HarvestPlus
Breeding Crops for Better Nutrition

The CGIAR Biofortification Challenge Program

2005 Annual Report for the Executive Council of the CGIAR

Submitted
by
Howarth Bouis, Director
and
Bonnie McClafferty, Donor Relations and Communications Coordinator

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HarvestPlus Programme
c/o IFPRI
2033 K Street, NW
Washington DC, 20006
USA
Tel. 1 202 862 5600
Fax. 1 202 467 4439

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HarvestPlus Annual Report to the Executive Council of the CGIAR

1.0 Executive Summary

The HarvestPlus Challenge Program has been fully operational since January 2004. Since that time the program has succeeded in establishing a strong network of 68 contracted institutions, supporting nearly 100 scientists across Asia, Africa, Latin and North America and Europe who are conducting research in plant breeding, human nutrition, nutritional genomics, and the essential aspects of socio-economic analysis that will make the program a success. Considerable effort has been placed in outreach activities to inform expert and layperson audiences about the program and the potential of biofortification as a strategy to reduce micronutrient malnutrition for billions of undernourished. In 2005 HarvestPlus work was cited in over twenty publications including peer reviewed journals, newsletter, magazines and daily newspapers in Asia, Africa and Latin America. In 2005, with additional support from the Bill and Melinda Gates Foundation, HarvestPlus expanded its research portfolio to begin "end user" research and implementation activities that will facilitate bringing biofortified crops into the food systems and onto the plates of the undernourished.

Plant breeding research activities have progressed across the six primary staple crops, rice, wheat, maize, cassava, beans and sweetpotato where full blown crop improvement research has taken hold after two years of primarily screening germplasm for parent material. For several crops screening is no longer a primary activity but is being continued to augment actual biofortification breeding/crop improvement work. Where nutrient dense parent lines remain elusive, screening activities have been intensified. Along the way several insights have been gained. Research has shown a direct correlation between iron and zinc uptake in plants meaning that breeding for efficiency in one mineral will increase the level of the other. Furthermore, gene by environment studies conducted on promising materials is proving that microenvironments can have profound effects on the expression of nutrients once in the field.

Nutrition research made significant gains in 2005 by establishing the target levels to be used by plant breeders to ensure an effect on human nutritional status. This was no small achievement given the complexities of diets, intervening factors such as bioavailability of nutrients, presence of anti-nutrients in the crops and diets and overall food consumption patterns of target populations. In addition to establishing targets, nutrition laboratories have been strengthened and scientists have been trained by HarvestPlus to conduct analyses of biofortified crops emerging from the program. Retention analysis is being conducted by HarvestPlus scientists on products to maximize the nutrient availability within the crops post-harvest. Crops that have been developed and appear to have all the favorable nutritional qualities are then tested in controlled human efficacy trials. By 2004, such trials have been conducted on high-iron rice and high beta carotene sweetpotato. These studies were published in 2005 in the Journal of Nutrition and The American Journal of Clinical Nutrition respectively.

HarvestPlus research on nutritional genomics is allowing the program to understand molecular pathways for transport of micronutrients within plants and identify genes responsible for nutrient inheritance. It is also giving clear indications of the potential and processes that should be considered when biofortifying via genetic transformation.

Ex Ante impact research is helping the program estimate the importance of biofortification as a nutrition intervention. The impact and policy component of HarvestPlus has developed models for assessing effect and has recently begun to establish baseline studies from which biofortified crops, when disseminate, will be evaluated. These studies will gauge food security and consumption patterns within target communities and populations and help focus HarvestPlus crop promotion activities on the most needy.

A new component specifically designed to reach end users of biofortified crops was added in 2005. The Bill and Melinda Gates Foundation provided the additional funding for this new project titled, *Reaching End Users of Orange-Fleshed Sweetpotato in East and Southern Africa*. HarvestPlus believes that in order for the undernourished to consume biofortified crops, agricultural extension and seed systems must be strengthened, viable markets must be developed and, most importantly, consumer behavior and food consumption decision-making must be thoroughly understood. It is within this end user component that HarvestPlus expands beyond a traditional agricultural research and development program and evolves into a viable public health intervention. Appropriately, the partnerships developed under this component are heavily weighted to informing and linking up with health and nutrition development partners, policy enablers, and food marketing specialists.

In 2005 Communication within HarvestPlus has dedicated its resources to spreading the word about HarvestPlus research outcomes to expert audiences in agriculture and nutrition, and creating opportunities to inform policy enablers, internationally and in target countries about the concept and potential of biofortified foods as a food-based nutrition intervention. In addition, the Technical Monograph series has been designed and developed to serve as protocol guides for other research programs working to biofortify crops. In 2005, 20 articles have appeared in peer reviewed journals, 8 newsletter and magazine pieces have been published about the program and 10 articles have appeared in newspapers and online media sources.

The finances for HarvestPlus have remained strong. In 2005, the pace of expenditures/disbursements increased to $9.5M, a twenty percent increase on 2004. Tables explaining contributions and disbursements are attached. Mentioned previously, in 2005 the Bill and Melinda Gates Foundation contributed an additional six million dollars to complete embark on work to reach end users with orange-fleshed sweetpotato in Uganda and Mozambique.

Summary of 2005

Research accomplishments

- ***Wheat***. Breeding has developed and disseminated progenitor nurseries with high levels of iron and zinc. Planting for GXE Studies in target regions commenced.
- ***Maize***. High levels of beta-carotene and zinc found in maize germplasm. Breeding advances.
- ***Rice.*** High levels of zinc found in milled rice germplasm. Breeding advances.
- ***Beans.*** High iron drought tolerant bush beans developed and full breeding program for iron dense climbers established.
- ***Cassava.*** Screening activities for high beta-carotene lines continues in close collaboration with Embrapa
- ***Orange Fleshed Sweetpotato.*** Adaptive breeding of high beta-carotene lines in Africa. Program to reach end users through effective dissemination initiated.
- ***Phase II crops.*** Germplasm screening advancing and several crops established full breeding program.
- Nutrition studies have developed nutritional targets for breeding for phase I and phase II crops.
- Methods and protocols have been developed and communicated for measuring bioavailability.
- Methods and protocols developed and communicated for sampling and limiting contamination during screening.
- Methods and protocols developed and published for carotenoid analysis.
- Human efficacy trials published for high-iron rice, AJCN July 2005.
- *Ex ante* analysis completed indicating cost effectiveness of biofortification.

