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ASSESSING THE POTENTIAL FOR FOOD-BASED STRATEGIES TO REDUCE VITAMIN A AND IRON DEFICIENCIES: A REVIEW OF RECENT EVIDENCE

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ABSTRACT

This paper reviews current knowledge and experience with food-based approaches to reduce vitamin A and iron deficiencies. It presents a review of recently published literature, highlights some of the lessons learned, and identifies knowledge gaps and research priorities. The main strategies reviewed are food-based interventions that aim at (1) increasing the production, availability and access to vitamin A and iron-rich foods through the promotion of home production; (2) increasing the intake of vitamin A and iron-rich foods through nutrition education, communication, social marketing and behavior change programs to improve dietary quality among vulnerable groups; and (3) increasing the bioavailability of vitamin A and iron in the diet either through home processing techniques or food-to-food fortification strategies. Plant breeding strategies are also discussed because of their potential to increase the content of vitamin A and iron in the diet as well as their bioavailability. The review highlights two contrasting facts. On the one hand, it is clear that the technologies and strategies reviewed have the potential to address many of the concerns about both the intake and the bioavailability of vitamin A and iron among impoverished populations. On the other hand, enormous information gaps still exist in relation to both the efficacy and the effectiveness of most of the strategies reviewed, even for approaches as popular as home gardening. Significant progress has been achieved in the past 10 years in the design and implementation of food-based approaches, particularly with respect to the new generation of projects integrating production and nutrition education and behavior change strategies. Yet, little has been done to evaluate their efficacy, effectiveness, feasibility, sustainability and their impact on the diets and nutritional status of at-risk populations. The same question as that posed in previous reviews decades ago remains at the end of the present review: what really can be achieved with food-based interventions to control vitamin A and iron deficiency? Food based approaches could be an essential part of the long-term global strategy to alleviate micronutrient deficiencies but their real potential is still to be explored.

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1. INTRODUCTION

Balanced diets are not accessible for a large proportion of the world's population, particularly those who live in developing countries. Many populations or subgroups of populations subsist on staple plant-based diets that often lack diversity (and also quantity sometimes), which may result in micronutrient deficiencies. Vitamin A and iron deficiencies are among the nutritional deficiencies of greatest public health significance in the world today. Almost one third of children in developing countries are affected to some degree by vitamin A deficiency, which impairs their growth, development, vision and immune function, and in extreme cases leads to blindness and death (UN ACC/SCN 1997; WHO 1995; Sommer and West 1996). Iron deficiency, which leads to anemia, is well-recognized as the most common dietary deficiency in the world (including developed countries), affecting mostly children and women of reproductive age (Gillespie 1998). It is estimated that more than half of all pregnant women in the world and at least one third of preschoolers suffer from anemia, and many more are iron deficient to some degree (UN ACC/SCN 1997). Iron deficiency is harmful at all ages. In young children it impairs physical growth, cognitive development and immunity; at school age it affects school performance; at adulthood it causes fatigue and reduced work capacity; and among pregnant women, anemia may cause fetal growth retardation or low birth weight, and is responsible for a large proportion of maternal deaths (Gillespie 1998). Because iron and vitamin A deficiencies disproportionately affect children and women during their reproductive years, they hinder both the development of individual human potential and the national social and economic development.

A body of knowledge and experience does exist to effectively address vitamin A and iron deficiencies through both short-term and long-term interventions. The most popular approaches are supplement distribution, food fortification, nutrition education, and the so-called "food-based strategies."

Food-based strategies—also referred to as dietary modifications—encompass a wide variety of interventions that aim at (1) increasing the production, availability and access to food—in the present case, vitamin A and iron-rich foods; (2) increasing the consumption of foods rich in these micronutrients; and/or (3) increasing the bioavailability of vitamin A and iron in the diet. Examples of interventions used to achieve these goals include the following.

- *Strategies to increase the **production** of micronutrient-rich foods.* These strategies include agricultural programs and policies to increase commercial production as well as programs to promote home production of fruits and vegetables (home gardens), small livestock production and aquaculture (fishponds).
- *Strategies to increase the **intake** of micronutrient-rich foods.* These approaches refer to nutrition education, communication, social marketing and behavior change programs to guide consumer food choices and to increase the demand for micronutrient-rich foods. They also include education interventions targeted at specific age groups such as the promotion of optimal breast-feeding and complementary feeding practices for infants and young children.[1]
- *Strategies to increase the **bioavailability** of micronutrients.* These include home processing techniques such as fermentation or germination to increase the bioavailability of micronutrients; food combinations that increase the bioavailability of certain micronutrients (also called food-to-food fortification strategies); and preservation and conservation techniques such as solar drying or production of leaf concentrates to extend the availability of seasonal fruits and vegetables throughout the year.
- *Plant breeding strategies*. Plant breeding technologies are also included in food based strategies because they can (1) increase the concentration of certain trace minerals and vitamins; (2) increase the bioavailability of micronutrients by

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[1] Breast-feeding promotion programs and education interventions to improve complementary feeding practices, although they are important for the control of micronutrient deficiencies, are not included in this review.

reducing the concentration of anti-nutrient factors (inhibitors of absorption); or

(3) increase the concentration of promoters of absorption.

In practice, most food-based strategies use some combination of interventions of these four groups. As an example, nutrition education and communication strategies can complement production interventions to ensure that increases in food supply or the income from marketed surplus, will in fact, translate into increased nutrient intakes by the targeted groups.

Food-based strategies are often described as a sustainable approach because the process empowers individuals and households to take ultimate responsibility over the quality of their diet through own-production of nutrient rich foods and informed consumption choices. These strategies are said to be “the ideal long-term goal toward which society strives—provision of assurance of access to a nutritionally adequate diet achieved through diversity of food availability, wise consumer selection, proper preparation, and adequate feeding” (Howson, Kennedy, and Horwitz 1998, 21). Food-based strategies are also appealing because they can address multiple nutrients simultaneously, including calories, proteins and various micronutrients, without the risk of antagonistic nutrient interactions or overload.

This paper reviews current knowledge and experience with food-based approaches, it discusses some of the lessons learned and the knowledge gaps, and it identifies research priorities. It is structured as follows: the next section provides a summary of the relevant issues related to intake and bioavailability of vitamin A and iron in developing countries. Section 3 reviews strategies to increase production and/or intake of vitamin A and iron; Section 4 focuses on strategies to increase bioavailability; and Section 5 reviews plant breeding approaches. The final section summarizes lessons learned and priorities for future research.

2. VITAMIN A AND IRON INTAKE AND BIOAVAILABILITY IN DEVELOPING COUNTRIES

VITAMIN A

Vitamin A is available from animal sources in the form of retinol or retinol esters, and from plant sources, particularly fruits and vegetables, in the form of provitamin A carotenoids. There are approximately 50 known active provitamin A carotenoids, of which beta-carotene makes the largest contribution to vitamin A activity in plant foods (McLaren and Frigg 1997). Until recently, it was assumed that the activity of beta-carotene was one-sixth of that of retinol, and for other carotenoids, the activity was estimated to be one-twelfth of that of retinol (FAO/WHO 1988). Recent findings suggest that the bioavailability of carotenoids in fruits and vegetables may be much lower than previously estimated (de Pee et al. 1995; de Pee and West 1996; de Pee et al. 1998b; Jalal et al. 1998). The bioconversion ratios in spinach for example have recently been estimated to fall between 33:1 and 73:1, as opposed to 12:1 (IVACG 1999). Research is currently under way to revise these previously established conversion factors.

In developing countries, most of the vitamin A is ingested from fruits and vegetables. Estimates suggest that more than 80 percent of dietary intake of vitamin A in Africa and South East Asia, for example, is from provitamin A carotenoids (WHO 1995). The main sources of provitamin A are yellow and orange fruits, orange roots—carrots in particular, and some sweet potato varieties—dark green leafy vegetables and palm oil.

Because of the current controversy regarding the bioavailability of provitamin A carotenoids, the potential of plant sources to significantly improve or even maintain vitamin A status in deficient populations is being questioned. One of the purposes of the present review is to shed light on this question by reviewing the experience to date with the use of food-based approaches to control vitamin A deficiency. Both interventions promoting plant sources of vitamin A (fruits and vegetables) and those focusing on animal products are reviewed.

IRON

Iron is present in food in both heme (in flesh foods such as meat, fish and poultry) and nonheme forms (in dairy products and eggs, and in plant foods such as beans, cereals, nuts, fruits and vegetables). Heme iron is highly bioavailable (15 to 35 percent is absorbed), whereas nonheme iron is much less bioavailable, with absorption rates ranging from 2 to 20 percent (Allen and Ahluwalia 1997). The factors that influence the amount of iron absorbed from a meal include the individual's iron status and requirements, the sources and content of iron in the meal, and the other meal constituents. Absorption of both heme and nonheme iron is affected by the individual's characteristics, but nonheme iron is particularly sensitive to the presence of inhibitors of iron absorption such as phytic acid, tannins, and selected dietary fibers (Hallberg 1981). Ascorbic acid and even small amounts of meat and fish, on the other hand, are active promoters of nonheme iron absorption (Fairweather-Tait 1995).

