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Special Issue on Improving Human Nutrition Through Agriculture

Based on the meeting on Improving Human Nutrition Through Agriculture: The Role of International Agricultural Research, held at the International Rice Research Institute in Los Baños, Philippines, 5–7 October 1999

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Foreword

It is widely agreed among nutritionists that quality diets, supplementation, fortification, nutrition education, and child care are all key elements of an overall strategy for reducing malnutrition in developing countries. There is disagreement, however, over the priorities that should be given to investments in programmes and policies in these specific areas. In part, this lack of consensus exists because some approaches may be implemented more quickly than others, because of perceived differences in the sustainability of specific instruments, and because of uneven information about the efficacy and cost-effectiveness of various strategies in various contexts. There is a relative dearth of information on food-based strategies, in particular.

How can agricultural scientists contribute to this debate? What actions can agricultural institutions take to improve nutrition? What benefit is there to coordination of these actions with programmes implemented by nutritionists? Can the agricultural community be persuaded to give a higher priority to human nutrition concerns in setting their research agenda?

A opportunity presented itself for an interdisciplinary exchange of views of these questions at a meeting entitled "Improving Human Nutrition Through Agriculture: The Role of International Agricultural Research," organized by the International Food Policy Research Institute (IFPRI), hosted by the International Rice Research Institute (IRRI), and held at IRRI's headquarters in Los Baños in the Philippines, 5–7 October 1999. The meeting brought together nutritionists and agricultural scientists from institutions in both industrialized and developing countries, some engaged primarily in research and others in programme implementation. Papers and discussion from this meeting are presented in this volume.

Although the meeting provided an opportunity for a dialogue among nutritionists, agricultural scientists, social scientists, and policy makers, the conference was convened officially as a discussion among scientists from the 16 agricultural research centres comprising the Consultative Group on International Agricultural Research (CGIAR) to set priorities for research related to human nutrition objectives within the CGIAR and for collaboration with institutions outside the CGIAR. For readers unfamiliar with the CGIAR, further information is provided in the Annex at the end of this volume. Additional details are available at *www.cgiar.org*.

Nevin S. Scrimshaw
Editor

Improving human nutrition through agricultural research: Overview and objectives

Per Pinstrup-Andersen

Abstract

There has been little dialogue in the past between agricultural scientists and human nutritionists to explore ways to solve the problem of malnutrition in developing countries together. This conference, held at an agricultural research center in a developing country, provides a unique opportunity to have such a dialogue. About one-half of the 95 in attendance are trained as human nutritionists, and nearly an equal number are plant scientists.

International agricultural research has made a major contribution to growth in food supplies in developing countries. It is widely recognized that lowering the prices of food staples has had a tremendously beneficial impact in alleviating malnutrition. However, the magnitude of micronutrient malnutrition as a public health concern, and the crucial role of poor dietary quality as an underlying cause, have now become widely recognized. Does agriculture have an equally important role to play in addressing micronutrient malnutrition as it has had in alleviating low energy intakes? It is at this crossroads that this conference meets.

Formally, the conference has been convened as a meeting of scientists from the 16 centres that comprise the Consultative Group on International Agricultural Research (CGIAR), with the objectives of taking stock of human nutrition-related research at CGIAR centres, determining research gaps and priorities for future CGIAR research, and identifying opportunities for outside collaboration and cooperation. A three-day conference agenda is designed to accomplish these goals, while at the same time allowing a general discussion of agriculture–nutrition linkages with partners from outside the CGIAR.

The need for a dialogue between agriculture and nutrition

Agriculture is the primary source of nutrients that sustain human life. This is sufficiently obvious that it is often ignored or forgotten. Malnutrition has long been recognized as a major public health problem in developing countries. Poor diets are a fundamental cause of malnutrition. Yet there has been little dialogue in the past between agricultural scientists and human nutritionists in exploring ways to solve this problem.

