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Strategies for Biofortification in Brazil

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In Brazil, the intake of vitamin A and minerals such as iron and zinc is below the recommended levels and their bioavailability in the diet is low. Biochemical studies show that some groups of the population have so low levels of micronutrient that intervention is needed. Most attempts to combat micronutrient deficiency elsewhere in the developing world have focused on providing vitamin and mineral supplements to the poor and on fortifying foods with these nutrients during processing after they have been harvested. But are these the best strategies?

In Brazil, the focus is instead on biofortification, an intervention strategy that is being developed to increase the content of particular micronutrients in staple food crops by agricultural, agronomic or biotechnological means. This means that the micronutrients are already in the crops when they are harvested, so they do not need to be added afterwards. When consumed regularly, biofortified foods will lead to increased micronutrient intake. Biofortification can complement the existing strategies and provide a sustainable, low-cost way of combating malnutrition.

Brazil has two biofortification programs: the HarvestPlus Challenge Program on Biofortification and the AgroSalud Program, both coordinated by the Brazilian Agricultural Research Corporation (Embrapa). The difference between the two programs is that the HarvestPlus Challenge Program focuses on breeding micronutrient-rich plant varieties, whereas the AgroSalud Program focuses on Latin America and the Caribbean and on post-harvest processing. The main food staples being studied in Brazil are cassava, sweet potato, rice, common beans, maize, wheat and cowpea.

Micronutrient deficiencies in the developing world

It is estimated that billions of people in poor countries suffer from micronutrient deficiencies because they lack the money to buy enough meat, poultry, fish, fruits, legumes and vegetables. Women and children in sub-Saharan Africa, South and Southeast Asia, Latin America and the Caribbean are especially at risk of disease, impaired cognitive abilities and premature death because of diets poor in crucial micronutrients (McGuire, 1993).

The World Health Organization has shown that micronutrient deficiency is not exclusive to the developing world, having also been observed in developed countries. Of the most commonly studied micronutrients, iron, vitamin A and iodine are the ones most correlated with public health problems, both in Brazil and worldwide, although calcium, zinc, selenium and copper are also important for development (Kennedy et al., 2003).

Diets that lack iron and zinc can cause anaemia, reduced capacity for work, immunological problems, retarded growth and even death (WHO, 2000). Iron-deficiency anaemia is probably the most important nutritional problem in Brazil, affecting 30–80% of children aged five years and under, depending on the region and income, although this deficiency is independent of social class or geographic distribution. The most important iron sources in Brazil are common beans and red meat, with 1–7% of the iron they contain being absorbed by the body (Favaro, 1997).

Zinc deficiency has been less well studied but will also have a high incidence because the food sources for these two nutrients are the same. Zinc is required for the activity of more than 300 enzymes, many of which act on the immune system and gene expression (McCall, 2000). Little is known about zinc deficiency in developing countries, although food sources that are rich in bioavailable iron are usually also rich in bioavailable zinc.

Vitamin A is essential for vision, growth and disease resistance. Vitamin A deficiency is a serious health problem in developing countries, causing blindness in children in 80 countries around the world. Increasing the intake of pro-vitamin A or carotenoids is one way of tackling this deficiency (Cozzolino, 2005).

Generally, there are three factors that cause variation in micronutrient levels in food: plant characteristics, such as age, degree of maturation, species, variety, cultivar and diet; environmental characteristics, such as climate, soil, rain and season; and processing parameters, such as storage, temperature, preservation method and preparation (Welch, 2001).

In developing countries, fortifying food with vitamin A and iron, and distributing supplements of these micronutrients to target populations, have been widely and successfully used to fight a lack of vitamin A and iron-deficiency anaemia (WHO, 1994). In regions with adequate infrastructure and well-established markets for delivering processed foods, such as salt, sugar and cereal flours, food fortification can greatly improve the micronutrient intake of vulnerable populations.

In Brazil, efforts in this direction started long ago by fortifying salt with iodine and adding fluoride to water in some regions. More recently, it has been mandatory to fortify wheat and maize flours with iron and folic acid to prevent anaemia and neural-tube defects, respectively (Cozzolino, 2005).

