3-6

Biofortification in a Food Chain Approach in West Africa

By:

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CASE STUDY #3-6 OF THE PROGRAM:
"FOOD POLICY FOR DEVELOPING COUNTRIES: THE ROLE OF GOVERNMENT IN THE GLOBAL FOOD SYSTEM"
2007

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Executive Summary

About 800 million people suffer from hunger, but even more suffer from micronutrient malnutrition, also called "hidden hunger." Iodine, vitamin A, iron, and zinc malnutrition are major concerns. About 2 billion people, mainly women and young children, suffer from deficiencies of iron and zinc, which lead to impaired growth and development, low daily work output, and increased mortality. The supply of iron (Fe) and zinc (Zn) falls short when people suffer from food shortages, when consumed foods have a low Fe or Zn content, or when absorption of Fe and Zn from consumed food is inhibited by the presence of antinutritional factors such as phytic acid and polyphenols in the diet. Current interventions are dietary diversification, supplementation, and fortification. In West Africa alone more than 80 percent of children and up to 66 percent of women suffer from iron deficiency. In Benin and Burkina Faso the prevalence of micronutrient malnutrition is also high. In these countries the interventions mentioned have only moderate chances of success owing to the low purchasing power of households, lack of elementary logistics, lack of central processing of food, and the high heterogeneity in production and consumption conditions. In 2000 biofortification was introduced as a new policy option at the global level.

Biofortification consists of breeding for micronutrients in staple crops. In 2001 the approach was extended to a food chain approach by Wageningen University. This approach to biofortification offers additional opportunities to alleviate micronutrient malnutrition in West Africa, as illustrated by the cases of Benin and Burkina Faso. Preliminary experiences in these two countries challenge current policies toward crop cultivation and nutrition, but also reveal a number of questions to be solved.

Your assignment is to advise national policy makers in Benin or Burkina Faso about which strategy or combination of strategies they should choose to solve iron and zinc deficiencies in rural and urban sorghum-growing and -consuming areas of these countries.

Background

The Magnitude of the Problem

Worldwide, 800 million people are subject to energy malnutrition, but even more suffer from micronutrient malnutrition (Table 1).

Table 1: Extent of Micronutrient Malnutrition

Micronutrient Deficiency	Number of People Affected (billions)	Regions Affected (in general)
Iodine	1.6 (1990); 0.5 (2000)	118 countries
Vitamin A	0.5, of which 0.28 are under age five with blindness	118 countries, mainly in Africa and Southeast Asia
Iron	4.0–5.0 have iron deficiency; 2.0 have iron deficiency anemia	Worldwide, including Europe and the United States
Zinc	2.0	Worldwide
Folic acid	?	Worldwide
Selenium	?	Especially China and the former Soviet Union

Source: WHO 2000.

Iodine and selenium deficiencies prevail in deficient environments—that is, environments with inadequate levels of iodine and selenium in soils, surface water, drinking water, or local produce. The decrease of iodine deficiency from 1.6 billion in 1990 to 0.5 billion in 2000 is largely due to the distribution of iodized salt. Efforts in only one country—China, with its huge population—contributed enormously to this improvement (WHO 1999). An estimated 250,000 to 500,000 vitamin A–deficient children become blind every year; half of them die within one year of losing their eyesight. Particularly vulnerable to iron deficiency are pregnant, menstruating, and lactating women and growing children. A general aggravating factor is blood loss caused by malaria, intestinal worms, lice, and ticks (Stoltzfus et al. 1997; Stephenson et al. 2000; Müller et al. 2001). In 1989 it was estimated that 60 percent of pregnant women, 45 percent of nonpregnant women, 50 percent of children and adolescents, and only 25 percent of men in developing countries were anemic (DeMaeyer et al. 1989). In 2001 the Micronutrient Initiative (Mason et al. 2001) reported anemia prevalence of 56 percent for pregnant and 42 percent for nonpregnant women in developing countries. Many school-aged children may also suffer from iron deficiency anemia, but data are scarce. The demand for iron by the unborn child is so high that even in industrial countries well-nourished women usually require iron supplements during part of their pregnancy.

