improving the bioavailability and density of limiting micronutrients iron, zinc, boron, vitamin A, etc.) and calcium in edible portions of important food crops. He is also interested in improving the nutritional quality and increasing health promoting substances, e.g., selenium, vitamin E, ascorbate) in fruits, nuts and vegetables, and in developing holistic food system solutions to malnutrition globally. He co-organized the food systems for improved health program at Cornell University, and has cooperative international research programs with colleagues in Australia, Bangladesh, India, Nepal, Egypt, Denmark, and Turkey. He also cooperates with several consultative group on international agricultural research CGIAR centers including IFPRI, CIAT, CIMMYT, and IRRI on a project directed at increasing the micronutrient iron, zinc, iodine, and provitamin A carotenoids) density of staple plant foods, i.e., rice, wheat, maize, beans, and cassava) through plant breeding and genetic modification to enhance human health globally.

### Dapeng Zhang, International Potato Center (CIP)

**Dapeng Zhang** received his Ph.D. from North Carolina State University in 1994 with specializations in plant breeding and genetics. He is currently the leader of the Sweetpotato Improvement Project at the International Potato Center (CIP), Lima, Peru. His work focuses on improving sweetpotato productivity and utilization in developing countries through the development of new sweetpotato cultivars with enhanced nutritional value, better processing characteristics, and resistance to biotic and abiotic stresses. Dr. Zhang, a twenty-year veteran plant breeder currently leads a multi-discipline research group that conducts decentralized plant breeding work in Asia and Africa. The group use both conventional and molecular tools to exploit the rich genetic diversity found in the sweetpotato germplasm held in trust in CIP genebanks. The group's research outputs include new sweetpotato varities, enhanced germplasm, and strengthened research capacities among national collaborators. His accomplishments include the development of a series of high dry matter, high beta-carotene sweetpotatoes populations now widely used in developing countries. Among these are 17 varieties released in Asia and Africa since 1996.