But there are limits to commercial fortification and supplementation. Fortified foods may not reach many of the people most in need because of poor market infrastructures. Supplementation also requires a good health infrastructure, a condition that is often lacking in developing countries. New approaches are therefore needed to ensure the wide availability of micronutrients in the diet.

Biofortification as an intervention strategy

The goal of biofortification is to help reduce the high prevalence of iron, zinc and vitamin A deficiencies by improving the micronutrient density of the staple food crops that are produced and consumed by low-income populations. Unlike traditional food fortification, biofortification does not require food to be processed centrally, as the micronutrients are already present in growing crops, making it more accessible to those who consume food that is grown locally, perhaps by themselves (HarvestPlus, 2008).

Biofortification is a long-term strategy aimed at increasing the micronutrient intake of large numbers of people throughout their lives, contributing to an overall reduction in micronutrient deficiencies in a population. However, it is not expected to treat severe micronutrient deficiencies or eliminate them in all population groups (HarvestPlus, 2008).

Even so, the introduction of biofortified crops will provide a sustainable and low-cost way of reaching people with poor access to formal markets or healthcare systems. Once the investment has been made in developing nutritionally improved varieties at central research locations, seeds can be adapted to the local growing conditions in numerous countries. Biofortified varieties can then provide benefits year after year throughout the developing world at a lower cost than either dietary supplements or fortification through food processing.

One way to ensure that farmers will like the new varieties is to give them a say about what traits are bred into the plants. Such participatory plant breeding, in which scientists take farmers' preferences into account during the breeding process, can be more cost-effective than confining breeding to research stations.

Preliminary research examining the feasibility of a plant-breeding approach for improving the micronutrient content of staple crops has made several important findings: substantial, useful genetic variation exists in key staple crops; breeding programs can readily manage nutritional quality traits, which for some crops are highly heritable and simple to screen for; the desired traits tend to be stable across a wide range of growing environments; and traits for high nutrient content can be combined with superior agronomic characteristics and high yields.

Where scientists can combine high micronutrient content with high yields, the nutritionally improved varieties are almost certain to be grown widely and marketed successfully. In fact, research showing that high levels of minerals in seeds also aid plant nutrition has fuelled expectations of increased productivity in biofortified strains.

Brazil's Biofortification Programs

HarvestPlus

The HarvestPlus Challenge Program on Biofortification was created to improve the nutritional quality of Brazil's main food crops, which can be adapted to suit the local growing conditions. It uses scientific and technological advances to improve the diet of some of the poorest populations in the world, who live on subsistence agriculture in the marginal zones of the tropics.

Initially, biofortification efforts will focus on six staple crops for which pre-breeding feasibility studies have been completed: beans, cassava, maize, rice, sweet potatoes and wheat. The program will also examine the potential for nutrient enhancement in 10 additional crops that are important components of the diets of people with micronutrient deficiencies: bananas/plantains, barley, cowpeas, groundnuts, lentils, millet, pigeon peas, potatoes, sorghum and yams.

The HarvestPlus objectives (HarvestPlus, 2004) are:

- Years one to four: Determine nutritionally optimal breeding objectives. Screen CGIAR germplasm for high iron, zinc and beta-carotene levels. Initiate crosses of high-yielding adapted germplasm for selected crops. Document cultural and food-processing practices, and determine their effect on micronutrient content and bioavailability. Discern the genetics of high micronutrient levels, and identify the markers available to facilitate the transfer of traits through conventional and novel breeding strategies. Carry out in vitro and animal studies to determine the bioavailability of the enhanced micronutrients in promising lines. Begin bioefficacy studies to determine the biological effect of the biofortified crops on the micronutrient status of humans. Initiate studies to identify the trends – and factors driving these trends – in the quality of the diets of poor people. Conduct cost–benefit analyses of plant breeding and other food-based interventions to control micronutrient malnutrition.