Consequences

Micronutrient deficiencies generally cause impaired growth, decreased productive and reproductive functions, decreased educability, and increased mortality of adults and children. Iodine-deficient people may forfeit 15 IQ points (Maberly et al. 1994). Other specific iodine deficiency disorders (IDDs) include goiter and cretinism. Vitamin A deficiency (VAD) may lead to blindness and reduced resistance to infection.

Iron deficiency (ID) affects both industrial and developing countries, and it is the main cause of iron deficiency anemia (IDA). In developing countries, the risk of anemia is worsened by other micronutrient deficiencies (folic acid, vitamin A, and B_{12}), parasitic infections such as hookworm and malaria, and chronic infections such as HIV. In infants and children anemia impairs psychomotor development, coordination, and school performance and decreases activity levels. In adults, iron deficiency reduces work capacity and decreases resistance to fatigue. In pregnant women, IDA is associated with an increased risk of maternal mortality, fetal growth retardation, premature birth, low birth weight, and even infant mortality (WHO 2000).

Zinc deficiency causes growth retardation or failure in fetuses, infants, and adolescents. It also may cause diarrhea, immune deficiencies, skin and eye lesions, delayed sexual maturation, and behavioral changes. Folate deficiency is associated with neural tube defects and colon cancer. Selenium deficiency is associated with Keshan disease, which results in heart failure affecting children and women of child-bearing age. It is also associated with Kashin-Beck disease, which leads to deformation of the joints affecting children between the ages of 5 and 13 years. Both diseases prevail in China and the former Soviet Union (WHO 2000).

In countries with micronutrient malnutrition, the symptoms mentioned are a heavy burden on the health budget. Communities with lower work performance and learning capacity display lower labor productivity and reduced capacity for innovation. In pupils with lower IQ, investment in education and training is less effective, and increased mortality reduces the number of trained people. Iron deficiency reduces the capacity for heavy manual work by 17 percent and the capacity for typical "blue collar" work by 5 percent (Hunt 2001). The total cognitive and physical losses in individuals affected by iron deficiency anemia alone lead to a 1 to 2 percent reduction in gross domestic product (GDP).

There is increasing evidence that certain micronutrient deficiencies can aggravate the effects of others. For instance, zinc deficiency inhibits the bioconversion of beta-carotene into retinol (Dijkhuizen et al. 2004). IQ increases more when iron is added to iodine supplementation than in response to pure iodine supplementation (Shresta 1994). Anemia decreases more when vitamin A is added to iron supplementation than in response to supplementation with iron alone (Suharno et al. 1993).

Important Concepts

Increased demands for micronutrients occur during menstruation, pregnancy, and growth and during replenishment of losses caused by diseases and parasitic infections. Improved hygiene, improved prophylactics, and treatment of infectious diseases can thus reduce replenishment demand. All demands for micronutrients need to be balanced by the supply or intake of micronutrients. Effective supply of micronutrients is determined by three factors: food intake, pro-nutrient content of the food, and the bioavailability and bioefficacy of the nutrient from the food.

Food intake depends on the availability of food, individual access to food, appreciation of food, and resources for food preparation. Availability results from local food production, markets, and distribution, whereas access to available food depends on income and price and on entitlements through social relations. Appreciation is determined not only by perception of attractiveness (such as taste, color, and texture), but also by safety (shelf life, type of spoilage) and by convenience or required preparation for consumption (peeling, cooking, and frying compared with snacks or fast food). At the consumer level, constraints can also stem from food habits and taboos. Many food taboos are more stringent for pregnant and lactating women, just at the time when their nutritional requirements are greatest (Bentley et al. 1999). Resources for food preparation include know-how, time, access to water and fuel, and cooking utensils.

