FOOD MODIFICATIONS AND IMPACT ON NUTRITION

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Summary

This article reviews a series of food modification approaches that can contribute to reducing the burden of micronutrient malnutrition in developing countries. The micronutrients emphasized are Vitamin A and iron because they are among the nutritional deficiencies of greatest public health significance in the world today. The strategies discussed are food-based interventions that aim at increasing the content and bioavailability of micronutrients in the diet. The rationale for this focus is that the main cause of Vitamin A and iron deficiency in developing countries is not so much the low intake of these nutrients, but rather their poor bioavailability from the sources available to low socioeonomic groups. For instance, both iron and Vitamin A are abundant in plant sources, but their bioavailability is much lower than from animal sources.

The specific food-based strategies reviewed are: 1) home preparation, preservation, and conservation techniques to increase the concentration of Vitamin A and iron during processing; 2) home-processing techniques such as fermentation and germination of cereals or legumes to increase the bioavailability of iron (and other micronutrients) from plant sources; 3) food-to-food fortification methods, which consist of selecting foods that can enhance the bioavailability of micronutrients when consumed together during a meal; and 4) plant-breeding strategies to increase the concentration or bioavailability of minerals (and provitamin A carotenoids) in staple foods. The review highlights two contrasting facts.

On the one hand, it is clear that the technologies described have the potential to address many of the concerns about the bioavailability of Vitamin A and iron. Except for plant breeding, many of the technologies involve simple, low-cost home-processing techniques, which in some cases are even part of the cultural background of the target populations. On the other hand, it is striking to see how little has been done to promote, implement, and evaluate the feasibility, sustainability, and the impact of these strategies in community trials. Food-based strategies are an essential part of the long-term global strategy to alleviate micronutrient deficiencies, and their real potential is yet to be explored.

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 deficiency 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. 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. 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. 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. 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 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 so-called food-based approaches. 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 micronutrient-rich foods (examples are agricultural activities to increase the supply of and access to food by vulnerable groups);
2. increasing the consumption of micronutrient-rich foods (this is usually accomplished by nutrition education and behavior change interventions); and
3. increasing the content and/or bioavailability of micronutrients in the diet (this can be achieved either through improved home-processing techniques, better selection of food and dietary combinations, or through plant-breeding technologies).

The present article focuses on the third category of interventions largely because these strategies have received relatively less attention to date in the fight against micronutrient malnutrition than other types of approaches. Additionally, for many micronutrients, and especially for Vitamin A and iron, the main cause of deficiency in developing countries is not one of low intakes, but rather poor bioavailability from the sources available to low socioeconomic groups. Both Vitamin A and iron, for example, are abundant in plant foods, but are of much lower bioavailability than from animal sources.

The article is organized as follows. First, a discussion of home preparation, preservation, and conservation techniques to increase the micronutrient content of foods during processing is presented. Solar drying methods for Vitamin A and cooking in iron pots for iron are reviewed. This is followed by a discussion of processing techniques such as fermentation and germination of cereals or legumes to increase the bioavailability of iron (and other micronutrients) from plant sources. The following section presents a short summary of food-to-food fortification strategies, or the selection of foods that can enhance the bioavailability of micronutrients when consumed together during a meal (this applies specially to iron). Finally, a brief overview of the possibilities of plant-breeding technologies to assist in the fight against micronutrient malnutrition is presented. The final section concludes with some recommendations for future research.

2. Home Preparation, Processing, and Conservation Techniques to Increase the Micronutrient Content of Foods

2.2. 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. It had been assumed that the activity of beta-carotene was 1/6 of that of retinol, and for other carotenoids the activity was estimated to be 1/12 that of retinol. But newer findings suggest that these estimates may be an overestimate of the real bioavailability of provitamin A carotenoids, and research is under way to revise these conversion factors.

In developing countries, most of the Vitamin A ingested is from fruits and vegetables. Estimates suggest that more than 80% of dietary intake of Vitamin A in Africa and Southeast Asia, for example, is from provitamin A carotenoids. 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 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. Clearly there are important research questions that need to be addressed, but many studies have previously shown that Vitamin A deficiency could be controlled, at least to some extent, by diets relying mainly on plant foods. Probably one of the aspects that deserves greater attention at this stage is to ensure that foods containing provitamin A carotenoids are being processed, preserved, and consumed under the most favorable conditions to preserve their provitamin A content and bioavailability. Some of the technologies available to reach these goals are summarized next.