Research needs and program management lessons

- Only a small portion of the gene banks have been tapped for micronutrient density genetic variation. There is tremendous scope for investment in germplasm screening.
- High throughput screening methods need to be developed and/or validated.
- Low bioavailability of iron when compared with zinc, requires higher concentrations of iron be added to obtain the nutritional target.
- Positive associations between iron and zinc concentration confirmed thus breeding for one mineral will result in a parallel increase for the other mineral.
- GxE and micro-environmental variation in the field significantly affect micronutrient content for minerals but are of lesser importance for provitamins A.
- Standardized screening procedures for carotenoid assays in plant breeding laboratories continues to pose a challenge
- Outreach to the nutrition community to gain feedback and buy-in has been essential.
- Data on the prevalence of certain micronutrient deficiency, incidence of diseases, and micronutrient intakes are difficult to obtain.
- Datasets that contain information on food consumption; as distinct from food balance sheets and intra-household consumption patterns are difficult to acquire.
- HarvestPlus positioning and messaging vis-à-vis the GMO debate is an issue that deserves more attention.

2.0 Background

2.1 Program objectives and structure

The goal of HarvestPlus is to reduce micronutrient malnutrition among poor populations in Africa, Asia, and Latin America, thereby improving food security and enhancing the quality of life. HarvestPlus seeks to bring the full potential of agriculture and nutrition sciences 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 one-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.

HarvestPlus focuses on three micronutrients that the World Health Organization recognizes as limiting: iron, zinc, and vitamin A. Full-time plant breeding programs are under way for six staple foods—rice, wheat, maize, cassava, sweetpotato, and common beans—that are consumed the majority of the world's poor in Africa, Asia, and Latin America consume and for which feasibility studies have already been completed. Pre-breeding feasibility studies are being undertaken for 10 additional staples: bananas/ plantains, barley, cowpeas, groundnuts, lentils, millet, pigeon peas, potatoes, sorghum, and yams. In 2005, considerable progress has been made in increasing the nutrient density of both phase I and II crops.

The primary objectives of HarvestPlus' 10-year plan (2004–2013) 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;

- Carefully test promising varieties under development to establish that sufficient nutrients are retained in staples as consumed, and that these nutrients are sufficiently bioavailable so that micronutrient status in undernourished people is improved;

- Identify varieties with superior agronomic, socioeconomic, and end user-acceptable traits; and measure the nutritional impacts of these improved varieties in community-based studies where these varieties have been adopted.

- Develop efficient, accelerated mechanisms for testing promising materials with farmers, consumers, and other end users, including those in the most nutritionally disadvantaged areas;

2.2 HarvestPlus Research strategy and priority matrix

Interdisciplinary crop-related research activities form the backbone of the HarvestPlus program. The objectives of HarvestPlus will be accomplished by coordinating *functional* research activities (scientific disciplines, the rows of the matrix below) within six Phase 1 *crop* groups (the columns of the matrix).

The major functional activities taking place across all crops include:

- Impact and policy research (i) to target regions where biofortification will have the greatest benefit and measurement of program impact and; (ii) to understand economic and social factors that determine the dietary quality of the poor and their micronutrient status, as well as policy advocacy based on that research;

- Reaching and fully engaging the end users within the crop development and diffusion strategies and, where necessary, through strategic communication activities to effectively change consumer behavior to enhance the dissemination and adoption of biofortified crops. Collaboration will take place with farmers, NARES, NGOs, and community-based public health specialists;

- Plant breeding based at CGIAR centers and NARES for the 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 promoting seed production where necessary;

- Food science and human nutrition research that will measure the retention of nutrients in processing and cooking, screening of promising lines for micronutrient bioavailability using in vitro methods and animal models, and stable isotope and efficacy studies involving human subjects to evaluate nutritional impact of the most promising lines intended for release;

- Application of novel advances in biotechnology, genomics, genetics, and molecular biology to identify and understand plant biosynthetic genes and pathways of nutritional importance; use of this knowledge (i) in marker-assisted selection for conventional breeding of Phase 1 crops and (ii) in initial development (but not release) of transgenic lines;

- Coordinated communication activities designed to provide support to internal project collaborators and external audiences, including donors, the academic and development communities, public officials, and the general media.

Two major activities fall within the purview of plant breeding and human nutrition, respectively, but are not related directly to specific Phase 1 crops. These are: pre-breeding feasibility studies based at CGIAR centers for 10 Phase 2 crops that are important in the diets of those with micronutrient deficiencies, but for which the knowledge base for biofortification has yet to be developed; and basic nutrition research to identify and reach consensus on a enhanced set of *breeding objectives* that potentially include (1) breeding for increased levels of compounds that improve nutrient bioavailability; (2) breeding for reduced levels of compounds, for example, phytates, that reduce nutrient bioavailability; and (3) increased levels of minerals and vitamins other than iron, zinc, and beta-carotene.

3.0 Research Accomplishments

3.1 Overview

Ten CGIAR research centers and nearly 90 NARES and Advanced Research institutes now make up the HarvestPlus research alliance. HarvestPlus biofortification research is being conducted by agriculture, nutrition and social scientists in Africa, Asia, Latin America, and the United States and within Europe (see appendix 1).

Specific crops have defined nutrients that have become the focus of HarvestPlus plant breeding activities. Breeding for pro-vitamins A carotenoids has centered on maize, cassava and orange-fleshed sweetpotato. Iron and zinc breeding work has concentrated on beans, rice and wheat. Exploratory work continues within these crops for additional nutrients and the presence or absence of nutrient promoter or inhibitor compounds but, for the time being, the bulk of the research is organized around maximizing the potential for any single crop to have an impact on a single nutritional deficiency. 2005 highlights in plant breeding include: High zinc wheat, high iron bean, and beta-carotene rich orange-fleshed sweetpotato adapted for East and Southern African farmers and consumers.

HarvestPlus nutritional genomics research is gaining insights related to gene discovery and processes and protocol for using genetic transformation to biofortify staple crops.

The research portfolio for food science and nutrition consists of developing protocols and standardized methods for analyzing nutritional value of biofortified crops, conducting retention studies and determining the bioavailability and efficacy of HarvestPlus crops *in vitro* and in human subjects.