The 16 agricultural research centres that comprise the Consultative Group on International Agricultural Research (CGIAR) as a group have formally recognized reduction of malnutrition as a CGIAR goal, through such mechanisms as increased food production, more stable food supplies, and increased purchasing power of the poor [1]. The focus of past CGIAR research activities related to nutrition, with a few exceptions, has been on protein–energy malnutrition. Research by plant scientists has concentrated on increasing crop yields, ensuring yield stability, reducing costs of production, and protecting the environment, while recognizing that nutritional benefits may accrue indirectly from increased crop production and so lower food prices.

Human nutritionists have focused on supplementation, fortification, and dietary diversification as the three principal interventions to reduce micronutrient malnutrition. Little attention has been paid by human nutritionists to agriculture per se as a complementary means to solving the dietary quality problem and the contribution that plant scientists might make in this area.

Can we do better than this? What are the benefits to an interdisciplinary dialogue on agriculture–nutrition linkages and identifying follow-up actions? Is it imperative that we do better than this? What are the consequences if the interactions between agriculture and nutrition are ignored by scientists and policy makers?

This conference provides a unique opportunity for having a dialogue between plant scientists and human nutritionists and for seeking answers to these

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questions. About one-half of the 95 in attendance are trained as human nutritionists. The remaining participants are primarily trained as plant scientists who have an interest in applying plant science to improving human nutrition. Social scientists are also here in smaller numbers. We come from research, implementing, and donor institutions and from international and national agencies, based in both developing and developed countries. We are meeting at an International Agricultural Research Centre, the International Rice Research Institute in the Philippines.

The role of international agricultural research in fighting malnutrition

International agricultural research has made a major contribution to growth in food supplies in developing countries. In the early 1960s, there was serious concern that population growth would outstrip the ability of the agricultural sectors of poor countries to produce sufficient food staples to keep food prices from rising and to avert widespread hunger. The opposite, of course, has happened. Rice, wheat, and maize prices, adjusted for inflation, have declined since Green Revolution varieties first became available to farmers in the latter part of the 1960s. Lower cereal prices have been a benefit to all consumers, but especially to poor consumers who spend a large share of their income on food. Producers have been more than compensated for lower prices by increases in productivity, i.e., lower costs per unit of output provided by modern high-yielding varieties developed at international and national agricultural research centres. The best evidence of their continued profitability is the widespread acreage of modern cereal varieties planted in developing countries.

During the 1960s and 1970s, ensuring sufficient energy was thought to be the most serious dietary constraint to improved human nutrition. It is widely recognized that lowering the prices of food staples, the most inexpensive sources of energy in the diet, has had a tremendous beneficial impact in alleviating malnutrition. This was accomplished despite a doubling of world population and the reaching of a land constraint for increasing agricultural production. Although malnutrition persists and is even getting worse in parts of Africa, the situation would certainly be far worse today if cereal prices had remained constant or risen.

Despite this success, the focus of the international nutrition community has now shifted. As outlined by Barbara Underwood in the following paper in this volume, as a result of much new research in the 1980s and 1990s, the magnitude of micronutrient malnutrition as a public health concern has become more widely recognized [2]. The crucial role of poor dietary quality as an underlying cause of this problem is now more fully appreciated at the turn of the millennium.

It is at this crossroads that this conference meets. Does agriculture have an equally important role to play in addressing micronutrient malnutrition as it has had in alleviating low energy intakes? Indeed, some take the view that the Green Revolution has caused a reduction in the diversity in diets, which in turn has increased micronutrient malnutrition. Such claims, however, typically do not consider the plight of the poor and the nutritional situation under the counterfactual situation of lower cereal yields and rising prices for food staples.

Conference objectives

Within this broader context, we have formally convened as a CGIAR-wide meeting, “Improving Human Nutrition Through Agriculture: The Role of International Agricultural Research,” with the following objectives:

- to take stock of activities related to human nutrition currently being undertaken at CGIAR centres;
- to identify gaps in the present CGIAR research agenda related to human nutrition;
- to communicate to outside agencies current and proposed research activities in order to identify complementarities with existing programmes and opportunities for collaboration and cooperation;
- to discuss whether a new direction for institutional arrangements is needed for undertaking human nutrition-related research within the CGIAR.