The nutrient content of a diet can be influenced by selecting available foods containing high levels of nutrients or by adding nutrients to specific foodstuffs (fortification) or to the diet (supplementation). Development of foods with increased nutrient content either through breeding (biofortification) or through processing will widen the choice. Public awareness of the importance of nutrients and their presence in foodstuffs is a prerequisite for an informed choice; still, some less favorable food habits may remain difficult to change.

The human body cannot always adequately assimilate nutrients. Bioavailability is the proportion of an ingested nutrient that is available for metabolic processing and storage in the human body. Bioefficacy is the proportion of the ingested nutrient that is effectively metabolized or converted into its active form. For example, the vitamin A precursor beta-carotene needs to be converted to retinol, which is the active form in the human body. In cereal grains, iron and zinc are bound to antinutritional factors such as phytic acid and tannins, and therefore up to 95 percent of these minerals are unavailable to the human body. Food processing can influence the content of all components within one foodstuff, leading to a higher or lower supply of micronutrients. Antinutritional factors present in one food item (such as tannins in tea) can negatively influence the bioavailability of nutrients in other food items consumed in the same meal (Hurell et al. 1999; Hallberg and Rossander 1982). Generally, animal foods are better sources of bioavailable micronutrients than vegetable sources (Engelmann et al. 1998). Apart from antinutritional factors, some food items contain factors that promote absorption of micronutrients. In particular, vitamin C from fruits and vegetables and proteins from animal products are known to promote micronutrient absorption.

Hunger and Micronutrient Malnutrition in Burkina Faso and Benin

In Sub-Saharan Africa the number of undernourished people increased from 169 million to 206 million between 1990–1992 and 2001–2003, but the proportion of undernourished fell from 35 to 32 percent of the population in the same period. In 2001–2003 Benin and Burkina Faso were among the countries doing better than average, with a decrease of 0.1 to 0.2 million in the number of undernourished people between 1990–1992 and 2001–2003 (FAO 2006b). Yet indicators for malnutrition in these two countries are still high, with a difference between the poorest and richest 20 percent of the population (Table 2).

The estimated share of the population in Sub-Saharan Africa at risk of inadequate zinc intake varies from 11 percent in Mali to 60 percent in Mozambique. Figures for Burkina Faso and Benin are relatively low, at 13 and 17 percent, but the prevalence of stunting is high, at 37 and 25 percent, respectively (Hotz and Brown 2004; Brown et al. 2001). Figures locally may differ from the average. In a study of three villages in Atacora province in northern Benin, anthropometric measurements in 80 children between the ages of 6 and 8 years showed the prevalence of stunting at about 30 percent (Mitchikpe 2007). In a study in 18 villages in northern Burkina Faso, 72 percent of the 709 study children between 6 and 31 months of age were found to be zinc deficient, with zinc serum levels below the threshold of 13 micromols

Table 2: Indicators of Hunger and Malnutrition

Indicator	Burkina Faso	Benin
Undernourished (% of total population)	17	14
Children underweight for age (% under age 5, 1996–2004)	38	23
Children under height for age (% under age 5)		
Among poorest 20% of the population	21	17
Among richest 20% of the population	15	12

Source: UNDP 2006.

per liter (µmol/l) (Müller et al. 2003). Supplementation with 12.5 milligrams (mg) of zinc sulphate six days a week for six months led to higher zinc serum levels and reduced the prevalence of diarrhea (Müller et al. 2001).

Anemia, generally seen as a sign of iron deficiency, is measured as hemoglobin (Hb) levels in grams per liter (g/l) in blood. Vulnerable groups are children and women of fertile age. In the mid-1990s the United Nations Children's Fund (UNICEF) estimated the prevalence of anemia (Hb < 110 g/l) among pregnant women in Sub-Saharan Africa at 44 percent (UNICEF 2000), whereas the United Nations Administrative Committee on Coordination/Subcommittee on Nutrition (ACC/SCN 2000) reported this prevalence to range from 47 percent in the east to 56 percent in the west of Africa. More recent data report that prevalence of anemia in women between 14 and 49 years of age varies between 48 percent in Burkina Faso and 65 percent in Benin (UNICEF 2004).