The new Reaching End User sub-component of HarvestPlus is built around the findings of two distinct research activities. A series of *diagnostic studies* will be conducted in the first year of the program to inform activities that will strengthen seed and extension systems, create viable markets and effectively understand how to generate demand for biofortified crops within households and communities. On-going *operations research* will inform the implementation of dissemination activities and will be conducted throughout the life of the end user sub-component.

3.2 Technical Outputs

Plant Breeding

Wheat

- Iron and Zinc

Progress has been made on wheat, where the focus is on increasing iron and zinc levels, which are at 47 µg/g and 55 µg/g, increased from 35 µg/g and 30 µg/g respectively. By 2005, advanced lines had been developed with elevated mineral concentration, high yield potential and resistance to yellow rust. These lines have the potential for significantly improving zinc and iron concentrations in wheat for India and Pakistan replacing widely grown varieties PBW343 and Inquilab which occupy >90% of the wheat area in the Punjab.

- Genotype by Environment Interactions

International yield trials (India, Pakistan China, Turkey, and Mexico) were conducted with the best biofortified lines to determine genotype x environment interactions in target areas. In Pakistan lines showed genotype x environment interactions that negatively impacted on the amount of zinc in the seed. Additional data from other GXE studies are currently being analyzed. In addition, an international screening nursery with micronutrient dense wild relative and adapted germplasm was assembled in 2005/2006 along with the establishment of an international testing network and dissemination of sampling and screening protocols.

Maize

- Pro-vitamin A Carotenoids

Maize breeding efforts are focusing on increasing the levels of provitamin A carotenoids to a target level of 15μg/g with less emphasis on minerals. Genetic variation for pro-vitamins A and β-carotene has been identified in temperate germplasm at the University of Illinois and intermediate to high concentrations in genetically unrelated tropical highland germplasm. The highest values present to date in germplasm adapted to the target areas are considered intermediate concentrations.

- Iron and Zinc

The aleurone layer, which surrounds the endosperm, is dense in minerals and protein. The incorporation of multiple aleurone layer (MAL) traits was being considered. In 2005, yield trials were conducted at three locations in Zimbabwe comparing nine iso-hybrids (normal and MAL version). Results revealed that MAL did not increase iron and/or zinc.

Rice

- Iron and Zinc

Polished rice with 8 ppm iron and 20 ppm zinc has been identified in germplasm collections at IRRI. Genotypes with zinc concentration close or at the nutritional target have been identified in preliminary screening. More than 500 breeding lines/landraces/cultivars of Korean origin were planted in replicated observation trials. These were screened for iron and zinc content and the results were validated in a 2^{nd} season.

Cassava

- Pro-vitamin A carotenoid

Genotypes that combine good agronomic performance and higher nutritional value (β-carotene and protein concentrations) have been identified, although the level of 8 μg/g for β-carotene is only about 50% of the nutritional target. To date, the genetic variation encountered for iron and zinc in cassava has been low. Results from EMBRAPA, Brazil, suggest that β-carotene can be further enhanced by using novel sources present in landrace collections.

Beans

- Iron

The breeding goal is to double the amount of iron in beans from approximately 50 μg/g to 100 μg/g. At 90 μg/g, the breeding goal is close to being achieved. The first set of selected materials combining high iron with superior agronomic attributes e.g. drought tolerance, was distributed to African partners for local evaluation. Three African cultivars are consistently high in iron. In germplasm screening, high iron levels of up to 127 μg/g were identified in accessions of *P. polyanthus.*

Sweetpotato

- Pro-vitamin A carotenoids

Plant breeding to increase the dry matter content of the provitamin A-rich orange varieties continues so as to improve the sensory characteristics and at the same time to improve the resistance to viruses and stress such as drought.

- Genotype x Environment

Over 30 local varieties of beta-carotene-rich sweetpotato have been identified and institutions in ten countries have received at least 30 clones with high β-carotene and dry matter contents for GxE studies.

- Dissemination

Over 3 million virus-free vines have been multiplied and distributed to farmers and for establishment of secondary multiplication nurseries in Uganda, Mozambique and other countries in East and Southern Africa. Dissemination of Orange-fleshed sweetpotato will benefit from additional activities that now overlap with the REU component of HarvestPlus (see REU).

Phase 2 Crops

- Screening and Crop Improvement through Breeding

In all Phase 2 crops screening has been conducted to identify: (i) progenitors to develop micronutrient dense germplasm and, (ii) those to be used in crosses for heritability studies and the development of molecular markers. With a focus on early impact, another objective was to promote and re-launch existing varieties with high micronutrient levels that were identified during this process. This was achieved for several Phase 2 crops including potato, pearl millet, banana/plantain, and barley.

- Genotype by Environment Interactions

G x E experiments were initiated in many Phase 2 crops to determine whether there was expression *per se* and stability of expression of micronutrients. In general, preliminary results revealed that mineral concentration was subject to environmental modification. Provitamin A carotenoids are in general highly heritable and hence less subject to G x E interaction

Biotechnology and nutritional genomics

- Gene Discovery

Research will continue to identify and understand the underlying molecular and biochemical mechanisms of specific genes and loci affecting the accumulation of iron and zinc and synthesis of provitamin A compounds in model systems, as well as their bioavailability.

- Modern Biotechnology and Transgenics.

Additional work on transgenic technology will yield lessons and molecular tools for other Phase 1 crops. For instance, unlocking the phenomenon of co-suppression of genes when combining plant and bacterial genes will instruct use of transgenic approaches for biofortification. This work is currently being done using Golden Rice and later can be applied to cassava. Iron accumulation and transport will be studied at the molecular level in rice, wheat, and beans to yield either markers for assisted selection breeding or for incorporation as part of a transgenic approach.

Human Nutrition

- Developing Standard Protocols

The carotenoid screening and assay methods training course was conducted in 2004 in Brazil and 2005 in Africa. Follow-up assistance was offered to African technicians whose laboratories received equipment grants in 2005.

Convenient methods to determine phyto-ferritin content of a variety of staple food crops is under development and review; further validation studies are planned.

It should be noted that unanticipated considerable investment of time and resources has been directed to nutrition protocols and method development. This comes as no surprise as developing nutrient-dense staple crops is an innovation that has few references or validated tools that can be readily applied.