Conference agenda

A three-day conference agenda is designed to accomplish these four specific CGIAR goals, while at the same time allowing a general discussion of agriculture–nutrition linkages. To frame the broad policy and research issues, during the morning of the first day we hear primarily from participants outside of the CGIAR. The opening address by the First Lady of the Philippines, Dr. Luisa P. Ejercito-Estrada, lays out the challenges faced and programmes being implemented by the government to improve nutrition in the Philippines. Her very participation at our conference, I think, is indicative of the high priority that developing-country governments place on nutrition and health programmes.

Next on the first morning agenda are viewpoints on agriculture–nutrition linkages from three disciplinary perspectives: those of human nutrition, plant science, and economics. These papers provide both a background on the malnutrition problem in developing countries (its prevalence and consequences and the evolution of interventions) and a conceptual framework for analysis of food systems and agriculture–nutrition linkages. These papers are followed by remarks by representatives of implementing institutions: a developing-country government (the Ministry of Planning in Bangladesh), a developed country research agency (US Department of Agriculture-Agricultural Research Service [USDA-ARS]), a multilateral donor (the Asian Development Bank), and a bilateral donor (US Agency for International Development [USAID]).*

During the second half of the first day and all of the second day, we then take stock of ongoing CGIAR research activities related to human nutrition. These are primarily presentations by CGIAR scientists, with commentary or complementary research reported on by technical experts from outside the CGIAR. This discussion is broadly divided into two parts, dealing with staple foods and non-staple foods.

First, plant-breeding research directed at changing the nutrient content of staple foods is reported. This discussion includes the use of both conventional plant-breeding and biotechnology; strategies to increase the mineral, vitamin, and protein content of plants and to reduce antinutrients; and research to determine the bioavailability of nutrients to humans.

Second, various efforts are reported to increase the supply of livestock, fish, vegetables, fruits, and pulses and so to diversify and improve the quality of diets, with a particular emphasis on research and other activities to understand the consequences for improvements in human nutrition. The discussions here cover descriptions of centre activities and strategies for improving human nutrition, studies of the effects on human nutrition of adoption of CGIAR technologies by farmers, and plant-breeding and processing methods for reducing toxins in foods.

Agricultural strategies must fit into a larger milieu of non-agricultural interventions to reduce micronutrient malnutrition. The morning of the third day provides an opportunity for human nutritionists to provide perspective for the plant scientists on the successes and limitations of existing micronutrient programmes and policies. This background can then lead into a discussion of how agricultural interventions can be dovetailed with existing strategies. This is accomplished by means of an in-depth case study of Philippine micronutrient programmes (to some degree representative of the Asian setting), with summary remarks on policies and strategies for Africa and Latin America, and some historical perspective from Europe.

The remainder of the third day is devoted to a discussion of priorities for future CGIAR research activities related to human nutrition and of post-conference follow-up activities both within the CGIAR and in collaboration with outside institutions. This is accomplished through participation in break-out groups that cover specific subtopics, followed by plenary discussions. The questions addressed by the various groups and conclusions reached are presented in the summary chapter at the end of these proceedings.

Changes since the previous CGIAR-wide meeting on human nutrition

It has been 15 years since the CGIAR has convened a system-wide conference on human nutrition. In the proceedings for that conference [4], 14 recommendations for follow-up activities are listed, which may be grouped as follows:

» Seven institutional and staff-related recommendations for increasing the capacity of CGIAR scientists to undertake nutrition-related research (both internally and in collaboration with other institutions) and to increase the priority of nutrition-related considerations in CGIAR research activities.
» Three recommendations to undertake research on the nutritional impacts of CGIAR technologies and of agricultural programmes and policies.
» One recommendation to incorporate nutritional considerations into CGIAR training programmes.
» One recommendation to develop methodological improvements for incorporating nutritional considerations into farming systems research.
» One recommendation to undertake research into ways that post-harvest storage and processing can enhance the nutritional content of foods.
» One recommendation for monitoring the nutrient and antinutrient content of new plant materials to avoid release of lines with standards below those normally accepted.

The agenda outlined above for the present meeting suggests a much more proactive and direct role for plant scientists in helping to solve nutritional problems than was perhaps perceived possible or useful 15 years ago. What is different now?