In preschool children in Africa, anemia prevalence ranged from 42 percent in West Africa to 53 percent in East Africa (ACC/SCN 2000). More recent data are based on partial surveys and statistical modeling techniques (UNICEF 2004) and show that the prevalence of anemia (Hb < 110 g/l) in children under five years of age in both Benin and Burkina Faso exceeds 80 percent. Of the reported anemic children in Benin, 9 percent had a severe form, 51 percent a moderate form, and 22 percent a mild form of anemia (EDSB 2001 in Ategbo and Dop 2003). In the study by Mitchikpe (2007) in 80 children between ages six and eight years in northern Benin, the prevalence of anemia (defined as Hb < 115 g/l) was 33 percent in the postharvest season and 70 percent in the preharvest season.

Socioeconomic Context in the Sorghum Area of Benin and Burkina Faso

In West Africa up to 80 percent of the population lives in the rural areas, and their main occupation is agriculture. Because of the lack of infrastructure such as roads and markets and the lack of transportation and purchasing power at the household level, households generally produce, process, and consume their own staple food. In Burkina Faso and northern Benin the staple food is sorghum. In the market, households generally buy only processed products such as salt, sugar, and oil or, when their harvest has failed, nationally produced staple foods. Micronutrient-rich foods such as meat, milk, and fish are part of meals at a number of ceremonies but hardly ever enter the diet on ordinary days because they are too expensive. In a study by Mitchikpe (2007), the contribution of animal products to daily intakes in households in Atacora province varied from 2 to 3 percent for energy, 5 to 6 percent for protein, and 1 to 2 percent for iron in preharvest and postharvest seasons, respectively.

Daily diets tend to consist largely of staple foods (sorghum, cassava, maize, or yam) and a watery vegetable sauce from tomato, onion, local eggplant, or peanut butter. Mitchikpe (2007) found in northern Benin that sorghum contributes 10–15 percent to daily iron supply and 13–21 percent to daily zinc supply in postharvest and preharvest seasons, respectively. But Fe and Zn bioavailability is inhibited by the phytic acid and polyphenols present in these sorghum grains. People occasionally harvest fruits and vegetables from the wild to eat as snack foods or to replace food in times of scarcity. A study by Glew et al. (1997) identified 24 indigenous plants consumed in Burkina Faso from which only baobab (*Adansonia digitata*) leaves, *Bixa orellana* seeds, and *Xilopia* species contained large quantities of Fe, whereas okra (*Hibiscus esculente*) flowers contained considerable quantities of Zn. Because these products are consumed irregularly and in very low quantities and also contain unknown quantities of antinutritional factors, their contribution to Fe and Zn supply is limited. In addition, these foods could contain promoters of micronutrient absorption such as vitamin C, although this factor has not been measured.

Food processing for daily meals is done predominantly at the household level. Food processing can also be a specialized job in the village in the case of beer brewing or preparation of snacks to be sold in the local market. Households use a number of different food-processing techniques to prepare sorghum-based foods with different tastes, structures, and shelf lives. Within these processing methods, it is possible to distinguish unit operations that are beneficial (fermentation, germination) or detrimental (cooking) for Fe and Zn content and bioavailability in sorghum-based foods. Yet the impact of the unit operations on micronutrient supply is still under investigation and not known at the level of the women in the household responsible for food processing.