- Years five to seven: Continue bioefficacy studies. Initiate participatory plant breeding and adapt high-yielding, conventionally bred, micronutrient-dense lines to particular regions. Release new conventionally bred biofortified varieties to farmers. Identify gene systems with the potential to increase nutritional value beyond traditional breeding methods. Produce transgenic lines experimentally and screen for micronutrients. Test for compliance with biosafety regulations. Develop and implement a marketing strategy to promote the improved varieties. Begin production and distribution
- Years eight to ten: Scale up the production and distribution of the improved varieties. Determine the nutritional effectiveness of the program, and identify factors affecting the adoption of biofortified crops, the impact on household resources, and the health effects on individuals

The HarvestPlus Challenge Program on Biofortification is an initiative of the Consultative Group on International Agricultural Research (CGIAR), which involves CGIAR research centers and partner institutions. It was planned for a 10-year period and is financially supported by the Bill and Melinda Gates Foundation and the World Bank, among others.

AgroSalud

The project "Combating Hidden Hunger in Latin America: Biofortified Crops with Improved Vitamin A, Essential Minerals and Quality Protein—AgroSalud" was intended to complement the HarvestPlus Challenge Program on Biofortification.

AgroSalud aims to reduce malnutrition and improve food and nutritional security in Latin America and the Caribbean through the consumption and production of biofortified crops and food products derived using traditional plant breeding methods. A specific objective is to reduce malnutrition caused by deficiencies in vitamin A, iron, zinc and protein in children and women of fertile age.

The main difference between the AgroSalud and the HarvestPlus programs is that AgroSalud focuses on Latin America and the Caribbean, and on post-harvest processing of crops that are important in the region, such as rice, beans, maize, cassava and sweet potato. Together with partners in different countries, AgroSalud carries out research in agronomy, nutrition, post-harvest technologies and social sciences to gather data that can be used to study the impact of biofortified crops and serve as a decision-making tool.

The AgroSalud objectives (AgroSalud, 2007) are:

- To develop, evaluate, disseminate and promote biofortified crops.
- To use traditional plant breeding methods to increase the contents of iron and zinc in maize, rice, beans and sweet potato, of tryptophan and lysine in maize, and of beta-carotene in sweet potato, cassava and maize.
- To measure the nutritional, economic and agronomic impact of these crops on producers and consumers.
- To determine the relevance and social, economic and financial viability of investing in the research and development of biofortified food products, as well as in their production, transformation and consumption.

The project, which is financed by the Canadian International Development Agency (CIDA), is led by five international organizations located in Brazil (the Brazilian Agricultural Research Corporation, Embrapa), Colombia (the International Center for Tropical Agriculture, CIAT; and the Latin American and Caribbean Consortium to Support Cassava Research and Development, CLAYUCA), Mexico (the International Maize and Wheat Improvement Center, CIMMYT) and Peru (International Potato Center, CIP). AgroSalud carries out work in Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua and Peru.

The HarvestPlus and AgroSalud programs were established in 2004 and are coordinated by Embrapa Food Technology, one of the research centers of the Brazilian Agricultural Research Corporation in Rio de Janeiro. The following research centers and institutions are also part of the Brazilian biofortification research net: Embrapa Rice and Beans, Embrapa Cassava and Tropical Fruits, Embrapa Maize and Sorghum, Embrapa Vegetables, Embrapa Mid-North, Embrapa Coastal Tablelands, Embrapa Wheat, Embrapa Soybeans, Embrapa Cerrados, Embrapa Tropical Semi-Arid, Embrapa Headquarters, Embrapa Office for Technological Innovation, the State University of Campinas (Unicamp), São Paulo State University (UNESP), the Federal University of Rio de Janeiro (UFRJ) and the Rural Federal University of Rio de Janeiro (UFRRJ).

The main objective of HarvestPlus is the identification of populations of cassava, common beans, maize, wheat and cowpea that have agronomic potential and higher levels of iron, zinc and pro-vitamin A than current crops. AgroSalud researchers study crops such as rice, sweet potato, common beans and cassava, and activities related to the post-harvest processing of these biofortified crops are also carried out. In addition, pilot projects are underway for the dissemination of biofortified foods (including pumpkin) in the states of Maranhão and Sergipe in Northeastern Brazil.