Staple crops provide a large proportion of the total daily intake of energy and micronutrients among poor populations who have limited access to animal foods (Allen et al. 1992; Ferguson et al. 1989). The main sources of iron in these populations—staple cereals, starchy roots, tubers and legumes—are in the nonheme iron form and have low bioavailability (Gibson 1994). Estimates indicate that cereals contribute up to 50 percent of iron intakes among households from lower socioeconomic groups in developing countries (Bouis 1996). The main problem with diets based on non-animal staples is that they usually contain large amounts of phytic acid (Gibson 1994; Allen et al. 1992), the most potent inhibitor of nonheme iron absorption. Strategies to reduce the phytic acid concentration of the diet should therefore be prioritized as one of the crucial food-based approaches to increase the bioavailability of iron from plant based diets. Experience with these strategies is reviewed in the following sections as well as the strategies that aim at increasing intake of animal products.

3. STRATEGIES TO INCREASE PRODUCTION AND/OR INTAKE OF MICRONUTRIENT-RICH FOODS

Increasing the production of micronutrient-rich foods is motivated by the assumption that vulnerable households do not include these foods into their diet because they are not available at the community or household level. Strategies that increase the intake of micronutrient-rich foods, without a production component, on the other hand, assume that household supply, availability and access are sufficient, but the lack of knowledge and awareness of nutritious foods leads to poor dietary choices. Clearly, both sets of assumptions are overly simplistic, explaining why in recent years, many of the micronutrient interventions have adopted a more holistic approach combining production and education activities.

VITAMIN A

Home gardening has been the most popular food-based strategy for the control of vitamin A deficiency, and various reviews have been published over the past 10 to 20 years. The first of these was a series of reviews supported by the VITAL Vitamin A Support Project (Peduzzi 1990; Soleri, Cleveland, and Wood 1991; Soleri, Cleveland, and Frankenberger 1991), which reviewed over 40 publications and looked at the impact of home gardens on consumption, nutritional status, and in some cases income. More recently, the ACC/SCN reviewed 13 dietary modification programs to control vitamin A deficiency, covering work published between 1989 and 1993 (Gillespie and Mason 1994). We updated this work and reviewed 10 new projects published between 1995 and 1999 (see Table 1 for references and summary of the studies reviewed).

By contrast with previous interventions, recent home production projects included a strong education and communication component. Some of the newer projects did not have a production component at all, but instead, were designed to promote increased intake of micronutrient-rich foods through social marketing and communication activities, often emphasizing the needs of small children and pregnant and lactating women. Also important, more recent projects have been designed to address multiple micronutrients, compared to the previous emphasis on vitamin A alone. Below we summarize the evidence of impact of these interventions on three main outcomes: (1) production and income, (2) knowledge, attitude and practices (KAP), and intake of targeted foods and nutrients; and (3) nutritional status indicators.

Impact on Production and Income

The literature indicates that most home gardens are implemented to increase household production of fruits and vegetables to supplement the grain-based diets of rural agricultural households (Solon et al. 1979; CARE/Nepal 1995; Greiner and Mitra 1995; English et al. 1997; English and Badcock 1998; HKI/AVRDC 1993). Thus, their main objective is to improve both household food supply and dietary quality. There are also reports of home gardens that aim at increasing the total food supply to the household during certain lean seasons (Immink et al. 1981), or to increase the availability of micronutrient-rich vegetables and fruits throughout the year (Marsh 1998). Few home garden projects mention the objective of increasing household income through the sale of products or of increasing women’s control over income even in cases where the intervention is mainly targeted to women.

Only a few projects looked at the impact on production by targeted households. A commonly used indicator to measure the impact on production is the number of households who have adopted garden cultivation as a result of the intervention. In Nepal and Bangladesh, for example, the proportion of households producing vegetables and fruits (in the case of Bangladesh) increased as a result of the home gardening and farming education interventions (CARE/Nepal 1995; Greiner and Mitra 1995). Few studies measured actual increases in the quantity of fruits or vegetables produced, although a number of studies showed an increase in the availability of vegetables or fruits among producer households (English et al. 1997; English and Badcock 1998; IFPRI et al. 1998;

Marsh 1998). For example, the projects reviewed by Marsh (1998) in Bangladesh showed an increase in the year-round availability of vegetables.

Only a few studies looked at the impact on income, farmer profits or household market sales. The study by IFPRI and collaborators (1998) in Bangladesh looked at the profitability of vegetable or fish production compared to rice, and linked this to changes in household income. They showed modest increases in income as a result of adoption. Also in Bangladesh, Marsh (1998) documented an increase in household income and in women's control over income as a result of the home gardening promotion efforts. An earlier evaluation of a home garden project by Brun, Reynaud, and Chevassus-Agnes (1989) in Senegal also documented a positive impact on women's income.

In sum, although relatively few projects have quantified the impact of home gardening projects on household production, income and women's control over income, those that have seem to indicate a trend for positive effects on these outcomes.

Impact on Knowledge, Attitude, and Practices (KAP), and on Intake of Vitamin A-Rich Foods

The absence of an integrated behavior change intervention with the home gardening strategy was notable in many of the earlier studies. Interventions tended to focus mainly on increasing adoption and promoting food production, but the role of nutrition education and communication was largely neglected (Ensing and Sangers 1986; Brun, Reynaud, and Chevassus-Agnes 1989). Not surprisingly, among these studies, most of those that looked at the impact on food intake or nutritional status, failed to demonstrate any significant change in these outcomes (Brun, Reynaud, and Chevassus-Agnes 1989; CARE/Nepal 1995).

By 1994, things had started to change and Gillespie and Mason (1994) in their review noted that more communication projects had been implemented in recent years, either as the main intervention or in combination with production activities. They highlighted two successful nutrition education and social marketing interventions using mass-media that showed a positive change in knowledge, attitude and practices, one carried out in Indonesia (Pollard 1989) and the other one in Thailand (Smitasiri et al. 1993). In Indonesia, among mothers who had heard the radio spots (42 percent of mothers), considerable positive attitudinal changes occurred regarding vitamin A, and consumption of dark green leafy vegetables had increased by 10 to 33 percent after two years, among the targeted group. Vitamin A capsule supplementation coverage had also increased from 35 to 58 percent, as a result of an increase in demand achieved by the social marketing program (Pollard 1989). In Thailand, increased knowledge and awareness about vitamin A resulted in increased intake of ivy gourd and fat (both of which were promoted by the social marketing campaign) among pregnant and lactating women and among preschool children (Smitasiri et al. 1993). In 1996, a follow-up to this project was implemented, which again, relied heavily on social marketing techniques, to promote community-based actions to increase micronutrient intake by vulnerable groups, specifically pregnant and lactating women, schoolgirls and children 2-5 years of age (Smitasiri and Dhanamitta 1999; Smitasiri et al. 1999). The evaluation showed that there was a cumulative improvement in KAP with respect to vitamin A and fat, that was accompanied by an increased intake of vitamin A among preschool children and pregnant and lactating women.

Another social marketing campaign promoting intake of dark green leafy vegetables and eggs in Indonesia (de Pee et al. 1998a), documented an increase in the percentage of children 12-36 months of age who had consumed at least one egg in the previous week. The quantity of dark green leafy vegetables prepared at home also increased from 93 to 111 grams per person, and the total vitamin A intake of both mothers and young children increased.

A unique education and behavior change project in Peru to increase the quality of the meals offered in community kitchens of Lima (*comedores populares*) showed a significant increase in the vitamin A, iron and vitamin C content of the meals provided (Carrasco Sanez et al. 1998). As a result, the intake of foods rich in these micronutrients increased among women using the community kitchen, and there was a resulting increase in the proportion of absorbable iron found in their diet.[2]

Of the **home gardening** interventions that had a strong education and behavior change component, several of them documented an increase in consumption that was attributed to the project. Among these was the HKI/AVRDC project in Bangladesh that demonstrated an increase in average weekly vegetable consumption per capita among target households (Marsh 1998). Intrahousehold consumption data also showed a higher consumption of dark green leafy vegetables by infants and very young children. In Viet Nam, a community nutrition project combining household garden production of carotene-rich fruits and vegetables, fishponds and animal husbandry with nutrition education (English et al. 1997; English and Badcock 1998), showed that participating mothers had a better understanding of vitamin A compared to mothers from the control commune. In addition, children from participating households consumed significantly more vegetables and fruits, and had greater intakes of energy, protein, vitamin A and iron.

In Kenya, new varieties of beta-carotene rich sweet potatoes were introduced to women's groups (Hagenimana et al. 1999). The control group participated in on-farm trials and received minimal agricultural support for the production of the new varieties of sweet potatoes, whereas the intervention group received nutrition education, lessons on food processing, and technical assistance. The intervention group experienced a statistically significant increase in the frequency of consumption of vitamin A-rich foods, compared to a decrease among the control group.