In Burkina Faso and Benin erratic rainfall conditions and low soil fertility constrain food production. Current soil and water conservation measures include application of crop residues, manure, mulch, and compost and construction of stone bunds, all requiring large amounts of labor. The choice between measures depends on resource endowments such as labor, means of transporting the soil amendments, and livestock to consume crop residues and produce manure. The measures taken potentially affect Fe, Zn, and phytic acid concentrations in sorghum grain. The measures aim at enhancing crop yields, however, and their impact on crop quality is hardly ever measured and is thus unknown at the farmers' level. Therefore any choice of a specific soil and water conservation measure does not yet take micronutrient supply into account.

Funds for buying fertilizer or building irrigation facilities are generally lacking except for cash crops such as cotton, for which fertilizers are provided through a loan to be repaid at the sale of the crop.

Several sorghum varieties exist, each with different Fe, Zn, phytic acid, and polyphenol concentrations and combinations. These traits are generally not investigated in locally used cultivars and are therefore not part of informed cultivar choice for micronutrient supply at the household level. Access to improved sorghum varieties in the countryside is relatively low. One reason is that the coverage of agricultural extension and seed supply is low. More important, however, is that given the hazardous environment, farmers apply a strategy of risk aversion, cultivating many varieties with different characteristics. In Benin, Kayodé, Linnemann et al. (2006) found no less than 76 varieties of sorghum in three farming communities.

Public services, including electricity, clean water supply, and health and education services, are scarce outside major cities. One reason is lack of infrastructure (clinics, schools, pumps, wells), goods (drugs, school books), and qualified personnel, whereas the demand for services grows with population growth. These factors, combined with a relative lack of roads and means of transport, make access to health and education services problematic.

Stakeholders

Children and women of fertile age have been identified as the groups most vulnerable to micronutrient malnutrition. These stakeholders should be reached with programs aiming to improving their situation. Such programs are the result of policy decisions at different scale levels, with national policies reflecting international treaties and debates. Decisions on the formulation and acceptance of Millennium Development Goals (MDGs) and on the formulation and execution of the programs of UN organizations like the Food and Agriculture Organization (FAO), UNICEF, and the World Health Organization (WHO) are all based on debate and negotiation between nation-states. Stakeholders at the national level are therefore policy makers in ministries that also represent their countries in international bodies such as FAO, the UN, and the New Partnership for Africa's Development (NEPAD). For the issue of micronutrient malnutrition, the ministries of health and agriculture are particularly important, and depending on the country, nutrition issues can be found in one of these departments. The decision makers at the national level are also confronted with demands and offers by international nongovernmental organizations (NGOs) such as Helen Keller International. Some NGOs work directly with local counterparts, local NGOs, churches, or other civil society groups through their own networks. These activities, although vital for those involved, generally reach only a limited number of stakeholders in a few locations. These groups are not considered here because they do not involve policies at a higher scale level.

At the local level, polices are implemented by civil servants at regional, provincial, and village levels. It is also important to consider traditional power structures because many decisions are made by civil society rather than by government-paid "civil servants." A number of avenues can be used to reach the mentioned vulnerable groups at the local level. Clinics for maternal care can be the entrance point for reaching women at different stages of pregnancy and child care. Children and their parents can also be reached through schools, and women can be reached through informal or formal women's groups. National agricultural research centers such as l'Institut de l'Environnement et Recherches Agricoles (INERA) in Burkina Faso and l'Institut National de Recherches Agricoles de Benin (INRAB) are important for agronomic research and extension that can help improve nutrition by supporting the breeding and cultivation of crops that contribute to micronutrient supply through daily diets.

Developing countries such as Benin and Burkina Faso also depend heavily on international donors to implement policies. Donors may be based in-country and be responsible for direct execution of programs at the local level, or they may support the national government through a co-funded program.

UN Organizations

World Health Organization. The WHO, the United Nations specialized agency for health, is addressing different micronutrient issues including iron deficiency and anemia. In this particular field WHO implements a package of public health measures in countries with high levels of iron deficiency and anemia, malaria, helminthes infections, and schistosomiasis. This package consists of three pillars: (1) dietary diversification including iron-rich foods, food fortification, enhancement of iron absorption, and iron supplementation to increase iron intake; (2) immunization and control programs for malaria, hookworm, and schistosomiasis to control infection; and (3) prevention and control of other nutritional deficiencies, such as vitamin B_{12}, folic acid, and vitamin A to improve nutritional status (WHO 2006).