The crops included in the program are already widely produced and consumed in Brazil, so farmers are already familiar with them and consumers do not have to change their diet to benefit from biofortification. Moreover, breeding to improve the mineral content will not necessarily alter the appearance, taste, texture or cooking qualities of the food.

Another expected outcome of the biofortification programs is an integration of countries in Latin America, the Caribbean, Africa and Southeast Asia, with Brazil developing and transferring not only the biofortified varieties but also the technology for post-harvest processing. So far, Brazilian researchers have collaborated with colleagues in 10 African countries to develop local capacity for carotenoid analysis, and a practical training course on carotenoid detection and analysis was organized in Tanzania in July 2005.

Progress in some individual crops

Cassava

Cassava (Manihot esculenta) is a white-fleshed root crop, classified as sweet or bitter depending on the amount of cyanide-producing compounds. This perennial crop, native to South America, is a major source of provitamin A for people in Northeastern Brazil, sub-Saharan Africa and parts of Asia where drought, poverty and malnutrition are prevalent.

Breeding Activities

Embrapa Cassava & Tropical Fruits has been working on the biofortification of cassava since 2003. The strategy is to develop genotypes from agronomically superior varieties that have high concentrations of carotenoids in the roots and, with less extensive research, to breed for iron and zinc content.

The work started with the screening and breeding of cassava for carotenoids to select varieties by spectrophotometry. The total carotenoid content in the best varieties ranged from 6.4 μg per g to 15.5 μg per g. These varieties were used as parents for the development of new clones with a higher content of total carotenoids. In the first generation, some clones showed an increase of more than 140% in their total carotenoid content (relative to the parents); in the second generation, the increase was approximately 200%.

The first cassava varieties with a high content of carotenoids and a low content of cyanide were selected from the Embrapa Germplasm Bank and chosen by farmers and communities in a participatory breeding experiment in Northeast Brazil. These varieties were selected and planted in controlled areas and their clones were harvested and selected by their characteristics in 2007.

In early 2006, two yellow-rooted clones with higher levels of beta-carotene—Dourada (Golden) and Gema de Ovo (Egg Yolk)—were officially launched at a ceremony attended by more than 100 farmers. This event was the first step towards the release of nutritionally enhanced germplasm.

In early 2008, the beta-carotene concentration in the 2003 generation was evaluated. The average concentration of beta-carotene in the roots was 5.4 μg per g, ranging from 2.6 μg per g to 9.1 μg per g. There was no direct relation between the values of total carotenoids with beta-carotene. The levels of hydrogen cyanide, iron and zinc were also evaluated in the selected roots of hybrids from the 2003, 2004 and 2005 generations. The maximum levels of iron and zinc in the 2003 generation were approximately 51 mg per kg and 34 mg per kg, respectively. In the 2004 generation, the iron and zinc levels varied from 1.0 to 77 mg per kg and from 0.5 to 87 mg per kg, respectively. In the 2005 generation, the levels of iron and zinc varied from 20 to 30 mg per kg and from 2.4 to 34 mg per kg, and cyanide varied from 20 to 350 parts per million. These data result from studies on the roots of 10-month-old plants.

Other seedlings, acquired from a self-fertilization field with different varieties of cassava with high values of carotenoids, are being harvested. Their hybrids, which are an intense yellow colour, will be chosen and planted to determine the value of total carotenoids, beta-carotene and cyanide.

The promising cassava roots, which have high levels of beta-carotene, iron and zinc, are being monitored in semi-arid regions of Brazil. A flour capable of conserving micronutrients is also being developed in partnership with Embrapa Food Technology. It could be used to produce bread, cake, pasta and other bakery products.

Carotenoid retention

Research has also been carried out at Embrapa Cassava & Tropical Fruits, in collaboration with São Paulo State University and the Federal University of Rio de Janeiro, to evaluate the retention of carotenoids in cassava roots and their by-products.