2.1.1. Techniques to Maximize Retention of Provitamin A During Cooking and Processing

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

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Bibliography

Adish A.A., Esrey S.A., Gyorkos T.W., Jean-Baptiste J. and Rojhani A. (1999). Effect of Consumption of Food Cooked in Iron Pots on Iron Status and Growth of Young Children: A Randomized Trial. *The Lancet* **353**, 712–716. [This study is an experimental trial that studied the effectiveness of promoting the use of iron cooking pots on the iron status and growth of children 2 years to 5 years of age in Ethiopia.]

Allen L.H. and Ahluwalia N. (1997). *Improving Iron Status Through Diet. The Application of Knowledge Concerning Dietary Iron Bioavailability in Human Populations*, 83 pp. Washington: John Snow, Inc./OMNI Project. [This is an excellent review of current knowledge on factors affecting iron bioavailability and of the potential impact of dietary interventions on iron status.]

Borigato E.V.M. and Martínez F.E. (1998). Iron Nutritional Status is Improved in Brazilian Preterm Infants Fed Food Cooked in Iron Pots. *The Journal of Nutrition* **128**, 855–859. [This study reports the findings of an experimental trial carried out in Brazil among premature 4 months old children to look at the impact of the use of iron cooking pots for 8 months on the infants' nutritional status.]

Dewey K.G., Romero-Abal M.E., Quan de Serrano J., Bulux J., Peerson J.M., Engle P. and Solomons N. (1997). A Randomized Intervention Study of the Effects of Discontinuing Coffee Intake on Growth and Morbidity of Iron-Deficient Guatemalan Toddlers. *The Journal of Nutrition* **127**, 306–313. [This is an example of a food-to-food fortification intervention to reduce the intake of coffee, an inhibitor of nonheme iron absorption. The study is a community-based trial that tested the effects of discontinuing coffee intake among preschoolers in Guatemala, on their growth and morbidity.]

García O.P., Díaz M., Rosado J.L. and Allen L.H. (1998). Community Trial of the Efficacy of Lime Juice for Improving Iron Status of Iron-Deficient Mexican Women. *The FASEB Journal* **12** (5), A647, Abstract 3762. [This study is another example of a food-to-food fortification intervention. This study is a community trial that tested the efficacy of adding lime juice to a typical Mexican meal composed of maize, beans, and salsa to improve iron bioavailability from the diet of nonanemic iron-deficient women.]

Gibson R.S., Yeudall F., Drost N., Mtitimuni B. and Cullinan T. (1998). Dietary Interventions to Prevent Zinc Deficiency. *The American Journal of Clinical Nutrition*, **68** (Suppl.), 484S–487S. [This paper reviews various food-based approaches to prevent zinc deficiency, which are the same as for the control of iron deficiency. The paper also describes an ongoing intervention in Malawi that uses an integrated approach to implement and test a combination of food-based strategies to combat simultaneously zinc, iron, and Vitamin A deficiencies.]

Graham R.D. and Welch R.M. (1996). Breeding for Staple Food Crops with High Micronutrient Density. *Working Papers on Agricultural Strategies for Micronutrients* **No. 3**, 97 pp. Washington, DC: International Food Policy Research Institute. [This is one of the most complete reviews of plant-breeding approaches to increase the concentration of micronutrients in staple crops.]

IVACG (International Vitamin A Consultative Group). (1993). *Toward Comprehensive Programs to Reduce Vitamin A Deficiency*. (Proceedings of XV International Vitamin A Consultative Group Meeting, Arusha, Tanzania, March 8–12, 1993) 161 pp. [This IVACG symposium summary reviews various intervention programs to preserve Vitamin A through home-processing techniques such as solar drying and the production of sweet potato buds and leaf concentrates.]

Mendoza C., Viteri F.E., Lönnerdal B., Young K.A., Raboy V. and Brown K.H. (1998). Effect of Genetically Modified, Low-Phytic Acid Maize on Absorption of Iron from Tortillas. *The American Journal of Clinical Nutrition* **68**, 1123–1127. [This is a small pilot study in humans that compared iron absorption from a low-phytate maize with absorption from a traditional variety of maize.]

Miller D.D. (1996*). Effects of Cooking and Food Processing on the Content of Bioavailable Iron in Foods. Micronutrient Interactions: Impact on Child Health and Nutrition*, 58–68. Washington: International Life Sciences Institute Press. [This is a thorough review of the effects of cooking and food processing on the bioavailability of iron in foods].

Rodríguez-Amaya D.B. (1997). *Carotenoids and Food Preparation: The Retention of Provitamin A Carotenoids in Prepared, Processed, and Stored Foods*, 88 pp. Arlington: John Snow, Inc./OMNI Project. [This is an excellent review of current knowledge on the effects of food preparation, processing and storage on the retention of provitamin A carotenoids in food.]