In Ethiopia, a home gardening and health and nutrition education intervention was built on to a previous dairy goat project. The participants increased their knowledge, attitude and practices related to vitamin A, child feeding practices and the prevention of night blindness (Ayalew, Wolde Gebriel, and Kassa 1999). These changes were accompanied by increases in frequency of intake of vitamin-A rich foods.

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[2] Vitamin C promotes the absorption of nonheme iron (iron from plant sources), when consumed at the same meal.

Thus, the studies reviewed consistently show the success of well-designed promotional activities using nutrition education, social marketing and mass media campaigns (with or without home gardening) to achieve significant increases in the consumption of micronutrient-rich foods (vitamin A in particular). Compared to the home gardening interventions carried out in the 1980s, that did not include education activities, the new generation of integrated production and education projects have been much more successful in improving knowledge, awareness, attitude and practices related to vitamin A.

Impact on Nutritional Status

The question of whether home gardens have a positive impact on vitamin A status has been examined in prior reviews and in some of the more recent studies, but evidence is still scant. In the set of earlier studies, home gardens were positively associated with a decreased risk of vitamin A deficiency (Cohen et al. 1985) and reduced clinical eye signs of vitamin A deficiency (Solon et al. 1979). Gillespie and Mason (1994) also concluded from their review that there was evidence that food-based approaches could be effective in the control of vitamin A deficiency. In our review of recent work, still only a few of the home garden and nutrition education studies actually measured their impact on vitamin A status indicators. In Bangladesh, Greiner and Mitra (1995) documented a slight reduction in night blindness associated with an increase in intake of dark green leafy vegetables in young children. Also in Bangladesh, higher intakes of eggs and dark green leafy vegetables among children and mothers were associated with greater serum retinol levels (de Pee et al. 1998a). In Thailand, serum retinol was measured only among school-aged girls, but significant increases were observed among the treatment group as well as reductions in the prevalence of vitamin A (Smitasiri et al. 1999).[3] In Viet Nam, serum retinol levels were not measured, however preschool children's growth was increased and

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[3] In addition to the social marketing intervention, this project included a strong school component, which aimed at improving nutrient content of school lunches.

the severity and incidence of acute respiratory infections were reduced. These improvements were associated with a program that combined the promotion of home production of vegetables, fish and animal husbandry with nutrition education (English et al. 1997; English and Badcock 1998). In Ethiopia, the prevalence of night blindness and Bitot's spots was lower among participants in the home gardening and nutrition education intervention, compared to a control group.

Conclusions on Strategies to Increase Production and/or Intake of Vitamin A-Rich Foods

Consistent with the findings from earlier reviews, this synthesis of more recent literature points to the potential of home gardening and promotional and education interventions to improve vitamin A nutrition. It is striking, however, to realize that five years after Gillespie and Mason's review, with an addition of ten new, apparently successful studies, we still do not have sufficient information to understand the real potential of these interventions to control vitamin A deficiency. The new studies have focused on community participation aspects and on the careful selection of appropriate sets of interventions for specific contexts. They also use considerably improved design and implementation strategies compared to previous studies. The evaluation protocols and the statistical analysis of findings, however, remain weak and lacking scientific rigor even in the more recent work. Failure to correct this crucial aspect will continue to slow down progress in understanding the real potential of production and education interventions to control vitamin A deficiency.

IRON

Compared to vitamin A, production and education interventions to increase the supply and intake of iron from plant foods have not been popular. This is not surprising since researchers have long raised questions about the potential for plant sources to make a major contribution to the control of iron deficiency in developing countries (Yip 1994; de Pee et al. 1996). Although many non-animal foods contain relatively large amounts of iron, the nonheme form of iron present in these foods has poor bioavailability. In addition, plant foods often contain a variety of inhibitors of nonheme iron such as tannins, phytates, and polyphenols. It is believed that to increase the household supply of bioavailable iron, promotional efforts may have to support the production of animal products such as small animal husbandry or fishponds, which would increase the supply of more bioavailable heme-iron. A few recent experiences in this direction are included in Table 1. In fact, of the 10 new studies reviewed, all of those that targeted increasing iron intake or iron status promoted the production and consumption of animal products. The study in Viet Nam, for example, promoted fishponds and animal husbandry (English et al. 1997); the Peru intervention increased availability and awareness of low-cost sources of heme iron, such as organ meats (Carrasco Sanez et al. 1998); adoption of fishponds was promoted in Bangladesh (IFPRI et al. 1998); and in Thailand, the home gardening intervention supported fishponds and chicken production as well as vegetable production (Smitasiri and Dhanamitta 1999).

Impact on Iron Intake and Iron Status

The Viet Nam project documented an increase in the intake of iron among children of households in the intervention communities (home gardens, fishponds and animal husbandry) compared with control communities (English et al. 1997; English and Badcock 1998). No mention was made, however, of whether the increased iron was from vegetable or animal sources. Furthermore, iron status was not measured. In Peru (Carrasco Sanez et al. 1998), the promotional effort to improve the quality of the meals offered at the community kitchens showed a significant impact on the intake of foods rich in iron and vitamin C, as well as in the total daily intake of vitamin C, heme iron and in the proportion of absorbable iron by the targeted group of women of reproductive age. The prevalence of anemia was also reduced significantly as a result of the intervention. In Bangladesh (IFPRI et al. 1998), preliminary results from the evaluation of the adoption of fishponds or commercial vegetable production suggest that there was no increase in the intake of fish or vegetables, respectively, among adopting households. There was also no evidence of improved iron status among members of adopting households. The evaluation is still ongoing and longer-term impacts will be assessed. In Thailand, preschoolers, school children and lactating women increased their iron intakes. Lactating women also increased their intake of vitamin C, a promoter of nonheme iron absorption (Smitasiri and Dhanamitta 1999; Smitasiri et al. 1999). Biochemical indicators of iron status were measured, but only among schoolgirls, and significant improvements in serum ferritin were observed. Unfortunately, the effects of the food-based intervention could not be separated from the effects of the overall strategy targeted to school girls, which included the weekly distribution of iron tablets for 12 weeks and improved dietary quality of school lunches (Smitasiri and Dhanamitta 1999).

In Ethiopia, preliminary results of the effects of commercialization of crossbred cows found a 72 percent increase in household income among adopters, while their food expenditure increased by only 20 percent (Ahmed, Ehui, and Jabbar 1999). Both vitamin A and iron intake was higher among adopters compared to non-adopters, but the authors did not differentiate between animal and plant sources of the micronutrients. Forthcoming analyses of the data will assess the impact on children’s nutritional status.

Conclusions on Strategies to Increase Production/Intake of Iron-Rich Foods

Clearly, experience with food-based approaches to increase production and/or consumption of heme or nonheme iron-rich foods is very limited. In addition to the well-known problems of bioavailability with iron from plant sources, the experience with animal production suggests trade-offs between increased income from selling home-produced animal products and increasing own consumption of these products to improve dietary quality. Evidence from household studies in Bangladesh and Ethiopia showed that increases in income through the sale of animal products, did not successfully translate into significant improvements in dietary quality. The results of both studies are preliminary, but reinforce the observation that promoting animal production without a strong nutrition education component may not be sufficient to achieve improved dietary diversity. Households may chose to improve their income rather than their diet, and the increases in income may be invested in basic necessities other than food. Thus the question of what exactly can be achieved through well-designed integrated production/education interventions to promote increased intake of animal products and to improve iron status remains largely unanswered.

4. STRATEGIES TO INCREASE THE BIOAVAILABILITY OF MICRONUTRIENTS AND THEIR RETENTION DURING PROCESSING

Various home processing techniques can be used to either increase the bioavailability of micronutrients or to ensure their retention during preparation, cooking or other processing techniques. For provitamin A compounds, the two main issues are (1) to ensure the retention of provitamin A during home preparation, cooking and preserving; and (2) to use home preservation techniques to make fruits and vegetables that are rich in provitamins A available all year long. For nonheme iron, the most crucial issue is to increase its bioavailability and this can be achieved through (1) home processes such as fermentation or germination; and (2) food-to-food fortification, which consists of selecting food combinations that promote nonheme iron bioavailability by increasing the amount of enhancers of absorption or decreasing the amount of inhibitors of absorption present in a meal. Cooking in iron pots can also increase the iron content of foods and is also discussed briefly in this section.

VITAMIN A

Effect of Cooking and Processing on the Bioavailability of Provitamin A

Provitamin A carotenoids are known to be easily destroyed during processing, exposure to light, heat treatment and storage, but clear estimates of the net retention rate of provitamin A from different processing techniques are not available (Rodríguez-Amaya 1997). What is known, however, is that heat treatments such as deep-frying, prolonged cooking and baking, and a combination of multiple preparation and processing methods result in substantial losses of provitamin A. The retention of provitamin A decreases with heat treatments in the following order: microwaving is the least harmful, followed by steaming, boiling and sautéing. Irrespective of the cooking method, retention always decreases with longer processing time, higher temperatures and cutting or macerating food. Yet retention can be improved by simple modifications, such as cooking with the lid on, reducing the time lag between peeling or cutting and cooking, and limiting the overall cooking, processing and storage time (Rodríguez-Amaya 1997).