The retention of carotenoids was evaluated in different types of cassava flour (traditional flour, oven-dried 'scraping flour' (55°C) and 'gari flour' (fermented flour)) and chips. The gari flour, oven-dried 'scraping flour' and boiled root retained more carotenoids after processing. Regarding the time of storage, the sun-dried scraping flour and chips lost the least amount of carotenoids, although it was not possible to correlate carotenoid retention with the cyanide content of the fresh varieties or the obtained products.

The retention of beta-carotene and total carotenoids in yellow cassava varieties were evaluated both after traditional cooking and as flour. The highest retention of beta-carotene (79.8%) was observed when yellow cassava samples were cooked half-covered with water and boiled in a pot with the lid on; the retention of total carotenoids was greatest (81.5%) when the cassava were cooked completely covered with water and boiled in a pot with the lid on.

These preliminary studies have given the research team the opportunity to explore the relationship between the loss of total carotenoid content and beta-carotene content and genetic variation.

Sweet Potato

Africa's predominant sweet potato (*Ipomoea batatas*) cultivars are the white- and yellow-fleshed varieties, which contain small amounts of beta-carotene. In contrast, the orange-fleshed variety, although much less common, is a rich source of beta-carotene and can be grown year-round, making it an ideal source of vitamin A. If sweet potato could be bred for local growing conditions, and if there were sufficient demand, farmers and consumers could switch to the orange-fleshed variety, increasing their vitamin A intake.

Breeding activities

Embrapa Vegetables has been working to increase the dry matter content of the provitamin A-rich orange-fleshed varieties to make them more palatable, as well as improving their resistance to viruses and environmental stresses. For the analyses, sweet potato genotypes, seeds and clones were imported from the International Potato Center (CIP) in Peru. Germplasm samples from the Embrapa Vegetables germplasm bank were screened, and orange-fleshed sweet potato samples were obtained from Brazilian farmers with the help of a popular television program.

Selected clones were evaluated for the productivity of their storage roots, amount of foliage, color, dry matter content, carotene content and flour productivity. The selected materials were planted again at low temperature to test their adaptability to severe climatic conditions, and the iron, zinc and carotene contents were evaluated.

The varieties sent by CIP were assayed and given nutritional evaluations in Maranhão and Sergipe, where field trials left them exposed to warm and rainy seasons. Six other clones with more than 100 mg per kg of beta-carotene were evaluated for beta-carotene, total and reducing sugar, starch content and sensory analysis.

Researchers are also developing ways of drying sweet potato plants without reducing the micronutrient content and of extracting the residue (bran) and the starch.

Post-Harvest Activities

Researchers from Embrapa Vegetables and Embrapa Food Technology have been working together to obtain flour from orange-fleshed sweet potato varieties. The flour was analysed for size and content of total carotenoids and beta-carotenes. Preliminary results show that the flour has good coloration and structure. French bread made with 15% sweet potato flour had a similar size to bread made with wheat flour; for sweet breads, 20% sweet potato flour could be used; for other breads, 50% was the acceptable limit.

Processing sweet potato chips using 0.5–1.0% citric acid led to satisfactory results in preliminary tests, with the intense orange colour being maintained, especially after drying. Flaked instant puree is still being studied, but preliminary testing has revealed a homogenous appearance and intense orange colour, even after reconstituting with water.

These tests have shown how versatile orange-fleshed sweet potatoes are. They can be used as fresh roots, consumed boiled, roasted, fried and mashed, and used as an ingredient in various recipes. The processing of these roots into flour will allow it to be applied to social programs such as school lunches.

Common beans

An inexpensive bowl of beans is the centerpiece of the daily diet of more than 300 million people. Common beans (*Phaseolus vulgaris L.*) provide significant amounts of protein, complex carbohydrates and dietary fibre, as well as iron and zinc.

Protein energy undernutrition (PEU) remains a common problem in much of the developing world. More than one third of children less than five years of age in developing countries suffer from PEU, and the proportion of children who are undernourished has changed very little during the past 20 years. Given the widespread consumption of beans throughout the world, efforts to improve their micronutrient content could potentially benefit large numbers of people.