The 1984 meeting was heavily influenced by the troubles experienced by the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) in the development of quality protein maize (QPM), the first major effort by a CGIAR centre to breed for nutritional quality. These difficulties are chronicled by Vasal [5] in this volume; these research activities were at a low ebb in the early 1980s. Although it took longer than originally expected, QPMs are now a success story.

New and more powerful plant-breeding techniques are available today. The use of biotechnology is a much debated and highly visible topic.

As already mentioned, our understanding of the nature of human nutritional problems is more complex. Micronutrient deficiencies are high on the public

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*Although the remarks of the First Lady and these four speakers are not published in these proceedings, specific points made are referenced in the concluding chapter [3].

health agenda, alongside energy. Food production, environmental, and human nutrition and health systems are increasingly strained as a consequence of population growth and the closing of the land frontier. Consequently, in finding solutions to problems that arise within these systems, it is more difficult today to ignore interdependencies among these systems.

Yet the fact that a CGIAR-wide meeting on human nutrition issues has not been held for 15 years is telling evidence that human nutrition is probably no higher on the CGIAR agenda than it was at the 1984 meeting. It is our challenge, then, to evaluate the potential of incorporating agricultural strategies into the fight against malnutrition. If that potential seems sufficiently high, we must then find ways to convey the message to other scientists, policy makers, and donor institutions that more resources need to be spent on new, innovative, and cost-effective agricultural approaches to improving human nutrition.

In closing, we thank those participants from outside the CGIAR for attending and helping us in this planning and priority-setting exercise. We appreciate the support of the agencies and institutions that you represent for providing the funding for you to come to the meeting. In this regard, we thank the USDA-ARS in particular, which sent six participants. We thank the USAID and the Government of Norway for providing major funding for the attendance of participants from developing countries and technical experts, and for the costs of publishing these proceedings. Thanks also to the staff of the International Rice Research Institute (IRRI) for their competent management of many logistical arrangements for such a large gathering and to IRRI for co-hosting this conference with International Food Policy Research Institute (IFPRI).

A map showing the locations of the 16 CGIAR agricultural research centres can be found in the Annex at the end of this issue.

References

1. Technical Advisory Committee of the Consultative Group on International Agricultural Research. CGIAR priorities and future strategies. Rome: Technical Advisory Committee Secretariat, Food and Agriculture Organization, 1987.
2. Underwood BA. Overcoming micronutrient deficiencies in developing countries: Is there a role for agriculture? Food Nutr Bull 2000;21:356–60.
3. Bouis HE. Improving human nutrition through agriculture: the role of international agricultural research. Conference summary and recommendations. Food Nutr Bull 2000;21:549–65.
4. Pinstrup-Andersen P, Berg A, Forman M. International agricultural research and human nutrition. Proceedings from a workshop held at the International Livestock Centre for Africa, 29 February–2 March 1984. Washington, DC: International Food Policy Research Institute, and Rome: United Nations Administrative Committee on Coordination/ Sub-Committee on Nutrition, 1984.
5. Vasal SK. The quality protein maize story. Food Nutr Bull 2000;21:445–50.

Overcoming micronutrient deficiencies in developing countries: Is there a role for agriculture?

Barbara A. Underwood

Abstract

Severe forms of protein–energy malnutrition still occur, but they are associated most commonly with devastating natural disasters and civil unrest. With the exception of sub-Saharan Africa, progress in combating chronic undernutrition is also occurring. The prevalence of vitamin and mineral deficiencies has also declined in nearly all countries, although the pace is slow for some micronutrient deficiencies, particularly iron-deficiency anaemia.

Nevertheless, the prevalence rates of micronutrient malnutrition remain high, with devastating consequences for health, cognition, and productivity. Much remains to be done, particularly in reducing iron, zinc, and vitamin A deficiencies, which up to the present have largely been attacked by using a medical model that relies on the distribution of supplements. Supplements are effective but are expensive in terms of the support devoted to repetitive use of scarce health manpower. Fortification can work in some places. Education and awareness of the public is crucial. The public must not be considered only as the target of imposed interventions. Civil society must become engaged in the process, with the goal of their becoming demanding consumers, participating in the action to achieve micronutrient adequacy.