Research is underway to resolve some of the conflicting evidence about the effects of processing on the bioavailability of provitamin A, to settle the controversy about the bioavailability of provitamin A from different foods, and to standardize the methods to analyze the provitamin A content of foods.

Preservation Techniques to Increase Availability Throughout the Year

Vitamin A is found in large amounts in relatively few foods that are often highly seasonal, such as orange fruits and dark green leafy vegetables. Although vitamin A is stored in the liver, the amounts ingested during the season of abundance may not be sufficient to maintain adequate vitamin A status throughout the year. Also, for provitamin A-rich foods like mangoes, for example, which ripen quickly, there are often substantial postharvest losses due to the fact that the population cannot consume all the available fruit over the short period of time of their availability. Thus, there is a need to develop techniques to preserve provitamin A-rich foods in order to ensure adequate supply through seasons of lower availability and to reduce postharvest losses. One such method is solar-drying. Another method to preserve fruits and vegetables is to compact them, such as in the production of leaf concentrates (Solomons and Bulux 1997). This method has the advantages of reducing the volume of the leaves, and of increasing the concentration of provitamin A carotenoids. This is particularly useful for young infants who have high nutrient requirements and a small gastric capacity. Leaf concentrates have been used in the formulation of special complementary foods for young children, and for high-nutrient dense flours for use by pregnant and lactating women.

Solar-drying is one of the most popular preservation methods for fruits and vegetables rich in provitamin A and has been promoted in many countries in recent years. Solar-drying is an improved alternative to the traditional sun drying method, which results in significant losses of beta-carotene (provitamin A) due to direct exposure to sunlight. With solar-drying, foods are dried in the shade, and higher air temperatures and lower humidity are provided in order to increase the drying rate, thus increasing the retention of provitamin A and reducing the final moisture content. This in turn increases the micronutrient concentration in the dried products and allows longer storage time. The greater beta-carotene retention in solar-dried compared to sun-dried fruits and vegetables is well documented (Linehan 1994). Although the rate of retention for different products varies, the range of retention during solar drying is estimated to be between 50 and 80 percent (FAO/ILSI 1997). Steam-blanching as a pretreatment to inactivate degrative enzymes has also been shown to reduce overall losses during drying and storage. This method, however, may not always be feasible in areas where safe water is scarce (Rodríguez-Amaya 1997).

Solar drying has been promoted in a number of developing countries in recent years (IVACG 1993). In Mali, Tanzania, Senegal, Haiti, and the Dominican Republic (most of these programs were promoted by VITAL), the feasibility of implementing solar dryers using locally available products was tested as well as the retention of provitamin A through the drying process and in some cases during preservation. A project, carried out by the International Center for Research on Women and OMNI, implemented and evaluated a solar drying intervention in Tanzania, but the results of the study are not yet available. The project evaluated whether women’s use of solar dryers reduced seasonal variations in the availability of vitamin A-rich foods and increased household income through surplus sales of the dried food products.

To our knowledge, the nutritional impact of solar drying interventions on dietary intake or on the micronutrient status of vulnerable groups has not been documented yet. The same is true for other similar initiatives, such as the ‘sweet potato buds’ in Guatemala (Solomons and Bulux 1997) and the leaf concentrates production in Sri Lanka (Cox et al. 1993) and in India (IVACG 1993), that have pursued the same objective of processing provitamin A-rich foods to concentrate and preserve their content during storage. The feasibility of these approaches at the community level, and their sustainability over time has been questioned recently (Solomons and Bulux 1997). An evaluation of a leaf concentrate production project in Sri Lanka indicated various problems with the implementation of the technology at the community level and the methodology was found unsustainable (Cox et al. 1993). Among other things, the machinery involved was expensive and unpopular, and women lacked motivation because they found the methodology too time consuming. More of these types of evaluations should be carried out to determine whether these apparently promising approaches can survive beyond the pilot project level, and whether they can be sustained over time and significantly contribute to reducing vitamin A deficiency.

IRON

Home Processing Techniques to Reduce Inhibitors of Nonheme Iron Absorption

As indicated earlier, nonheme iron from cereals or other plants is poorly absorbed because of the presence of inhibitors of iron absorption, particularly phytic acid. Various food-processing techniques, which have traditionally been used in meal preparation across countries in Africa, Asia, and Latin America, do exist to reduce the phytic acid content of plant-based staples. Some techniques such as fermentation, germination or malting involve enzymatic hydrolysis of phytic acid, whereas other nonenzymatic methods such as thermal processing, soaking or milling can also reduce the concentration of phytic acid in some plant staples. Detailed information about these methods and their effect on improving nonheme iron bioavailability is available in the literature (Allen and

Ahluwalia 1997; Miller 1996; Gibson and Ferguson 1996; Svanberg 1995). Only a brief summary is provided here.

Enzymatic hydrolysis of phytic acid. Enzymatic hydrolysis of phytic acid in whole grain cereals and legumes can be achieved by soaking, germination or fermentation. These processes enhance the activity of endogenous or exogenous phytase (Lorenz 1980; Chavan and Kadam 1989).

Germination consists of soaking seeds in water in the dark, usually for up to 3 days, to promote sprouting. During the germination process, phytase activity increases, causing the phytic acid to break down. Germination also reduces other antinutrients, including polyphenols and tannins. The amount of certain vitamins, including riboflavin, B-6 and vitamin C increases during germination, as well as the bioavailability of calcium, iron and zinc (Sandberg 1991; Camacho et al. 1992).

Malting is a technique that grinds and softens whole grains by soaking them in water until sprouting occurs. Drying and milling typically follow malting. Many cereal-based porridges are prepared by malting, a process that increases bioavailability of iron and zinc by reducing phytic acid levels.

Fermentation: Acid and alcoholic fermentation can be used for cereals, legumes or vegetables, to increase their nutritional value and improve their physical characteristics. Fermentation can be spontaneous (using the microorganisms that are naturally present in food), or started with an inoculation. Fermentation improves the bioavailability of minerals, such as iron and zinc, as a result of phytic acid hydrolysis. Other nutritional advantages are the increases in the content of riboflavin and vitamin B_{12}. During fermentation, some microorganisms synthesize vitamin B_{12}, thus increasing the content available in plant-derived foods, where it is normally not present. There is also some evidence that fermented foods have anti-diarrheal effects in children (Mensah et al. 1990). Additionally, fermentation is a time saving preparation method for mothers, since family members can safely eat fermented foods throughout the day.

Soaking is another technique to increase the amount of soluble iron. For example, soaking flour for 24 hours increases the amount of soluble iron by up to tenfold (Svanberg 1995). Under optimal pH conditions, soaking wheat or rye flour for 2 hours, completely hydrolyzed phytic acid (Sandberg and Svanberg 1991).

Combining fermentation, soaking and germination techniques is also highly efficient in activating endogenous phytase enzymes to degrade phytic acid and to reduce, to some extent, the amount of polyphenols that inhibit nonheme iron absorption (Svanberg 1995). Sour dough leavening, for instance, can completely degrade phytic acid.

Nonenzymatic methods for reducing phytic acid content. Nonenzymatic methods, such as thermal processing, soaking and/or milling can also be used to reduce the phytic acid content of plant-based staples. Mild heat treatment reduces the phytic acid content of tubers but not cereals and legumes (Marfo et al. 1990). Soaking can reduce the phytic acid content of certain legumes and cereals that contain water-soluble sodium or potassium phytate (Cheryan 1980). Milling can help reduce the phytic acid content of certain cereals, if their phytic acid is localized within a specific part of the grain such as the germ (corn) or aleurone layer (wheat, triticale, rice, sorghum, rye) (O’Dell, de Bowland, and Koirtyohann 1972). This strategy, however, will also result in significant losses of vitamins and minerals (iron among others), which are also found in the aleurone layer or germ.

Experience with these home processing techniques. Several studies have been carried out to develop complementary food mixtures using germination and malting techniques at home, also referred to as the amylase-rich food technology (Gopaldas et al. 1986; Mosha and Svanberg 1990; Hansen et al. 1989; Pederson et al. 1989; Singhavanich et al. 1999; Allen and Ahluwalia 1997). Using these techniques, cereal grains are sprouted, dried and then ground into flour. Amylase—an enzyme that breaks down starch and reduces its water-holding capacity—is activated during germination. Hence only small amounts of flour are needed to reduce the viscosity of thick porridges. Interest in this technology has been driven by the need to reduce the viscosity, while maintaining the nutrient density, of complementary food mixtures for young infants who have limited gastric capacity (Gopaldas et al. 1986; Brown and Begin 1993).

A number of studies have evaluated the reductions in viscosity and the nutrient composition of amylase-rich foods. Other studies have looked at related aspects of preparation time and cost, and organoleptic properties (Gopaldas et al. 1986; Pederson et al. 1989; Hansen et al. 1989; Mosha and Svanberg 1990; Singhavanich et al. 1999). Only a few community trials, however, have tested the acceptability of the products by mothers and children, and the impact of promotional efforts on behavior change, adoption rates and sustainability over time (Vaidya 1988; Gopaldas et al. 1991; Guptil et al. 1993; Kibona et al. 1995). None of the above studies provide information on the impact of these interventions on the nutrient intake or the nutritional status of weaning-age infants, the main target group of these interventions.