- Retention studies

Our studies have shown that the retention of carotenoids from sweet potato and cassava following different cooking and processing procedures can be high (e.g., $\geq$90%) among some varieties but much lower among others (e.g., ~20%).

- Bioavailability of micronutrients in Phase 1 crops

In Vitro and animal models: A competitive grant to develop an *in vitro* screening method for provitamin A carotenoid bioavailability is underway. This study will compare the Caco-2 cell model and a gerbil model and each will be compared directly with results from the human study of beta-carotene absorption from sweet potato. A pig model will be used to confirm observations in chicks that the non-provitamin A xanthophyll, lutein, enhances iron absorption to the same extent as β-carotene.

Human Subjects: Two human studies of absorption, one of β-carotene from orange flesh sweetpotato and one of zinc from zinc-biofortified wheat are underway in collaboration with the International Atomic Energy Agency through our joint competitive research program. A human study of the effects of inulin on iron and zinc absorption is being planned and will be conducted once a high inulin source of wheat is made available. An additional study is underway to determine the independent and combined effects of polyphenols and phytate on iron absorption from iron-rich colored beans.

Studies of gut function (intestinal permeability and small bowel overgrowth) are being incorporated into ongoing studies of human absorption (high-zinc wheat; beta-carotene-rich sweet potato) to determine to what extent these ‘host’ factors affect bioavailability.

Impact and Policy

- *Ex ante* Studies

Estimates of the benefits of biofortification were computed by collaborators based on a methodology developed by HarvestPlus (see HarvestPlus Technical Monograph 4) for selected countries for all six Phase 1 crops. These individual country/crop estimates have been compiled into a synthesis paper.

- Methods for ex post impact assessment

The launching of the REU sweetpotato activities have necessitated a shift in focus of the Impact and Policy program to focus more explicitly on *ex post* impact assessment. To this end, a multi-disciplinary group of experts (comprising nutritionists, economists, statisticians and anthropologists) was invited to a workshop, to come to discuss the particular challenges of measuring impact when agriculture is used as a public health intervention, and to come to a consensus on the framework for impact assessment, and on specific tools and methodologies that will be used to determine impact of beta-carotene-dense sweetpotato on the nutritional status of target communities in Mozambique and Uganda.

Reaching End Users (REU)

In 2005, a proposal titled, *Reaching End Users with Biofortified Crops: best Practices for Dissemination of Orange-Fleshed Sweetpotato in East and Southern Africa*, was developed as a research based implementation exercise that is designed as demonstration trials to rigorously evaluate the implementation of biofortified varieties and the effectiveness of biofortified crops in meeting the nutritional requirements of target populations. Though not part of the original challenge program work plan, HarvestPlus was fortunate enough to have a flagship crop ready for dissemination within the first phase of the program. Beta-carotene dense and regionally adapted, orange fleshed sweetpotato provided an opportunity to move further down the product marketing chain and develop a research typology and implementation framework for evaluating best practices for dissemination of biofortified crops. The REU activities couple operations research and implementation activities to understand three distinct pillars of activity including: the development of functional seed systems, strengthening markets, and understanding behavior change parameters necessary for consumer acceptance. Thus, the aforementioned "End User" proposal was written and then funded by the Bill and Melinda Gates Foundation.

- REU research and Implementation planning meetings for OFSP.

A series of stakeholder consultation and crop specific REU research planning meetings were held between March and June, 2005. The meetings brought together the commodity crop researchers from CGIAR Centers, Advanced Research Institutions, NARES, NGOs, experts in nutrition and agribusiness, and the private sector as well as small scale farmers.

3.3 List of sub-programs/projects

HarvestPlus China

In April of 2005 the HarvestPlus-China program advisory committee approved eight proposals for funding, each proposal involving two to four collaborating institutions. HarvestPlus will provide $400,000 in funding for these proposals, matched by another $400,000 from Chinese funding sources. HarvestPlus serves as a catalytic role in the establishment and implementation of biofortification work in China.

The first annual meeting of HarvestPlus-China was held in Beijing in October, 2005 and was attended by 60 scientists. Progress is being made in lobbying for a biofortification window in the upcoming five-year plans for the Chinese research funding programs. The Chinese government has provided a small amount of funding ($25,000) for the operation of the HarvestPlus-China office at CAAS. HarvestPlus supports the holding of the HarvestPlus-China annual meetings.

India Biofortification

As a result of concerted efforts from HarvestPlus collaborating institutions in the region in 2005, The Indian Department of Biotechnology announced it would release $1.5 million to Indian researchers for development of biofortified varieties of rice, wheat, and maize. The target nutrients are iron and zinc. HarvestPlus continues to serve as advisors the biofortification program for India.

4.0 Progress on other CP Activities

4.1 Capacity building

The CGIAR centers working with H+ have begun to incorporate biofortification within their regular training course curriculum. Scientists and students were invited to attend conference and crop research workshops to understand the HarvestPlus strategy and advances in biofortification research. Students working on biofortification-related activities have presented at several international conferences, backstopped by HarvestPlus scientists. Thirty nutrition researchers from Africa and China have been trained in standardized protocols for carotenoid analysis and laboratories have been reviewed and upgraded for high throughput analysis of bioavailability and nutrient retention in HarvestPlus crops.

HarvestPlus Technical Monograph series has been developed as training manuals for collaborators. These “how to” guides provide gold standard HarvestPlus procedures and protocols that researchers should consider when conducting biofortification research. In 2005, four monographs were added to the original two.

The Impact and Policy component has provided opportunities for six graduate students to work in the field to develop baseline measurements for impact analysis. In addition, in 2005, two dissertations were awarded to students engaged in HarvestPlus research activities.

4.2 Data management

HarvestPlus has developed a large “living” database (housed at CIAT) that records all critical information emerging from, and particular to, plant breeding for nutrient density for phase 1 and phase 2 crops. These data are collected from crop leaders, and recorded on a semi-annual basis. The database serves as a primary library of information to guide and inform the plant breeding component of the program. Examples of data collected include raw and processed genotypic data from micronutrient analyses and data/information relevant for the interpretation of the results. This information will be complemented by genotypic data from retention- and bioavailability studies and data for micronutrient absorption inhibitors and promoters.

4.3 Donor Relations and Communication

- Conferences, symposia and workshops

In 2005, HarvestPlus supported special sessions at: International Union of Nutrition Scientists, American Association for the Advancement of Science, and the International Wheat Congress.