Researchers are trying to endow common bean seeds with higher levels of iron and zinc, with the aim of doubling the quantity of these minerals to 50 p.p.m. for zinc and 100 p.p.m. for iron. If this can be achieved, the biofortified beans will provide much of the mineral requirements of the malnourished people in Northeastern Brazil.

Breeding activities

Researchers at Embrapa Rice and Beans have been developing biofortified common beans in the Brazilian states of Goiás and Pernambuco. Their research is focused on increasing the concentrations of iron and zinc in agronomically superior cultivars, specifically those tolerant to drought and adapted to the environment in Northeastern Brazil. But first the Grain Quality laboratory required the purchase of an atomic absorption spectrophotometer and a ball mill. The scientists also improved the mineral analysis methodology, based on the AOAC method with modifications by the Waite Agricultural Research Institute of the University of Adelaide in Australia, and other adaptations were made to avoid iron contamination.

Traditional cultivars, breeding cultivars, landraces and accessions from Embrapa's germplasm bank and CIAT's core collection were planted for multiplication during winter, under irrigation, in Santo Antônio de Goiás, Porangatu and Petrolina. These genotypes were harvested, sampled and sent to Embrapa Rice and Beans, where the average iron and zinc levels were found to be 76 p.p.m. (ranging from 40 to 130 p.p.m.) and 26 p.p.m. (ranging from 7 to 58 p.p.m.), respectively. The best accessions were used as parents in crosses to select genotypes with high levels of iron and zinc, which were included in commercial groups of beans. All the iron and zinc results were validated at Embrapa Food Technology in Rio de Janeiro. Based on these results, Embrapa Rice and Beans has chosen two cultivars, BRS-Marfim and BRS-Pontal, for a pilot study; their iron and zinc contents were found to be around 80 p.p.m. and 45 p.p.m., respectively.

Research into the drought resistance of common beans has been underway since 2006. The first experiments were carried out in Santo Antônio de Goiás and Porangatu in Goiás state. Pre-selected genotypes were planted and either properly irrigated or given insufficient water. After harvesting, the grains were analyzed for iron and zinc.

At the end of the experiment, genotypes that presented good yields of iron and zinc without water stress were selected, along with those that were less susceptible to water stress.

These trials were repeated to confirm the adaptability and stability of mineral contents in different locations and environmental conditions. It was found that iron and zinc absorption by common beans is not strongly affected by water stress. The productivity of 81 genotypes and 20 populations with a high iron content planted in Porangatu was also investigated. In 2007, Porangatu suffered a severe drought, providing seven germplasms with drought tolerance; these were also evaluated for iron and zinc contents.

A new trial was planned in 2008 to select drought-tolerant samples. The genotypes used were selected from five sources: a nursery of samples grown under drought and high-temperature conditions; the CIAT Core Collection; new cultivars; Brazilian landraces; and a phenotype trial. The results are still preliminary, although, some cultivars already appear to be drought tolerant, such as BRS Pontal (iron level of 80.2 p.p.m. and zinc level of 49.6 p.p.m.) and BRS Agreste (iron, 78.8 p.p.m. and zinc, 45.6 p.p.m.).

These trials have yielded promising genotypes with high iron and zinc contents, good yield performance and less susceptibility to water stress, and some of these will be fast-tracked into use in Brazil.

Mineral retention

Research carried out at Embrapa Food Technology in collaboration with the Federal University of Rio de Janeiro sought to evaluate the retention of iron and zinc in common bean cultivars after cooking. The iron and zinc contents of raw and cooked grains were evaluated, along with various varieties of beans used in broth prepared according to traditional Brazilian cooking methods. The levels of iron and zinc in cooked beans were dependent on the cooking method. When the beans were immersed in water and cooked in a pressure cooker, the iron contents in the broth are significantly higher than when the beans are cooked in a Teflon pan with the lid partly open. In contrast, the zinc content was preserved in cooked grains regardless of whether the beans were previously immersed in water or not or cooked in a pressure cooker or a Teflon pan. Most of the iron and zinc remaining in the beans after cooking was concentrated in the kernels, so to maximize the mineral intake, it is important to consume the cooked beans in the broth.