Gibson and collaborators initiated a community trial to combat iron, zinc and vitamin A deficiency in Malawi using an integrated approach that combines a variety of the strategies described previously (Gibson et al. 1998). Using a participatory approach, the community selected the specific interventions that were to be promoted in the project. The acceptability and feasibility of the intervention was based on careful consideration of the social, cultural, economic and environmental conditions found in the communities where the project would be implemented. The set of interventions included (1) agricultural and horticultural activities to promote the production of sunflower seeds, groundnuts, soybeans, vitamin A rich foods and green leafy vegetables; (2) food preservation and processing methods such as solar drying and sunflower oil press to increase availability and intake of provitamin A and fat; and (3) the promotion of fermentation to enhance the content and bioavailability of micronutrients in the diet. This integrated approach was also combined with an intensive social marketing and communication strategy to promote changes in knowledge, attitudes and practices and to achieve sustained behavioral change. The forthcoming evaluation of this project will contribute immensely to our understanding of the potential of integrated food-based strategies to alleviate micronutrient malnutrition in young children and mothers.

Food-to-Food Fortification (or Dietary Combinations)

Food-to-food fortification strategies to improve iron nutrition consist of dietary modifications to either include in a meal foods that can promote the absorption of nonheme iron or to exclude foods that inhibit nonheme iron absorption.

Increasing the intake of enhancers of nonheme iron absorption. Relative to iron, the strategy involves increasing the intake of foods that contain substances that can enhance nonheme iron absorption, such acid ascorbic-rich fruits or vegetables (lemon), at the same meal as nonheme iron is consumed (Monsen 1988). Meat and fish consumed even in small amounts are also known to markedly increase nonheme iron absorption. The iron bioavailability of a typical Latin American diet based on maize and beans, for example, can be improved by the same magnitude with either 75 grams of meat or 50 milligrams of ascorbic acid (Svanberg 1995). The addition of small amounts of meat or fish to the diet would seem like one of the most desirable and effective approaches to increase the bioavailability of nonheme iron, but economic, cultural or religious factors among at-risk populations in developing countries often hamper the feasibility of this approach. We are unaware of any community trials that have tested either the efficacy or the feasibility of this strategy in developing countries.

The effect of ascorbic acid to improve body iron stores has been tested in a few prospective studies summarized by Svanberg (1995). These experiments, however, used vitamin C supplements, as opposed to food sources of vitamin C, and thus are not considered food-based approaches. A recent community trial carried out in rural Mexico did test the efficacy of adding lime juice (as a source of ascorbic acid) to a maize, beans and salsa meal to improve iron bioavailability from the diet of non-anemic iron-deficient women (Garcia et al. 1998). The study showed that 25 milligrams of ascorbic acid (in the form of lemonade) consumed at two meals a day for 8 months doubled iron absorption from the typical meal and improved iron status of the participating women, compared to a control group. Effectiveness trials are needed to test whether this type of dietary modification can be sustained over time.

Reducing the intake of inhibitors of nonheme iron. The other dietary modification that can improve nonheme iron absorption is to reduce the intake of foods and beverages with meals that inhibit nonheme iron absorption. For instance, modifying the practice of drinking coffee and tea with the meal to consuming it 1 to 2 hours after could significantly reduce the inhibitory effect of these beverages on nonheme absorption. For instance, consumption of only one cup of tea of normal strength has been shown to reduce iron absorption by as much as 60 percent (Disler et al. 1975) In Costa Rica, coffee consumption among pregnant women was associated with a lower iron status (hemoglobin) of their infant, one month after birth (Muñoz et al. 1998). Other foods such as oregano, red sorghum, spinach and cocoa, which all contain galloyl phenolic groups, and are known to inhibit nonheme iron absorption, should also be avoided with meals containing mainly foods of vegetable origin (Gibson 1997). Again, very little experience is available to determine whether such approaches could be efficacious and effective in improving iron status among poor populations in the developing world. A recent study carried out in Guatemala tested the effects of reducing coffee intake on growth, morbidity and iron status of iron-deficient toddlers (Dewey et al. 1997). Sweetened coffee served with bread is a popular breakfast meal in Guatemala among children starting from as early as 4 to 6 months of age. The trial randomly allocated iron deficient toddlers into two groups, one that would continue to consume coffee and the other one that would receive a substitute drink containing sugar and coloring. Although the study was highly successful in achieving the behavior change (children apparently liked the substitute drink and mothers were willing to serve it to their children), reducing coffee consumption had no impact on the iron status of young children. Positive effects on growth were observed among children who had discontinued coffee consumption, but had once consumed more than 100 milliliters per day. Again, evidence of the efficacy of this type of interventions in other population groups is urgently needed.

Cooking in Iron Pots

Cooking in iron pots has long been recognized as a potential way to increase the iron content of food (Brittin and Nossaman 1986). Two different experimental trials tested the effectiveness of promoting the use of iron cooking pots on the iron status of young children. The first study was carried out in Brazil among premature 4 months old children (Borigato and Martínez 1998). The second study was done in Ethiopia among 2-5 year old children (Adish et al. 1999). Both studies showed statistically significant improvements in hematologic values, including iron stores, over a period of 8 and 12 months for the Brazil and Ethiopia study, respectively. The iron added to food cooked in iron pots was found to be bioavailable (Borigato and Martínez 1998). The laboratory analysis from the Ethiopian study found five times more iron available in meat and vegetables that was cooked in an iron pot compared to the same meal cooked in an aluminum pot. In Ethiopia, it cost approximately $5,000 to provide iron pots to a population of 10,000 (with average family size of 6) compared to an estimated cost ranging from $8,000 to $20,000 to supplement women from a similar size population pool for 1 year (Levin 1986). The authors concluded that iron pots appear to be a relatively low-cost, and possibly sustainable approach to increase the iron intake and status of deficient populations (at least of young children). They caution that the potential toxicity of using iron pots among iron-replete populations needs to be researched (Adish et al. 1999).

CONCLUSIONS ABOUT STRATEGIES TO INCREASE THE BIOAVAILABILITY AND RETENTION OF MICRONUTRIENTS DURING PROCESSING

This review highlights two contrasting facts. On the one hand, it is clear that the technologies do exist to address some of the main concerns about the bioavailability of vitamin A and iron. Many of these technologies also seem to involve simple and low-cost home processing techniques, which in some cases are even part of the traditional background of the target populations. On the other hand, the limited effort to promote, implement or evaluate the available technologies in community trials or in large-scale interventions is striking. It is not clear why this is the case, but surely, the scarcity of funding for program research and implementation in this area is a main constraint.

5. PLANT BREEDING STRATEGIES

Traditionally plant breeding has been used primarily to improve farm productivity, usually by developing crops with higher yields. When crossing varieties with particular traits, scientists also attempt to monitor and maintain consumer characteristics such as taste, cooking qualities, and appearance. These characteristics are important because they have a bearing on market prices, and consequently on profitability, which motivates farmers to adopt the improved varieties. Until recently, breeding to enhance the nutrient content of crops for human nutrition purposes has rarely been an explicit objective, largely because the presumption was that nutrient-enhanced crops may be lower yielding, and thus, would jeopardize profitability and adoption by farmers. Recent research, however, indicates that at least in the case of trace minerals (iron and zinc, in particular), the objectives of breeding for higher yield and better human nutrition do largely coincide. That is, mineral-dense crops offer various agronomic advantages, such as greater resistance to infection, and thus lower dependence on fungicides, greater drought resistance, and greater seedling vigor, which in turn, is associated with higher plant yield (Graham and Welch 1996). With these new developments, one of the most serious barriers to combining human nutrition and plant breeding objectives has been lifted.

The possibilities of improving micronutrient nutrition through plant breeding are numerous. They include (1) increasing the concentration of minerals (iron or zinc), or vitamins (beta-carotene); (2) reducing the amount of anti-nutrients such as phytic acid; and (3) raising the levels of sulfur-containing acids, which can promote the absorption of zinc. This section summarizes the potential nutritional benefits of each of these approaches and updates progress in this area. More detailed information can be found in the literature (Graham and Welsh 1996; Ruel and Bouis 1998; Bouis 1996).

INCREASING THE MINERAL OR VITAMIN CONCENTRATION OF STAPLE CROPS

The main question about the potential benefits of using mineral- or vitamin-dense staple crops is whether the increased concentrations will in fact result in significant increases of bioavailable minerals (or vitamins) and consequently improve the nutritional status of deficient populations. For this to happen, vulnerable groups have to consume the improved varieties of staple crops in sufficient quantities, but even more importantly the net amount of **bioavailable** nutrients ingested must be increased relative to traditional crops.