In March, HarvestPlus sponsored a national-level symposium to raise awareness about biofortification for Brazil exclusively. The Ministry of Agriculture and Embrapa hosted the event. In addition, HarvestPlus researchers were asked to present research results in an additional 70 events across all disciplines involved in the program.

- Expert consultations

HarvestPlus component leaders convened several methodological roundtables including: *In vitro* Analysis of Bioavailability, Establishing Indicators of Impact for Biofortification, and Communications for Transgenic Biofortified Crops. These workshops bring in expertise from outside the HarvestPlus alliance to review and strengthen strategies and methods.

- HarvestPlus Alliance Publications

See appendix 2: Publications and Media Hits

5.0 Program Governance and Management

A detailed "Governance and Management Handbook" was developed in the first semester of 2004. The Handbook is a living document that is reviewed and revised with approval and guidance from the Program Advisory Committee.

5.1 HarvestPlus Program Advisory Committee

Role and Function of the PAC, Audit Committee and IFPRI and CIAT Boards
The HarvestPlus PAC is an external independent advisory body that provides governance and oversight to facilitate the program's complex collaborative arrangements. The PAC is not a legal entity, but has been delegated authority from the CIAT and IFPRI boards. The PAC comprises (1) 12 experts from developing and developed countries, (2) one member each from the CIAT and IFPRI boards, and (3) the director-generals of CIAT and IFPRI, for a total of 16 members. The HarvestPlus Audit and Finance Committee, is made up of representatives from IFPRI and CIAT audit committees and a member of PAC with expertise in finance and administration. The committee provides assistance to the PAC in fulfilling fiduciary responsibilities related to accounting, reporting and internal financial controls. The Audit Committee reports to the PAC on a semi-annual basis.

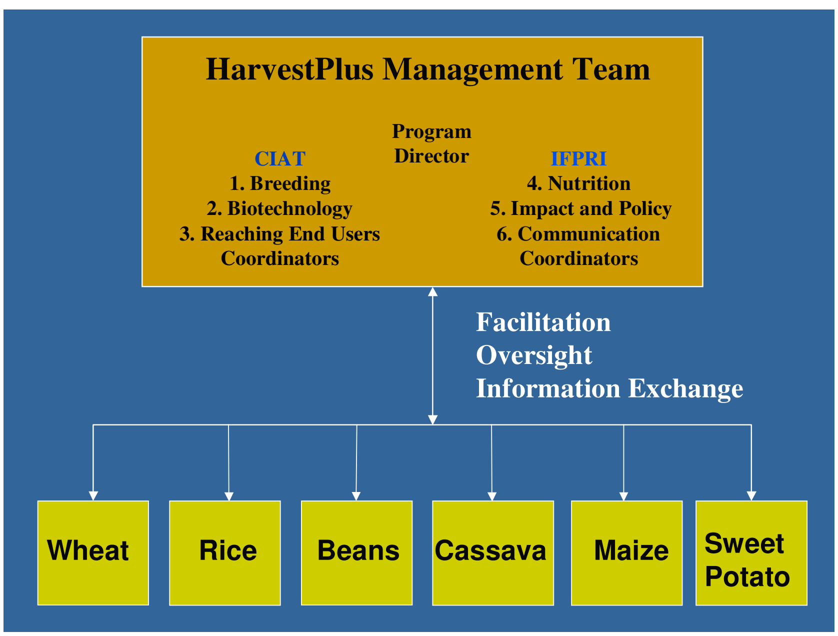
Role and Function of the CIAT and IFPRI Boards
CIAT and IFPRI have overall oversight and fiduciary responsibility for HarvestPlus. The two centers have accordingly entered into a Cooperative Research Agreement (March 2003) with the objective of combining complementary expertise's in the development and implementation of HarvestPlus.

The CIAT and IFPRI boards have delegated authority and related responsibilities to the PAC to undertake their mandate as an independent expert body. Two PAC members, one each from the boards of IFPRI and CIAT are responsible for reporting the progress being made under HarvestPlus to their respective boards. The CIAT and IFPRI boards nominated the initial PAC members, and the PAC is responsible for nominating subsequent members who are then approved by the boards of CIAT and IFPRI. In the event of conflict between CIAT, IFPRI, and the PAC, CIAT and IFPRI and the PAC chair will seek arbitration services and abide by the final decision of the arbitrator.

Activity Report
The PAC meet semi-annually to review work plans/progress, receive updates from the PMT and deliberate over the progam's strategic research priorities. Detailed minutes are produced from the semi annual meetings that are then approved during the following meeting.

5.2 Program Management Team (structure and activity report)

Program Management Team Structure
The HarvestPlus program management is grounded in crop and nutrition-related research and dissemination activities and is guided and advised by a team of program managers that are institutionally housed within CIAT and IFPRI. These program managers offer the set of expertise required to fulfill HarvestPlus's mission through facilitation, program oversight, and information exchange.



Activity Report
In early 2005 the final two coordinators were appointed, namely the breeding coordinator, based at CIAT-Colombia, and the reaching end user coordinator based at CIAT-Uganda.

5.3 Operational issues and challenges

As HarvestPlus activities expand, especially in the areas of Reaching End Users, and in collaborating with Linkage projects, national biofortification efforts (e.g. China and India), and (potentially) other biofortification projects (e.g. Gates Grand Challenges in Health), the time, effort, and travel required by members of the Program Management Team (PMT) to maintain contacts and share information within the PMT about all aspects of collaborative activities, is becoming increasingly challenging. The PMT members currently are based in three locations around the world (Washington, DC; Cali, Colombia; and Kampala, Uganda) which increases the challenges of intra-PMT communications. The PMT is looking into ways to cultivate regional representatives by component of the program that will serve as Ambassadors with technical expertise in biofortification areas.

6.0 Finance

6.1 Financial objectives and outcomes

From an accounting and reporting perspective, the IFPRI-CIAT arrangement is a joint venture, whereby each participating organization recognizes revenue/income that it *earns* from the provisions of research services under the terms of contractual arrangements. The contractual management of the HarvestPlus Challenge Program includes joint control (CIAT and IFPRI); whereby no single organization is in a position to unilaterally control the activities. The accounting approach therefore underscores the consortium approach for Challenge Programs, which explicitly acknowledges that the desired outcomes cannot be achieved by organizations working alone.