UNICEF. For 60 years UNICEF has aimed to help children survive and grow, from early childhood through adolescence. Among other things, UNICEF supports child health and nutrition, setting goals such as "reduce the prevalence of anemia (including iron deficiency) by one third by 2010." To achieve this objective it uses a comprehensive approach. One component consists of educational campaigns to clarify the important role of iron in the diet. It also promotes and financially supports fortifying staples such as flour as an alternative for reaching people for whom iron-rich foods—liver, red meats, eggs, fish, whole-grain bread, legumes—are not widely available or affordable. It also provides iron–folic acid supplements during pregnancy to help prevent anemia in mothers and severe neural tube defects, such as spina bifida and anencephaly, in the fetus. Finally, in malaria-endemic countries, anti-malarial interventions, such as bed nets, are provided because malaria is often the major factor underlying anemia. The UNICEF health program in Burkina Faso seeks to improve child survival by reducing infant mortality through immunization and micronutrient supplementation activities. The country office also ensures that women receive training in health, nutrition, and hygiene. In addition, collaboration between UNICEF and the WHO has led to a 40 percent reduction in guinea-worm cases, contributing to reduced body-iron losses (UNICEF 2006).

NGOs

Helen Keller International. The objective of Helen Keller International (HKI) is to fight and treat preventable blindness and malnutrition. According to HKI's website,

> HKI's nutrition programs include vitamin A, iron/folic acid, zinc, and multi-micronutrient supplementation; food fortification; homestead food production

(including community and school gardening); and school health education initiatives. The promotion of breastfeeding and complementary feeding is a component of the nutrition programs. HKI also conducts nutritional surveillance to provide critical data to governments and other development partners (HKI 2006).

HKI enables the distribution of vitamin A twice a year to 9 million preschool children in Africa, including Burkina Faso, in 2003. The Homestead Food Production (HFP) program integrates strategies for long-term nutritional health with those for addressing poverty. HKI helps communities establish homestead gardens, for instance in Burkina Faso, and to cultivate fruits and vegetables rich in vitamin A and other micronutrients. Most household gardens yield surplus food that is sometimes consumed but often sold for additional income, enabling families to reduce their poverty levels and gain economic independence. An intervention aimed at replacing white-fleshed sweet potato with production and consumption of a vitamin A–rich improved orange-fleshed sweet potato was successful in Mozambique. The entire intervention is being replicated in Burkina Faso and Niger (HKI 2006).

International Programs

The Micronutrient Initiative. Following the outcomes of the World Summit for Children, the Micronutrient Initiative (MI) started in 1992 aiming to protect the world's children from micronutrient malnutrition. During the nine years that MI operated as a secretariat within the International Development Research Centre (IDRC), it supported nutrition programs in more than 75 countries. MI was governed by a committee of representatives of its major donor organizations: UNICEF, the World Bank, the U.S. Agency for International Development (USAID), and the Canadian International Development Agency. Through partners like UNICEF and HKI, MI helped governments in Africa, including Burkina Faso, reach 16 million children with vitamin A capsules. MI has also worked with these partners and national governments to improve the integration of vitamin A delivery with regular health services. In 2001 MI changed status and became governed by an independent board of directors. In 2004 MI provided technical and operational support to governments and industries to design and implement national programs for the fortification of cereal flours, cooking oils, salt, and condiments (MI 2005).