As indicated previously, the main sources of iron in impoverished populations are staple cereals and starchy roots, tubers and legumes. Thus iron is in the nonheme iron form and has low bioavailability (Gibson 1994). Estimates indicate that cereals contribute up to 50 percent of iron intakes among households from lower socioeconomic groups (Bouis 1996). For zinc, the contribution from non-animal sources can be as high as 80 percent, as shown for preschoolers in Malawi (Ferguson et al. 1989). This means that doubling the iron or zinc density of food staples could increase total intakes by at least 50 percent. The main problem, though, is that diets based on non-animal staples usually contain large amounts of phytic acid (Gibson 1994; Allen et al. 1992), which inhibits both nonheme iron and zinc absorption. Some argue that in circumstances where phytic acid is so prominent in the diet, raising the concentration of minerals in plants through plant breeding may not be sufficient to counteract the inhibitory effect of phytic acid on mineral absorption. The argument continues that even if, for instance, the nonheme iron concentration of the grain is increased two- to four-fold, there may still be enough phytic acid to bind the extra minerals, in which case the net absorption of iron would not be increased.

Results based on animal (rat) models suggest that the percent bioavailability remains constant when traditional crops are compared to mineral-enhanced crops, and that the final result is a net increase in bioavailable mineral. Rats, however, have substantially more intestinal phytase activity than humans (by a factor of about thirty) and, therefore, are more able to absorb iron or zinc from high phytate foods than humans (Iqbal, Lewis, and Cooper 1994). Human bioavailability studies are urgently needed to address this critical question.

To date, most of the progress in developing mineral-dense staple crops has come from screening for genetic variability in the concentration of trace minerals. The crops tested (wheat, maize, rice, and beans) have shown significant genotypic variation, up to twice that of common cultivars for minerals and even greater variation was found for beta-carotene in cassava. Positive correlations between mineral concentrations have been found, indicating that varieties with greater iron concentration are most likely to also contain greater concentrations of zinc.

Increasing seed ferritin is another plant breeding approach that has the potential to increase the content of bioavailable iron in plant foods (Theil, Burton, and Beard 1997). The approach is promising because ferritin, a common source of stored iron in seeds and developing plants, appears to be highly bioavailable (Theil, Burton, and Beard 1997). New genetic engineering experiments are also currently being conducted with rice to simultaneously increase their concentration of vitamin A and iron. The approaches include (1) increasing the iron content of the rice with a ferritin transgene; (2) reducing the phytate content of cooked rice with a transgene for a heat-stable phytase (which allows enzymatic hydrolysis of phytates during cooking); and (3) increasing the concentration of cystein in rice (a promotor of nonheme iron and zinc absorption) by increasing the resorption-enhancing effect from a transgenic sulfur-rich methallothionin-like protein (Potrykus et al. undated).

Although encouraging, this area of research is still at an early stage of development and much more extensive screening and genetic engineering must be undertaken before the potential impact on human nutrition can be assessed.

REDUCING THE PHYTIC ACID CONCENTRATION IN THE PLANT

A complementary approach to increase the concentration of plant minerals is to act directly on their main inhibitor of absorption, phytic acid. Research in humans has shown that minimal amounts of phytic acid added to meals can produce a severe inhibition of nonheme iron absorption (Sandström and Lönnerdal 1989). Although studies do not agree on the exact cut-off point at which nonheme iron absorption is significantly improved by the removal of phytic acid, some argue that almost complete removal (< 10 milligrams/meal) is necessary (Hurrell et al. 1992). Another study has shown that as little as 50 milligrams of phytic acid in a meal can cause a 78 to 92 percent reduction in nonheme iron absorption (Reddy et al. 1996).

To provide an idea of the order of magnitude, daily intakes of phytic acid among preschool children from populations whose staple diets are based on cereals, legumes, and starchy roots and tubers are estimated to range from 600 to 1,900 milligrams, that is 200 to 600 milligrams per meal (Gibson 1994). Among Mexican adult men and women, whose diets are based on maize (tortillas), beans and rice, intakes of phytic acid are in the order of 4,000-5,000 milligrams per day (Allen et al. 1992). Cereals such as whole wheat, corn, and millet contain approximately 800 mg of phytic acid per 100 grams of cereal.

A key issue, then, is whether plant breeding can achieve the magnitude of reduction in phytic acid that may be necessary to obtain significant improvements in absorption of both zinc and nonheme iron. If, as suggested by Raboy (1996), phytic acid in staple foods can be reduced by a factor of two-thirds, and if dietary phytic acid comes mainly from staple foods, it is likely that this strategy would impact bioavailability of zinc and iron simultaneously, and potentially calcium, manganese, magnesium, and possibly even other trace minerals.

A small pilot study was carried out recently to measure iron absorption from a low-phytate maize. The improved variety contained approximately 35 percent of the phytic acid content of regular maize, but its concentration of macronutrients and minerals was unchanged (Mendoza et al. 1998). Iron absorption was almost 50 percent greater from the low-phytic maize compared to the traditional maize. These results are encouraging for populations that consume maize-based diets and efforts to the phytic acid content of staple cereals even further are underway.

INCREASING THE CONCENTRATION OF PROMOTER COMPOUNDS (SULFUR-CONTAINING AMINO ACIDS)

Another potentially complementary approach to increase the bioavailability of minerals in staple crops is to increase the concentration of specific amino acids that may promote mineral absorption. These are sulfur-containing amino acids, namely methionine, lysine and cysteine. At this time, there is little information about the agronomic advantages or disadvantages to increasing the concentration of sulfur-containing amino acids in staple foods. In terms of human nutrition, it appears that a small increase in amino acid concentration is needed to positively affect the bioavailability of iron or zinc, and therefore, it is unlikely to affect plant functions significantly (Welch 1996). Again, this is an area that is currently being researched.

CONCLUSIONS ABOUT PLANT BREEEDING APPROACHES

Involving agricultural research in the fight against micronutrient malnutrition holds great promise. Because trace minerals are important not only for human nutrition, but for plant nutrition as well, plant breeding has the potential to make a significant, low-cost,[4] and sustainable contribution to reducing micronutrient, particularly mineral deficiencies in humans. Furthermore, increasing farm productivity in developing countries is an important spin-off effect. There is increasing evidence that because iron, zinc and provitamin A have such important synergies in absorption, transport and function in the human body, enhancing all three nutrients simultaneously could achieve maximum impact (Graham and Rossner 1999; Garcia-Casal et al. 1998). The genetic resources needed to meet this challenge are available and research is ongoing to unveil the most promising and viable alternatives.

6. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Probably the most recurrent question raised throughout this review is what really can be achieved through food-based strategies to reduce micronutrient malnutrition. This is true for both iron and vitamin A and would most likely be true for other micronutrients as well. Surprisingly, this is also true for the whole range of food-based interventions reviewed, suggesting that some of the most basic information needed to expand the use of these strategies is not available. Questions on the efficacy and the effectiveness of food-based approaches remain largely unanswered, in spite of the fact that some strategies, such as home gardening, have been extremely popular and have been implemented in a large number of countries for decades.

Food based strategies to control vitamin A and iron deficiencies are at different stages of development. The experience and progress with vitamin A is generally more advanced than with iron. Table 2 provides a summary of where current knowledge stands relative to the efficacy and the effectiveness of the food-based strategies reviewed for vitamin A and iron, respectively (Tables 2A and 2B). The research needed to achieve progress and to improve our understanding of the potential of food-based approaches for

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[4] Estimates of the cost of plant breeding compared to other interventions to control iron deficiency are presented in Ruel and Bouis 1998.

the alleviation of vitamin A and iron is also summarized in the table for each micronutrient and each strategy.

It is clear from Table 2 that plant breeding strategies are still at a very early stage compared to other approaches and that information is not yet available on their potential efficacy and effectiveness. The only exception is a small pilot study that suggests that low-phytate maize may increase iron absorption. Additional studies on human bioavailability are needed to understand the full potential of plant breeding, but this research was a first step in that direction. It is well recognized, nonetheless, that plant breeding strategies are promising because of their immense potential to improve the dietary quality of populations relying mainly on cereal staples. In addition, if new varieties are similar to traditional varieties in terms of organoleptic characteristics, these strategies will not require any behavior change from the part of the consumer, which relieves one of the main challenges of most food-based approaches.

Until a few years ago, the potential of plant sources to control vitamin A deficiency was assumed, based on calculations made using the conventional bioconversion factor that was applied to all beta-carotene sources (Florentino et al. 1993). Estimates were then made of amounts of vegetables that needed to be consumed by different family members to meet their daily requirements. Based on these calculations, it was estimated that families needed to cultivate only a small plot to grow enough vegetables to meet their daily requirements (Marsh 1998). Thus, it was assumed that increasing provitamin A intake through home gardening would be both efficacious and feasible. The recent controversy suggesting that carotenes have much lower bioavailability than previously assumed, however, challenges these estimates and raises fundamental questions regarding the potential efficacy of all plant-based strategies to control vitamin A deficiency. Research to revise the bioconversion factors and to quantify the concentration of bioavailable vitamin A in different foods must be pursued. Well-controlled epidemiological trials are needed to establish what can be achieved by dietary modifications and to answer the points listed in Table 2 concerning the ideal conditions necessary to maximize impact. These questions include which products should be promoted, in what amounts, for how long, what is the role of various factors at the host level (such as age, health, nutritional status and parasites) and at the food level (food matrix, food processing, composition of the diet) that affect the bioavailability of provitamin A.