Sustaining the progress that has been achieved will depend on underpinning the medical model with food-based approaches that address multiple nutrient and phytochemical needs for optimal health. Agriculture, by investing in the Green Revolution, can rightly be credited for its contribution to reducing food shortages and the protein–energy malnutrition problem. A similar opportunity exists now for agriculture to invest in developing more micronutrient-dense staple crops, while not neglecting continued research on the production of livestock and small animals, fish, vegetables, and legumes.

Some historic landmarks with respect to micronutrient deficiencies

Five decades ago, international agencies and public health officials recognized severe protein–energy malnutrition as a problem worthy of attention and expenditure of resources. Four decades ago, classic signs of deficiencies of vitamins, such as vitamin A, and of minerals, such as iron and iodine, were added to the list of scourges frequently associated with protein–energy malnutrition and deserving of special medical attention. Three decades ago, a "doomsday" mentality gripped the world because pundits predicted that global food shortages were inevitable, given the explosive growth in population that was occurring, primarily in the developing world. Two decades ago, perceptions began to change as evidence accumulated that some interventions were having positive impacts. In 1990, just one decade ago, commitments to accelerated actions were initiated at several UN agency-initiated conferences:

» the 1990 UNICEF-sponsored World Summit for Children with a call for "a reduction in severe and moderate malnutrition among children under 5 by half the 1990 rate by the year 2000," including elimination goals for micronutrient malnutrition;

» the 1992 World Health Organization/Food and Agriculture Organization (WHO/FAO) International Conference on Nutrition that reinforced earlier goals and extended to "elimination of death from famine";

» the 1996 FAO-sponsored World Food Summit that endorsed earlier goals and declared "the commitment to achieving food security for all, and to an ongoing effort to eradicate hunger in all countries, with an immediate view to reducing the number of undernourished people to half its present level no later than 2015."

Changing perceptions

Progress through the last half-century in addressing global food, nutrition, and health problems obviously

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has engaged planning by agriculturists and nutritionists, as well as those concerned with population growth, but not always from a consensus view. Indeed, some confusion occurred among nutritionists, whose debate shifted from stressing calories, to protein quality, and back to calories as the primary global nutrition problem to combat. This confusion spilled over to the agriculture sector as to appropriate agricultural policies to serve both human nutrition and national production and development needs. For example, would simply producing more low-cost, energy-dense food, e.g., rice, wheat, corn, or even cassava, which are widely consumed by the poor, solve the problem, or should major emphasis be placed on crops qualitatively more balanced in their amino acid content, such as legumes, or livestock, even though they are somewhat more costly? The population sector also debated the best approach to curb the rate at which population growth was outstripping per capita food availability.

Each sector responded by changing its perceptions of the problem:

» the population control sector, from only distributing contraceptives to promoting the status of women in society;

» the agriculture community, by investing in the Green Revolution, for which the Consultative Group on International Agricultural Research (CGIAR) system can take a large share of the credit;

» the nutritionists, by a change from a focus on medically managing only third-degree malnutrition to controlling less severe undernutrition affecting vastly larger populations, with consequences not only for physical development, but also for cognitive and immunological development.

Dividends from these investments by agriculture and changed perceptions by nutritionists and family planners are reflected in the Fourth Report on the World Nutrition Situation of the UN Sub-Committee on Nutrition, showing a progressive improvement from 1980 to the present (fig. 1)[1]. In most countries today, mortality rates among infants and young children are at historic lows, and life expectancy is at historic highs. Severe forms of protein–energy malnutrition still occur, but they are associated most commonly with devastating natural disasters and civil unrest that have lead to displacement of persons, prolonged crop failures, or lasting economic crises. With the exception of sub-Saharan Africa, progress in combating chronic undernutrition is also occurring, although slowly.