Financial transactions of the HarvestPlus, inflows and outflows of funds, are processed through the accounting and internal control systems of CIAT and IFPRI. The two centers prepare an annual supplemental schedule to their audited financial statements showing sources and application of funding.

In 2005, the pace of expenditures/disbursements increased to $9.5M, a twenty percent increase on 2004.

The Audit Committee of HarvestPlus and the Finance Division of CIAT and IFPRI monitor the rate of utilization of funds by recipient collaborating organizations. Funds provided to recipients (including CIAT and IFPRI) through 31 December 2005 have been fully accounted for by recipient through June 2006.

CIAT and IFPRI executed a cooperative research agreement in March 2003, which provides that CIAT and IFPRI enter into a contractual arrangement with other participating organizations (CGIAR-supported centers and other institutions) to complete specific program activities with deliverables.

HARVESTPLUS CHALLENGE PROGRAM
Cash Receipts and Cash Disbursements

Cash Receipts

Donors	***2003***	***2004***	***2005***	***Total***
Denmark		887,613	348,000	1,235,613
World Bank	3,000,000	2,500,000	2,000,000	7,500,000
Gates	7,000,000	0	8,750,000	15,750,000
Austria	54,482	0	0	54,482
Sweden	0	108,613	189,000	297,613
DFID	0	452,000	1,357,000	1,809,000
ADB	0	0	233,900	233,900
USAID	0	0	2,400,000	2,400,000
ILSI	0	0	200,000	200,000
Accrued Interest CIAT	9,000	21,274	40,000	70,274
Accrued Interest IFPRI	18,000	41,509	184,000	243,509
Foreign Exchange Gain (Loss)	0	25,924	-61,000	-35,076
Total Revenues:	***10,081,482***	***4,036,933***	***15,640,900***	***29,759,315***

Cash Disbursements

Partners				***Total***
CIAT	207,000	799,000	872,000	1,878,000
CIMMYT	133,000	620,000	654,000	1,407,000
CIP	78,000	452,000	509,000	1,039,000
ICARDA	40,000	84,000	85,000	209,000
ICRISAT	80,000	216,000	304,000	600,000
IITA	53,000	561,000	540,000	1,154,000
EMBRAPA	0	82,000	196,000	278,000
IRRI	60,000	450,000	509,000	1,019,000
IFPRI	0	663,000	1,631,000	2,294,000
IPGRI	0	0	40,000	40,000
Institute of Crop Sciences	0	0	74,000	74,000
RIMCU	20,000	0	20,000	40,000
University of Adelaide	25,000	459,000	424,000	908,000
Danish Institute of Agricultural Science	0	132,000	409,000	541,000
Michigan State University	0	412,000	374,000	786,000
Royal Veterinary and Agricultural University	0	25,000	16,000	41,000
University of Freiburg	0	298,000	302,000	600,000
University of Natural Resources and Applied Life Science	0	37,000	0	37,000
Ohio State University	0	0	40,000	40,000
Zheijang University, China	0	0	30,000	30,000
China Agricultural University	0	0	20,000	20,000
Chinese Academy of Sciences	0	0	10,000	10,000
Chinese Academy of Agricultural Sciences	0	0	28,000	28,000
USDA	0	878,000	230,000	1,108,000
WARDA	0	0	30,000	30,000
WORLD VISION	0	0	125,000	125,000
Other	0	53,000	55,000	108,000
Program Management (including Program Advisory Committee, Communications and CIAT)	1,322,000	1,625,000	1,953,000	4,900,000
Total Cash Disbursements:	***2,018,000***	***7,846,000***	***9,480,000***	***19,344,000***
Total Cash Receipts less Total Cash Disbursements:	***8,063,482***	***-3,809,067***	***6,160,900***	**10,415,315**
Total Cumulative Cash Receipts less Total Cumulative Cash Disbursements (Carryover):	***8,063,482***	***4,254,415***	***10,415,315***	

6.2 Other issues on Financial Management

Fundraising and Intellectual Property Management

A proposal: *"Reaching End Users with Biofortified Crops: Best Practices for Disseminating Orange Flesh Sweetpotato (OFSP) in East and Southern Africa"* was developed and funded by the Bill and Melinda Gates Foundation in November 2005.

Open Source Solutions being Considered
Open sources solutions for managing intellectual property are a means for creating a dynamic protected commons of new enabling technologies. It is an interesting and potentially new way of spanning public and private interest. Technologies can be maintained in the public domain and at the same time allow legitimate products to be patented for investment. The challenge is to select the platform with which to collaborate. HarvestPlus will further investigate its applicability for the program's knowledge and technology needs.

7.0 Lessons Learned

Plant Breeding
Micronutrient analysis in 2005 confirmed a positive association between iron and zinc concentration common to Phase 1 and Phase 2 crops. Breeding for one mineral will result in a parallel increase for the other mineral.

Genetic variation for micronutrients and implications for breeding
By 2005/06, only a small proportion of the genetic resources available in gene banks had been assayed. Hence, there is scope identifying higher levels via additional screening.

Bioavailability
Due to substantially lower bioavailability of iron when compared with zinc, higher concentrations have to be added to obtain nutritional target levels and therefore measurable impact. The product development time for iron biofortified crops will likely be prolonged.

The development of high-throughput screening methods
Minerals are concentrated in the aleurone, close to the seed coat and the embryo. The effect of degree of polishing and milling on micronutrient concentration and equipment needed to be researched, to determine the variation for minerals in milled products as prerequisite for breeding. This requirement has caused a delay in breeding especially for rice.

Efficient breeding for minerals and provitamin-A carotenoids hinges on the development of high throughput screening methods for a large number of samples, thus short turnaround time is also essential.

Genotype x Environment Interactions effect micronutrient content
Further research needs to be conducted on the effect of growing environments on micronutrients. This requires multi-site and multi-year experiments, which can take into account variation due to locations, years as well as differences in crop management practices from farmer to farmer.

Food Science and Human Nutrition
Institutionalizing and promoting standardized screening procedures for carotenoid assays in plant breeding laboratories is a challenge.

The production and investment in international public goods such as the HarvestPlus Technical Monographs and presentations at special session at international nutrition conferences is essential to engage, and get feedback and buy-in from the international nutrition community.