Evaluating nutrition

One aim of the nutrition studies in Brazil is to evaluate the potential of biofortified crops in school meals in two Brazilian states where micronutrient deficiencies are particularly prevalent. The studies are being carried out in partnership with the Brazilian Ministry of Health and with the support of the National Fund for School Development (FNDE/MEC), the agency responsible for school meals in Brazil. The micronutrient deficiency was identified, and the distribution program established, on the basis of data from the National Research of Demography and Health (PNDS), the Budget Family Research (POF) and the Feed and Nutrition System Monitoring (SISVAN), among other sources.

The state of Maranhão in Northeastern Brazil was chosen for a pilot project for three reasons: it has a high level of malnutrition (42%), low coverage from supplementation programs (vitamin A and iron), and high agricultural potential. The nearby state of Sergipe has similar nutritional problems to Maranhão and was also included in the study.

The project nutritionists went to São Luis, Icatu and Chapadinha in Maranhão, and Aracaju, the capital of Sergipe, where meetings were organized with administrative agencies and local institutions responsible for agriculture, education and health in order to present the objectives of the AgroSalud program. In Maranhão, partnerships were established with representatives of universities (the Federal University of Maranhão and the private university centers of Maranhão), the National Food Security Council (CONSEA) and the state's Health Secretary. In Aracaju, a work plan was developed in collaboration with the Federal University of Sergipe and Embrapa Coastal Tablelands

While the nutritionists were in Maranhão and Sergipe, they also collected data on iron and vitamin A deficiencies in the target sites, explored the governmental programs set up to prevent these deficiencies, conducted research about cooking and food preparation methods, evaluated possible partnerships with non-governmental organizations, evaluated the local production of the project's target crops (cassava, maize, rice, beans and sweet potato), evaluated the logistics of food distribution in the area and collected data on the local eating habits. They also discussed the possibility of establishing partnerships with local programs, including the National School Lunch Program (PNAE) and the Food Acquisition Program (PAA). In both states, they established a partnership with the representatives of Brazil's National Commodity Supply Agency (CONAB). Despite this, the logistics strategies will be defined after the sensory evaluation tests (for palatability), which will be carried out with school and pre-school children in 2009 in Maranhão e Sergipe.

The sensory evaluation requires the authorization of the local Ethics Committee and the local Education Secretaries and the training of volunteers and meetings with parents and school directors. Agreements have been signed in Maranhão and Sergipe for work to start and to raise funds.

Sergipe and Maranhão are not only home to these studies but are also the expected location of a 'biofortified food channel'. Agrosalud will evaluate the agronomical performance of biofortified crops in the region, assess the acceptability of the biofortified crops to local producers and children, and explore the way the biofortified crops are integrated into the local diet.

Conclusion

Many developing countries lack the distribution systems to reach the poorest people. With biofortification, the distribution network is less of a problem. When households grow micronutrient-rich crops, the biofortified foods are already in the hands of the people who need them; there is no need to have them delivered. Little intervention or investment is needed once local farmers have adopted the new seed. Moreover, micronutrient-rich seed can easily be saved and shared by even the poorest households.

The ultimate solution to eradicating undernutrition in developing countries is to substantially increase the consumption of meat, poultry, fish, fruits, legumes and vegetables among the poor. Achieving this will take many decades and untold billions of dollars. In the meantime, biofortification makes sense as part of an integrated food-systems approach for reducing undernutrition. It addresses the root causes of micronutrient malnutrition, targets the poorest people, uses built-in delivery mechanisms, is scientifically feasible and cost-effective, and complements existing interventions to control micronutrient deficiencies. It is an essential first step in enabling rural households to improve their nutrition and health in a sustainable way.

Embrapa has valuable experience in the development and promotion of local systems for distributing seed, thanks to its work with seed systems and its contributions to disaster response. These established systems offer a natural route for disseminating biofortified seed. Local agricultural committees and seed enterprises will play a crucial role in getting micronutrient-rich varieties into the hands of growers on the ground.

The results presented here are the consequence of the hard work of more than 150 people in different regions of the country who sought to achieve the objectives of HarvestPlus and AgroSalud.

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