HarvestPlus. HarvestPlus is an international, interdisciplinary, research program that seeks to reduce micronutrient malnutrition among the poor by combining agriculture and nutrition research to breed nutrient-dense staple foods (such breeding is called biofortification). This goal is being pursued by a Global Challenge program of the Consultative Group on International Agricultural Research (CGIAR) in alliance with research institutions and implementing agencies in developed and developing countries, and coordinated by the International Center for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI). The coordination includes the plant breeding, human nutrition, crop dissemination, policy analysis, and impact activities that are carried out at international agricultural research centers, national agricultural research and extension institutions, and departments of plant science and human nutrition at universities in both developing and developed countries.

Initial biofortification efforts focus on six staple crops for which pre-breeding feasibility studies (Graham et al. 2001; Bouis 2002) 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 in the diets of those with micronutrient deficiencies: bananas/plantains, barley, cowpeas, groundnuts, lentils, millet, pigeon peas, potatoes, sorghum, and yams.

HarvestPlus recognized that conventional breeding might not be sufficient to reach nutritional targets and therefore also promotes research on genetically modified organisms (GMOs) to increase the speed and magnitude of improvement. HarvestPlus is in close contact with human nutritionists regarding the scientific basis for the nutritional targets of breeding efforts (HarvestPlus 2007).

Wageningen University. In 2001 Wageningen University started an international research program on sorghum with universities and national agricultural research systems (NARSs) in Benin and Burkina Faso. It used a food chain approach incorporating research in the domains of soil and plant and food processing, to enhance uptake and distribution of Fe and Zn to edible plant parts and retention of Fe and Zn when transforming grains into food. It included research on current food-processing methods and identification of those unit operations within them that concentrate Fe and Zn and deactivate or remove phytic acid and polyphenols, and consumption patterns identifying sources of Fe, Zn, and phytic acid in daily diets. Research results showed that micronutrient content and bioavailability in sorghum grain could be influenced by fertilizing practices. Phosphorus (P) fertilizer applied to sorghum crops led to higher yields but also higher phytic acid, leading to a lower bioavailable zinc supply in the grains (Traore 2006 in Slingerland et al. 2006). Zn fertilizer led to higher Zn in sorghum grain. Zn-P fertilizer thus led to higher Zn of lower bioavailability. Research showed that several food-processing activities reduced phytic acid levels in the sorghum-based foods, potentially increasing Fe and Zn bioavailability (Kayodé et al. 2007, and Kayodé, Nout, et al. 2006). After reduction of phytic acid levels, however, bioavailability remained low. During processing, other antinutritional factors such as tannins present in sorghum grains may have been transformed into more inhibiting forms (Kayodé et al. 2007; Matuschek et al. 2001). As a result of milling, both antinutritional factors and micronutrients decreased, leading to the question of how to optimize milling for the highest supply of bioavailable Fe and Zn (Kayodé, Nout, et al. 2006).

The biofortification approach and the food chain approach are complementary, the former focusing on breeding, and the latter focusing on genotype–environment interactions and the fate of micronutrients and antinutritional factors during food processing and in interaction with other dietary components during consumption.

Policy Options

Six policy options may be considered to alleviate or prevent micronutrient malnutrition: dietary diversification, supplementation, postharvest processing, fortification, biofortification, and a food chain approach. The options aim at interventions either in the food and nutrition domain or in the domain of plant breeding and food production.

Dietary diversification represents a combination of actions. One action is to identify food items (wild and cultivated) with high micronutrient content and bioavailability and to promote their consumption. When the supply of these foods is low, interventions may aim to increase their availability by promoting cultivation of specific crops or raising of livestock, presuming that the products are locally consumed. Promotion of income-generating activities is considered important because it improves purchasing power and allows people to buy specific nutritious food items (such as meat) in the market. This is an indirect way of improving supply. Simultaneously, the public should be made aware of the nutritious quality of the foodstuffs available to them so they can make informed choices. Communication designed to change behavior, rather than technological development, is an important tool in this strategy. The behavior change approach is often associated with more general objectives such as empowerment of women or poor people, and these objectives may reinforce the dietary diversification strategy.