At the same time as this puzzling controversy is unfolding, evidence continues to accumulate about the effectiveness of well-designed and carefully implemented strategies promoting the intake and/or production of provitamin A-rich foods using social marketing and behavior change approaches. Although evaluation designs are often weak and thus, do not allow firm conclusions about impact, there is certainly a consistent trend indicating a positive association between these interventions and vitamin A intake and status in some cases. It may be that publication bias is playing a role, in the sense that only positive studies make it to the published literature, but there are also some examples of nonconclusive results in studies that have weaker designs. Thus, in spite of the fact that information about the efficacy of food-based approaches is lacking, we have reasons to believe that well-designed food-based approaches may play an important role in the control of vitamin A deficiency. The quality of the information available to judge the effectiveness of these strategies, however, is inadequate and evaluation designs must be improved. Evaluations should include a careful analysis of the role of different intervention components on all direct outcomes likely to be affected, and should gather information to document the mechanisms involved. They should also measure the multiple indirect effects that the interventions may have on aspects such as their contribution to the diet of other family members, or the benefits for other micronutrient deficiencies.

This review did not cover the cost-effectiveness of alternative food based interventions, because such studies are noticeably absent from the literature. A few exceptions exist, however, of studies that compared a single food based strategy to supplementation and food fortification interventions (Popkin et al. 1980; Grosse and

Tilden 1988; Phillips et al. 1996), using aggregate data. Cost-effectiveness analysis of alternative food-based interventions is needed in addition to studies that contrast food-based approaches with supplementation and fortification strategies. Analyses of food-based interventions should capture spill over effects and both short-term and long-term costs that influence the sustainability of alternative interventions.

Similar to vitamin A, iron faces information gaps on the potential efficacy of food-based approaches relying on plant sources to improve iron status. Nonheme iron presents even more obstacles than provitamin A because the bioavailability of nonheme iron is low and plant based diets have such high concentrations of inhibitors of absorption. The efficacy of animal foods to control iron deficiency is well-established, and there is no doubt that these products can improve absorption of nonheme iron and maintain iron status at least among certain population groups. The exact amounts of different foods required and the frequency of intake needed, however, are not well documented. Efficacy trials to determine the minimum requirements of animal products to control iron deficiency among different age and physiological status groups are needed to determine whether this is an area that should be pursued.

The main concern about promoting animal products to improve iron status is their prohibitive cost for most of the populations affected by the deficiency. Therefore, additional information on the minimum amounts of animal products that would be required to complement a plant based diet to achieve a certain net amount of absorbed iron would be the first step towards assessing the feasibility of such approaches. The few studies that have looked at the effectiveness of promoting animal food production have encountered the predictable problem that increased income resulting from adoption may not result in improved dietary quality (IFPRI et al. 1998; Ahmed, Ehui, and Jabbar 1999). Research should explore issues related to the supply and demand of animal products that affect both farmers’ incomes and consumer prices. Additionally, research should look at the income and consumption trade-offs involved in animal production and how these affect the household’s dietary quality. Promoting the increased intake of lower-cost sources of animal foods such as liver and entrails should be further explored, as the approach was successful in Lima with the community kitchen project (Carrasco Sanez et al. 1998). However, interventions that promote animal products may be constrained by cultural and religious factors that prohibit their inclusion in the diet of the most at-risk populations.

Various food processing techniques and food combinations do have positive effects on increasing the bioavailability of nonheme iron, however, very little information exists in the literature on the efficacy of these approaches for the control of iron deficiency. It is surprising, for instance, that with all the amylase technology studies carried out to improve the dietary quality of complementary foods, none of these studies actually tested their impact on micronutrient status (or even on growth). The same is true for the food-to-food fortification approaches. Inhibitors and promoters of nonheme iron absorption are well identified and their effect on reducing nonheme absorption is well documented in laboratory setting. Yet, there are no clear guidelines on what magnitude of impact can be expected from, say, substituting tea for another drink during meals, or postponing coffee consumption 2 hours after the meal. Very little also has been done to look at the feasibility and effectiveness of promoting the necessary behavior changes to reduce the intake of inhibitor compounds or to increase the intake of promoters with the meal. Again, some of these approaches may not be successful, especially in the long-term, because they often require behavior changes on strongly entrenched cultural practices. Research should address both the feasibility of modifying specific practices and the more basic question of what is the minimal level of change necessary to achieve the level of improvement in iron bioavailability that will make a difference for iron status.

In conclusion, our review suggests that the area of food-based interventions has been increasingly active and successful over the past few decades. The design and implementation of these strategies have also significantly improved. This work has been largely driven by nongovernmental organizations and other local institutions, and has mainly targeted vitamin A deficiency. The nutrition and agriculture and communications research community and donors, however, have dramatically neglected this area. This neglect has prevented further progress because even the most basic information is lacking for advocacy purposes to stimulate interest or generate funds for research and program implementation. Without the fundamental demonstration of efficacy, it will be difficult to motivate investment in sophisticated effectiveness and evaluation trials.

Food-based approaches are complex, requiring a set of integrated activities and a wide variety of inputs and outcomes to be measured. This makes the evaluation of food-based approaches more difficult and costly. By comparison, a capsule distribution program can be evaluated by designing an intervention as a double blinded, randomized controlled probability trial. The evaluation would then require measuring only a few key indicators at baseline and post-intervention in a placebo and a treatment group, and inferences of causality could be generated from the evaluation results. For food-based approaches, randomization is often not feasible (at least at the household level) and double-blindness is not possible, therefore plausibility designs have to be used. This means that the evaluation design has to include the measurement of as many potentially confounding factors as possible to increase the plausibility that the results obtained can actually be attributed to the intervention. This again, may explain why so few strong evaluation studies exist. Food-based approaches need to be revisited and they need to be treated with the same scientific rigor as other strategies have. They are an essential part of the long-term global strategy for the fight against micronutrient malnutrition and their real potential desperately needs to be explored.

TABLES

Table 1. Summary of intervention and evaluation designs of recent studies reviewed (1995-1999)

			Intervention			Evaluation		Findings			
Country	Reference/ year	Target nutrients	Production	Nutrition education (NED)	Target groups	Design	Methods	Production	Income	KAP + Dietary intake	Nutritional status
Nepal	CARE/Nepal 1995	Vitamin A	•Home gardening •Irrigation •Agriculture extension •Seed distribution	—	1)HH 2)Children 6-60 mos.	•Before (1992) •After (1995)	HH Survey	Increase in percent of households producing vegetables	—	Diet shows insufficient vitamin A intake by mothers and children	Deterioration of nutritional status of children (no control)
Bangladesh	Greiner and Mitra 1995	Vitamin A	•Home gardening •Seeds •Farming education	NED	1)Women 2)Children	•Treatment/control •Before/after	•HH survey •Clinical assessment •24-hour recall	Increase in percent of households growing vegetables and fruits in both treatment/control	—	Increased knowledge of function of vitamin A	Slight decrease in night blindness
Viet Nam	•English et al. 1997 •English and Badcock 1998	•Vitamin A •Vitamin C •Iron •Iodine •Proteins, calories •Fat	•Home gardens •Fishponds •Animals	NED	1)Mothers 2)Children <6 years	•Treatment/control •After	•HH survey •Morbidity recall •KAP •Anthropometry •Food intake	Increased production of vegetables, fruits, fish, eggs	—	•Increased KAP •Greater intake of vegetables, fruits, energy, proteins, vitamins A & C, iron in children, compared to control	•Reduced severity and incidence of ARI •Improved growth of children
Peru	Sanez et al. 1999	•Vitamin A •Vitamin C •Iron	—	•NED in community kitchen •Capacity building	Nonpregnant women of reproductive age	•Treatment/control •Before/after	•Interviews •Focus groups •Biochemical assessment	—	—	•Increased quality of meals (vitamins C, A) •Increased intake of foods rich in iron, vitamin C •Increased intake of vitamin C, heme iron, proportion absorbable iron	Reduction in prevalence of anemia
Indonesia	de Pee et al. 1998b	Vitamin A	—	Social marketing campaign, including mass media, face-to-face communication to increase intake of DGLV and eggs	1.Mothers 2.Children <36 mos.	Before/after	•HH survey •24-hour recall •Biochemical analysis	—	—	•Increased percent of children and mothers who ate at least 1 egg in past week •Increased amount of vegetables prepared per person per day •Increased vitamin intake of children and mothers •Increased vitamin A intake from eggs and plants	•Serum retinol increased (associated with egg consumption) •Dose-response relationship

(continued)

Table 1 (continued)