Impact and Policy
Challenges on ex ante estimates
Estimates, particularly on prevalence of certain outcomes and diseases, and of micronutrient intakes, have been difficult to obtain. While some of these data gaps may be filled in subsequent surveys, this will not be the case for many of the prevalence data.

Challenges on modeling micronutrient demand and mapping
Identifying and obtaining data sets that contain information on food consumption; as distinct from food balance sheets, has been difficult; more difficult still to find are data sets that contain information on intra-household consumption patterns.

Nutritional Genomics
A test system consisting of cassava cells needs to be employed which - by transformation - would allow HarvestPlus to screen Psy genes from different types and origins for effectiveness of beta carotene expression

HarvestPlus has also discovered that many of the predicted mineral-related genes in the rice genome may not be playing a role in mineral homeostasis, and thus attention can focus on the subset of actively expressed genes.

Reaching End Users
Getting biofortified crops to targeted end users is an enormous challenge that will force HarvestPlus to think creatively beyond its existing disciplinary base and institutional paradigms. New partnerships with marketing experts, behavior change communication and health communication specialists will need to be forged both internationally and regionally. Relationships will need to be fostered between HarvestPlus and the enabling communities of policy makers, technology diffusers, and consumers groups both internationally, in targeted countries, and within regions and communities.

Communications
HarvestPlus positioning and messaging vis-à-vis the GMO debate is an issue that deserves more attention. A public voice on GMOs and biofortified transgenic crops is lacking and HarvestPlus could serve the role with sufficient investment.

APPENDIX 1
HARVESTPLUS ALLIANCE MEMBERS
2005

Africa	
Ethiopia	Awassa Agricultural Research Centre, Awassa
Ghana	Crop Research Institute (CRI)
	Kenya Agricultural Research Institute (KARI)
Madagascar	Center of Rural Development and Applied Research (FIFAMANOR)
	National Institute for Agriculture Research (INIA), Maputo
Mozambique	World Vision
Pretoria	Agricultural Research Council
Rwanda	Rwanda Agricultural Research Institute (ISAR-Rubona)
Tanzania	Sugarcane Research Institute, Kibaha
Uganda	Namulonge Agricultural and Animal Research Institute
Zambia	Mansa Technology Assessment Site
Asia	
Bangladesh	Bangladesh Rice Research Institute
	International Centre for the Control of Diarrhoeal Disease Research
	Centre for Health and Population Research
China	Si-Chuan Agricultural University
	Center for Disease Control and Prevention of Sichuan Province
	Nanchong Agricultural Institute, Sichuan Province
	Xuzhou Center for Sweet Potato
	Crop Research Institute, Shandong Academy of Agricultural Sciences
	Huaxi Public Health School, Sichuan University
	The Institute of Nutrition and Food Safety, Chinese Center for Disease Control and Prevention
	Institute for Nutritional Sciences, Shanghai Institute for Biological Sciences, Chinese Academy of Sciences
	Institute of Crop Science, Chinese Academy of Agricultural Sciences
	The Biotechnology Research Institute of the Chinese Academy of Agricultural Sciences
	Institute of Genetics and Developmental Biology, Chinese Academy of Sciences
	College of Life Sciences, Zhejiang University
	Zhejiang University
India	Banaras Hindu University
	National Institute of Nutrition, Hyderbad
	Aarogya: Center for Health-Nutrition Education and Health Promotion
	Punjab Agricultural University (PAU)
Philippines	Philippine Rice Research Institute, Maligaya, Munoz
Australia, Europe, North America	
Australia	University of Adelaide, Waite Campus
Canada	Sembiosys Canada Inc.
Denmark	Royal Veterinary and Agricultural University, Department of Nutrition

	Danish Institute of Agricultural Sciences (DIAS)
	Laboratory of Gene Expression
Germany	University of Freiburg
Turkey	Sabanci University-Istanbul
United States	Children’s Nutrition Research Center, Baylor College of Medicine, USDA-ARS
	University of Colorado
	Purdue University
	Ohio State University
	Michigan State University
	Program in International Nutrition, Department of Nutrition, University of California-Davis
	University of Wisconsin
	Louisiana State University
	World Vision, USA
Uzbekistan	Scientific Center for Standardization of Drugs and Medicaments – Pharmaceutical Institute
	Center for Social and Marketing Research in Central Asia “Expert fikri”
Vienna	University of Natural Resources and Applied Life Science
Latin America	
Brazil	Empresa Brazileira de Pesquisa Agropecuaria EMBPRAPA Mandioca e Fruticultura)
	Empresa Central Tuber Crops Research Institute
	Fundação Arthur Bernardes (FUNARBE)
Colombia	PABRA-ECABREN-SABRN
Mexico	University Autonoma Queretaro
Peru	Instituto de Investigación Nutricional
CGIAR and related Centers	
	International Center for Tropical Agriculture (CIAT)
	International Maize and Wheat Improvement Center (CIMMYT)
	International Potato Center (CIP)
	International Center for Agricultural Research in the Dry Areas (ICARDA)
	International Center for Research in the Semi-Arid Tropics (ICRISAT)
	International Food Policy Research Institute (IFPRI)
	International Institute of Tropical Agriculture (IITA)
	International Network for the Improvement of Banana and Plantain (INIBAP)
	International Rice Research Institute (IRRI)
	West African Rice Development Association (WARDA)

APPENDIX 2
PUBLICATIONS AND MEDIA HITS

Peer-Reviewed Publications 2005

Abbo S., Molina C., Jungmaa R., Grusak MA., Berkovitch Z., Reifen R., Kahl G., Winter P. Reifen R. Quantitative trait loci governing carotenoid concentration and weight in seeds of chickpea (*Cicer arietinum* L.). Theoretical and Applied Genetics (2005); 111: 185-195.

Chávez, A.L., T. Sánchez, G. Jaramillo, J.M. Bedoya, J. Echeverry, E.A. Bolaños, H. Ceballos, and C.A. Iglesias, 2005. Variation of quality traits in cassava roots evaluated in landraces and improved clones. Euphytica 143:125-133

Garnett, T.P. and Graham, R.D. (2005). Distribution and remobilisation of iron and copper in wheat. Annals of Botany 95,817-826.