Ruel M.I.T. and Bouis H.E. (1998). Plant Breeding: A Long-Term Strategy for the Control of Zinc Deficiency in Vulnerable Populations. *The American Journal of Clinical Nutrition* **68** (Suppl. 2), 488S–498S. [This is a review of the potential of plant-breeding strategies to help control zinc deficiency. The review focuses on human nutrition aspects.]

Ruel M.T. and Levin C.E. (2000). Food-*Based Approaches. Nutritional Anemias* (ed. U. Ramakrishnan). US: CRC Press. [This is a recent extensive review of the literature on a whole range of food-based approaches. It reviews the experience with implementing these strategies in developing countries, and highlights future research needs.]

Solomons N.W. and Bulux J. (1997). Identification and Production of Local Carotene-Rich Foods to Combat Vitamin A Malnutrition. *European Journal Clin. Nutrition* **51** (Suppl. 4), S39–S45. [The authors review the difficulties encountered in implementing three different types of food-based approaches for Vitamin A control: the production of potato buds in Guatemala, the use of solar dryers in the Caribbean, and the production of leaf concentrates.]

Svanberg U. (1995). *Dietary Interventions to Prevent Iron Deficiency in Preschool Children. (Proceedings of the Iron Interventions for Child Survival* (ed. P. Nestel). London: USAID, OMNI, and ICH, 31–44. [This is a good summary of the potential of dietary strategies to reduce the intake of inhibitors, or to increase the intake of promoters of iron absorption.]

Biographical Sketches

Marie T. Ruel, Ph.D., is a senior research fellow at the International Food Policy Research Institute (IFPRI) in Washington, DC. IFPRI is a nonprofit, internationally funded organization that undertakes research and outreach activities on public policies related to agriculture and food, with the objective of reducing poverty and improving food consumption and nutrition among the poor in developing countries. At IFPRI, Dr. Ruel leads a global research program to analyze diet quality and diet changes of the poor. The program aims at identifying effective food and agriculture policies to improve the diet quality, health and nutrition of the poor and focuses both on problems of under- and over-nutrition. In her first 6 years at IFPRI, Dr. Ruel led a multi-country program on the food security and nutrition implications of rapid urbanization in developing countries. One of her areas of emphasis is to develop methodologies to measure and to quantify the concept of childcare, one of the key determinants of childhood malnutrition along with food security and adequate childcare. She also conducts applied research in program evaluation and nutrition policies. Her work in this area includes both operational and impact evaluation, and combines the use of qualitative and quantitative approaches. She is also involved in research in the area of micronutrient deficiencies, with a main emphasis on food-based strategies.

Dr. Ruel earned a Ph.D. in international nutrition from Cornell University. Before joining IFPRI in 1996, she was head of the Nutrition and Health Division of the Institute of Nutrition of Central America and Panama/Pan American Health Organization (INCAP/PAHO) in Guatemala, where she worked for six years. While at INCAP/PAHO, in addition to her administrative and leadership responsibilities, she conducted epidemiological research in maternal and child health and nutrition, in breastfeeding and complementary feeding, and in child growth and micronutrient deficiencies. She also carried out applied research in the areas of growth monitoring, design, and evaluation of food aid and school feeding programs, and nutritional surveillance and information systems.

Howarth E. Bouis, Ph.D., is an economist at the International Food Policy Research Institute (IFPRI), where he has been employed since receiving his Ph.D. from the Food Research Institute at Stanford University in 1982. IFPRI, headquartered in Washington, D.C., is a nonprofit, internationally funded organization which undertakes research and outreach on public policies related to agriculture and food, with the objective of reducing poverty and improving food consumption and nutrition among the poor in developing countries.

His research at IFPRI has focused on the interface of economic factors which influence food consumption and nutrition outcomes, primarily in Asia, with a particular interest in micronutrient malnutrition. This research has involved analysis of household surveys, publication of research findings in scientific journals, discussion of policy implications for research findings with developing country governments and international agencies, and training and research collaboration with developing country academics and government offices.

He is director of the CGIAR Micronutrients Project that seeks to develop nutritionally improved (micronutrient-dense) staple food crops. This is a collaborative effort among plant scientists at three internationally funded agricultural research centers located in Colombia, Mexico, and The Philippines (CIAT, CIMMYT, and IRRI, respectively), in collaboration with plant scientists and human nutritionists at the USDA, the University of Adelaide in Australia, and several developing country institutions.