Supplementation is periodic administration of pharmacological preparations to target groups by way of injection, capsules, or tablets (Lotfi et al. 1996; WHO 1997; Stoltzfus and Dreyfuss 1998). For iron, it may involve daily consumption of iron-containing pills; for vitamin A and iodine, larger single doses can be stored by the body and metabolized over a period of time. For children, two high-dose vitamin A supplements per year have proven to be a safe, cost-effective, and efficient strategy to resolve vitamin A deficiency (UNICEF 2006). If supplements must be administered on a regular basis, compliance by the target group is a prerequisite. Administration can be successful when it is adjusted to the regular habits of the target group. Pregnant women and infants can be reached in pregnancy and postnatal clinics. Distribution of supplements can be effective when logistics are in place to reach the same target group—for instance, during a vaccination campaign against measles.

Postharvest food processing aims to transform primary products into edible, enjoyable, nutritious dishes. In addition, it preserves food for storage and distribution by killing pathogens and by providing an unfavorable environment for pathogen multiplication and growth in case of contamination. In cereals, dehulling and pearling can remove a majority of antinutritional factors that are present in the outer layers of the grain. Unfortunately these processing steps also remove part of the micronutrients. Soaking, heating, fermenting, and other processing steps can lead to chemical and physical changes and inactivation of specific anti-nutritional factors and can increase micronutrient bioavailability (Svanberg et al. 1993; Kayodé, Linnemann, et al. 2006).

Fortification is defined as the addition of pro-nutrients to foods that are regularly consumed by most of the population. Examples are iodized salt and vitamin A– and vitamin D–enriched margarine. A prerequisite for successful fortification is the availability of basic foods or ingredients that undergo centralized processing so that the fortificant can be added in a controlled and safe manner. These food items must be generally consumed by the target population in such quantities that the risk of excessive intake of the fortificant is negligible. To promote use of fortified products, non-fortified alternatives are generally taken out of the market.

Biofortification implies the fortification of vegetable foods with bioavailable micronutrients through conventional breeding (Graham et al. 2001) or with the use of GMO techniques. Breeding goals can be increased micronutrient content, decreased content of antinutritional factors that affect micronutrient bioavailability, or both. Examples are golden rice (rich in pro-vitamin A), high-quality protein maize (increased lysine), low–phytic acid barley, and orange-fleshed sweet potato (rich in pro-vitamin A) (Bouis 2000). Additional care must be given to genotype–environment interactions to assure that the crop can perform well (produces tubers or seeds) and expresses its value under different field conditions. Biofortification in a broader sense includes increasing micronutrient content in a crop through manipulation of the crop's environment, such as by adding fertilizer.

A food chain approach comprises the extended biofortification and the postharvest approach and pays attention to dietary diversity (Slingerland et al. 2006). This interdisciplinary approach aims to increase the supply of bioavailable Fe and Zn from cereal-based foods. Research is conducted on the following themes: soil, water, and crop management to enhance uptake of Fe and Zn by plants, plant physiology aiming at enhanced translocation of Fe and Zn to the grain, screening of genotypes for high Fe and Zn and low content of antinutritional factors (ANFs) in their grain, interaction between genotype and management leading to high Fe and Zn and low levels of ANFs in the grain, food processing to increase Fe and Zn concentration and decrease ANFs in cereal-based food, sources of Fe and Zn and ANFs in daily diets and their interaction, and intervention studies to determine if improved foods lead to health impacts. Permanent interaction between the topics is key to this approach, to allow, for instance, any proposed improvement at the plant level to be evaluated in the light of the possibilities at the food-processing level and vice versa. In addition, current management and food-processing practices and dietary habits are taken as a starting point, in order to favor improvements that can be perceived as slight modifications rather than large changes.

Assignment

Your assignment is to advise national policy makers in Benin or Burkina Faso about which strategy or combination of strategies they should choose to solve iron and zinc deficiencies in rural and urban sorghum-growing and -consuming areas in the two countries.

Additional Readings

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