			Intervention			Evaluation		Findings			
Country	Reference/ year	Target nutrients	Production	Nutrition education (NED)	Target groups	Design	Methods	Production	Income	KAP + Dietary intake	Nutritional status
Bangladesh	IFPRI et al. 1998	•Vitamin A •Iron	•Vegetable production •Fishponds •Credit and agricultural training	—	1)Women 2)Their household and children	•Three groups: fishponds vegetables control •Before/after	•HH survey •Anthropometry •Biochemical analysis	Increased production of vegetables and fish	Slight increase in income from adoption of fish or vegetable technology	•No increase in consumption of fish among fishpond group •Increase in vegetable intake among vegetable group	No effect on hemoglobin from fishponds or vegetable production
Kenya	Hagenimana et al. 1999	Vitamin A	•Introduction of new variety of sweet potatoes •Training in food processing techniques	NED to increase intake and use processing techniques	1)Women's groups 2)Children 0-5 years	•Treatment/control •Before/after	•HH survey •HKI vitamin A food frequency questionnaire •KAP	—	—	•Greater HKI score for frequency of intake of vitamin A-rich foods in children (control group had decreased intake)	
Thailand	Smitasiri and Dhanamitta 1999 Smitasiri et al. 1999	•Vitamin A •Vitamin C •Iron •Iodine	•Seeds distribution •Farmer women training •Promotion of gardens, fishponds, chicken	•Education •Social marketing	1)Pregnant, lactating women 2)Children 2 to 5 years of age 3)School girls	•Treatment/control •Before/after	•HH survey •24-hour recall •Biochemical assessment (in school girls)	—	—	•Increased KAP about vitamin A, iron •Increased intake of vitamin A in all target groups •No increase in fat intake •Increase in iron intake in 2-5 year old, in 10-13 year old, in lactating women •Increased intake of vitamin C in lactating women	•Blood samples in school girls: -increased serum retinol -reduction in vitamin A deficiency -increased mean hb (not significant) -reduced anemia prevalence (not significant) -reduction in low serum ferritin
Bangladesh	Marsh 1998	Vitamin A	•Vegetable home garden •Agriculture training •Seeds	NED	1)Women 2)Children	•Treatment/control •Before/after	•HH survey •Vegetable production •Size of cultivated plot •Income •Intake of vegetables	•Increase in vegetable production •Increase in size of plot cultivated •Increase in year-round availability of vegetables	•Increase in income •Increase in women's control of income	•Increase in vegetable consumption per capita •Increase in vegetable consumption of children	—
Ethiopia	Ayalew, Wolde Gebriel, and Kassa 1999	Vitamin A	•Agriculture training •Food preparation •Seeds	•Health education •NED	1)Women 2)Children	•Treatment/control •After	•HH survey •Qualitative research •HKI vitamin A food frequency questionnaire	—	—	•Increase in KAP about vitamin A, night blindness •More diversified diet •Higher HKI vitamin A food frequency scores	•Reduced prevalence of night blindness and Bitot's spots

Table 2. Summary of information gaps and research needs (in italics) relative to the efficacy and effectiveness of food-based approaches

A) VITAMIN A

STRATEGY/EFFICACY - EFFECTIVENESS	PRODUCTION/EDUCATION STRATEGIES TO INCREASE SUPPLY AND INTAKE	PROCESSING TECHNIQUES TO INCREASE BIOAVAILABILITY	PLANT BREEDING STRATEGIES
EFFICACY			
1. Under **ideal** conditions, can it improve vitamin A status?	• Previous calculations using conventional bioconversion factors had established amounts of vegetables/fruits needed to meet daily requirements. Recent efficacy trials challenge these estimates, showing smaller effects than expected and suggesting that b-carotene in plant is less bioavailable than previously thought. ➢ *Continued research is needed to revise bioconversion factors for different foods; new efficacy trials are needed to re-establish efficacy of plant foods in improving vitamin A status of different vulnerable groups.*	• Same questions as for production/education interventions ➢ *Same research needs as production/education strategies*	• No information available ➢ *More plant breeding research needed* ➢ *Human bioavailability trials needed*
2. What are the **ideal** conditions necessary to improve vitamin A status? • How much is needed? • Of which product • For how long? • Which other factors need to be taken into account? A) At the host level (parasites, age, nutritional and health status, etc.) B) At the food level (food matrix, food preparation, composition of the diet)	• Research is currently being done in this area. Current information suggest that: A) Bioavailability may be different in children and mothers B) Parasites need to be controlled C) Fat needs to be present in the diet D) Bioavailability may be greater in fruits than in dark green leafy vegetables ➢ *Continued research is needed to determine how various host and food factors affect bioavailability of carotenoids and what are the conditions that can maximize efficacy of interventions based on plant food sources.*	• Same questions as for production/education interventions ➢ *Same research needs as production/education strategies*	• No information available ➢ *Same as above*
EFFECTIVENESS			
1. What impact do these interventions have under real life conditions?	• Although evaluation designs are often weak, various production/education strategies have demonstrated an impact on a variety of outcomes, including vitamin A intake and status ➢ *Well-designed, prospective evaluation studies are needed to look at the impact of different intervention approaches on all outcomes that may be affected. Evaluations need to carefully monitor mechanisms, long-term impacts, cost and sustainability.*	• No information was found on effectiveness of these types of interventions to improve vitamin A status ➢ *Research is needed to understand potential effectiveness of techniques such as solar drying, leaf concentrates*	• No information available ➢ *More plant breeding research needed* ➢ *Human bioavailability trials needed*
2. What elements of these interventions are necessary to achieve impact?	• Strong education components seem to be essential for interventions to increase production or intake, although this has not been tested formally. • Many strategies use integrated approaches, that seem to be successful, but this does not allow to disentangle the effects of specific components. ➢ *Research is needed to evaluate the contribution of various components of the intervention packages to the impact and to establish best intervention packages for particular situations*	• No information ➢ *Same as above*	• No information available ➢ *Same as above*

(continued)

Table 2 (continued)

B) IRON

STRATEGY/EFFICACY - EFFECTIVENESS	PRODUCTION/EDUCATION STRATEGIES TO INCREASE SUPPLY AND INTAKE	PROCESSING TECHNIQUES TO INCREASE BIOAVAILABILITY	PLANT BREEDING STRATEGIES
EFFICACY			
1. Under **ideal** conditions, can it improve iron status?	• **Plant foods**: there are serious doubts about the potential efficacy of improving iron status through the promotion of plant-based foods only ➢ *The potential to improve iron status through plant-based strategies needs to be assessed formally. Perhaps a combination of production, education and methods to increase bioavailability would be efficacious* • **Animal foods**: Evidence exists from developed countries that animal food consumption improves and can maintain adequate iron status	• **Food processing:** Information exists on their impact on the bioavailability of iron in food. Their potential impact on iron status is not known. • **Food-to-food fortification**: There is some evidence of efficacy of lemon juice to improve iron status ➢ *More research is needed on the efficacy of both these strategies to improve iron status*	• Small efficacy trial tested the impact of low phytate maize on iron absorption • Efficacy trial looking at the impact of iron-dense rice on iron status of women is about to start in the Philippines ➢ *More plant breeding research is needed as well as human bioavailability trials*
2. What are the **ideal** conditions necessary to improve iron status? • How much is needed? • Of which product • For how long? • Which other factors need to be taken into account? C) At the host level (parasites, age, nutrition, health status) D) At the food level (food preparation, diet composition (absorption inhibitors, promoters)	• **Plant foods**: None of these questions have been formally addressed • **Animal foods:** It is not clear how much of different animal products would be needed to improve iron status of different groups ➢ *Efficacy trials are needed to answer these questions for both plant and animal foods and for different age and physiological status groups. For animal foods, minimal requirements to improve and/or maintain iron status should be established because of issue of cost.*	• **Food processing strategies:** No information • **Food-to-food fortification**: One pilot study shows amount of lime juice and duration of intervention that could improve ferritin levels of women ➢ *Research is needed on doses, levels, specific aspects of these strategies that will provide 'ideal' conditions for efficacy*	• No information available ➢ *Same as above*
EFFECTIVENESS			
1. What impact do these interventions have under real life conditions?	• **Plant foods:** No evidence of impact on iron of any plant-based only production/education interventions ➢ *Effectiveness trials of plant based strategies should be carried out once efficacy trials have established their potential for impact.* • **Animal foods**: Although evaluation designs are often weak, a few recent production/education strategies have demonstrated an impact on iron status ➢ *Well-designed, prospective evaluation studies are needed to look at the impact of different intervention approaches on all outcomes that may be affected. Evaluation should also monitor mechanisms, long-term impacts, cost and sustainability.*	• **Food processing:** Some community trials show feasibility of implementing these interventions, but no information on impact on iron status • **Food-to-food fortification**: No information available ➢ *Need effectiveness trials to determine potential of these approaches to achieve impact and to be sustainable.*	• No information available ➢ *Research in this area would be premature until efficacy is demonstrated*
2. What elements of these interventions are necessary to achieve impact?	• **Animal foods:** Surely, a strong education component will be necessary to promote increased intake of animal products. Production alone is not sufficient to achieve greater dietary diversity and it remains to be seen whether education can overcome economic constraints related to consumption of animal products ➢ *Evaluation research should specifically address the issue of affordability of animal products, and the trade-offs between increased income from the production and sale of products and improved household dietary quality*	• No information	• No information available ➢ *Research in this area would be premature until efficacy is established*

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