Genc, Y., Humphries, J.M., Lyons, G.H. and Graham, R.D. (2005). Exploiting genotypic variation in plant nutrient accumulation to alleviate micronutrient deficiency in populations. J. Trace Elem. Med. Biol. 18, 319-324.

Graham, RD, J Stangoulis, Y Genc, G Lyons. Selenium increased growth and fertility in higher plants. In CJ Li et al (eds) *Plant nutrition for food security, human health and environmental protection* pp. 208-209. Beijing, China: Tsinghua University Press.

Grusak, M.A., Cakmak, I. 2005. Methods to Improve the Crop-Delivery of Minerals to Humans and Livestock. In: Broadley, M.R., White, P.J., Editors. Plant Nutritional Genomics. Oxford:blackwell Publishing. P. 265-286.

Grusak, M.A. 2005. Golden Rice Gets a Boost from Maize. Nature Biotechnology. 23(4):429-430.

Grusak, M.A. 2005. Legumes. Types and Nutritional Value. Encyclopedia of Human Nutrition, 2nd Edition, Allen & Prentics, editors. New York: Elsivier Publishing; P 120-125.

Haas Jere D., J.L. Beard, L.E. Murray-Kolb, A.M. del Mundo, A.Felix, and G.B. Gregorio 2005. Iron-biofortified rice improves the iron stores of non-anemic Filipino women. *Journal of Nutrition.* 135:2823–2830.

Lopez-Millan, A., Ellis, D.R., Grusak, M.A. 2005. Effect of Zinc and Manganese Supply on the Activities of Superoxide Dismutase and Carbonic Anhydrase in Medicago Truncatula Wild Type and Raz Mutant Plants. Plant Science. 168:1015-1022.

Lyons, G.H., Genc, Y., Stangoulis, J.C.R., Palmer, L. and Graham, R.D. (2005). Selenium distribution in wheat grain, and the effect of postharvest processing on wheat selenium content. Biological Trace Element Research 103, 155-168.

Lyons, GH, I Ortiz-Monasterio, Y Genc, J Stangoulis, R Graham. Can cereals be bred for increased selenium and iodine concentration in grain? In CJ Li et al (eds) *Plant nutrition for food security, human health and environmental protection* pp. 374-375. Beijing, China: Tsinghua University Press.

Lyons, G.H., Ortiz-Monasterio, I., Judson, G., Genc, Y., Stangoulis, J.C.R. and Graham, R.D. (2005). High-selenium wheat in Australia: Biofortification for better health. J. Trace Elem. Med. Biol. 19: 75-82.

Lyons, G.H., Ortiz-Monasterio, I., Stangoulis, J.C.R. and Graham, R.D. (2005). Selenium concentration in wheat grain: Is there sufficient genotypic variation to use in breeding? Plant and Soil 269, 369-380.

Lyons, G.H., Stangoulis, J.C.R. and Graham, R.D. (2005). Tolerance of wheat (*Triticum aestivum* L.) to high soil and solution selenium levels. Plant and Soil 270, 179-180.

Nestel, P., H. Bouis, J.V. Meenakshi, W. Pfieffer (2005). Biofortification of staple food crops. Symposium: Food fortification in developing countries. American Society for Nutrition. 1064-1067.

van Jaarsveld P.J.,M.Faber, S.A.Tanumihardjo, P.Nestel, C.J Lombard, and A.J.S.Benadé, 2005. ß-Carotene-rich orange-fleshed sweetpotato improves the vitamin A status of primary school children assessed by the modified-relative-dose-response test. *American Journal of Clinical Nutrition.* 81: 1080 - 1087.

Wang H. L., M.A. Grusak. 2005. Structure and Development of *Medicago truncatula* Pod Wall and Seed Coat. Ann. Bot., Apr 2005; 95: 737 - 747.

Welch, R.M. and Graham, R.D. (2005). Agriculture: the real nexus for enhancing bioavailable micronutrients in food crops. J. Trace Elem. Med. Biol. 18: 299-307.

HarvestPlus Technical Monographs

Failla, Mark L., Chitchumroonchokchai, Chureeporn. 2005. *In vitro* Models as Tools for Screening the Relative Bioavailabilities of Provitamin A Carotenoids in Foods. HarvestPlus Technical Monograph Series 3.

Stein, Alexander J., Meenakshi, J.V., Qaim, Matin, Nestel, Penelope, Sachdev, H.P.S., Bhutta, Zulfiqar A. 2005. Analyzing the Health Benefits of Biofortified Staple Crops by Means of the Disability-Adjusted Life Years Approach: a Handbook Focusing on Iron, Zinc and Vitamin A. HarvestPlus Technical Monograph Series 4.

Haskell, Marjorie J., Ribaya-Mercado, Judy D., and the Vitamin A Tracer Task Force. 2005. Handbook on Vitamin A Tracer Dilution Methods to Assess Status and Evaluate Intervention Programs. HarvestPlus Technical Monograph Series 5.

Sonja Y. Hess, David I. Thurnham, Richard F. Hurrell. 2005. Influence of Provitamin A Carotenoids on Iron, Zinc, and Vitamin A Status. HarvestPlus Technical Monograph Series 6.

MEDIA LIST 2005

Source	Date	Title	Country	Event	Comments
Reuters	22 Feb	A Little Meat Adds a Lot to Poor Kids' Diets	USA	No Event	Mentions IFPRI as well as Howarth Bouis' research
Medical News Today	28 Mar	Golden Rice Humanitarian Board's Statement on Development of New Golden Rice Strain with Higher Levels of β carotene	UK	No Event	
Minda News	01 Dec	IRRI Pushes Fortified Rice	Philippines	AGM 2005	Cites HarvestPlus
Dominican Today	05 Dec	Nutritionally Enhanced Rice Reduces Iron Deficiency	Dominican Republic	AGM 2005	HarvestPlus press event
VOA News	09 Dec	Iron Rich Rice Boosts Women's Nutritional Health	International	AGM 2005	HarvestPlus press event
Business World	09 Dec	Farm R & D Funding Key to Facing Competition	Philippines	AGM 2005	HarvestPlus press event
United Press International	16 Dec	Rice Research Pays Off Big	International	No Event	Mentions HarvestPlus
United Press International	21 Dec	Catholic Sisters Prove Enriched Rice Value	Philippines	No Event	Quotes Howarth Bouis, Director HarvestPlus