The prevalence of classic clinically evident vitamin and mineral deficiencies has also declined in nearly all countries, and dramatic progress towards their elimination as public health problems has occurred, although the pace is slow for some micronutrient deficiencies, particularly iron-deficiency anaemia. Progress in child survival and development is attributed to gains in underlying factors of reduction in social disparities, increased access to health care, and increased food availability. Improvements in national economics and equity also have had spin-off for households and community development as well as for child survival and development.

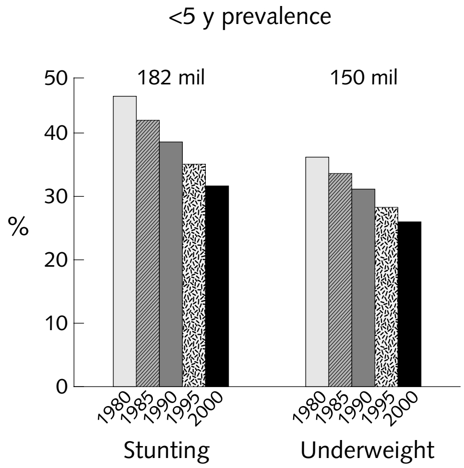

FIG. 1. Trends in stunting and underweight among children in developing countries, 1980–2000. The estimated numbers of stunted and underweight children in 2000 are 182 and 150 million, respectively. Source: ref. 1

The world situation at the dawn of a new millennium

Nonetheless, at the dawn of a new millennium, the Sub-Committee on Nutrition estimates that in the developing countries 30 million babies will be born undernourished annually, that these countries will be plagued by prevalences of over one-fourth underweight and one-third stunting among pre-schoolchildren, and that they will be burdened by the reduced productivity of about 15% of the adult population who also will be underweight. Hence, the quantity of food available to the vulnerable is a persistent problem with which agriculture must continue to be concerned into the new century. Issues of dietary quality, particularly with respect to micronutrients, will be of equivalent concern and will need to capture sustained investment by agriculture. However, adequate quantity and quality of the food supply alone are insufficient. Improvements in health and family care will also be needed for maximum benefits to accrue.

Dietary quality issues

Dietary quality relates to the essential nutrient content, particularly essential micronutrients. Micronutrients are those vitamins and minerals needed in small amounts to support physiological functions that must be provided in foods or as supplements because they cannot be made by the body in amounts sufficient to meet needs. Currently three micronutrients have captured attention as being of public health concern: iron, vitamin A, and iodine. Because zinc nutrition shares many traits similar to that of iron, and because there is increasing evidence of the impact of zinc deficiency on growth, diarrhoeal disease, and other health-related factors, it can be assumed that it is already a problem of public health concern. There are other micronutrients that are likely to be recognized as public health concerns as more is learned of their prevalence and health consequences.

Size and consequences of the micronutrient problem and progress in control

As with protein–energy malnutrition in the latter part of the twentieth century, perceptions with respect to micronutrients have changed from a focus on the results of clinical deficiencies of micronutrients (such as anaemia, goitre, and eye problems) to the hidden consequences of inadequate nutrition that compromise immune function, cognitive development, growth, reproductive performance, and work productivity. Indeed, an estimated 3.5 to 5 billion people are iron deficient, 2.2 billion are iodine deficient, and 140 to 250 million are deficient in vitamin A. These numbers exceed those estimated to be stunted and underweight at the end of the twentieth century (182 and 150 million, respectively)(fig. 1).

Progress is being made, particularly with respect to iodine deficiency (fig. 2). I will not pursue this issue further, because an effective solution through the universal iodization of salt is in hand. But much remains to be done, particularly in reducing iron, zinc, and vitamin A deficiencies, which to the present have largely been attacked by using a medical model that relies on the distribution of supplements. Most agree that sustaining the progress that has been achieved will depend on underpinning the medical model with food-based approaches. Agriculture, by investing in the Green Revolution, can rightly be credited for its contribution to reducing food shortages and the protein–energy malnutrition problem. A similar opportunity exists now for agriculture to invest in developing more micronutrient-dense staple crops, while not neglecting continued research on livestock and small animals, fish, vegetables, and legume production. Investments in food-based approaches address multiple nutrient and phytochemical needs for optimal health. They also sustain the gains being made by short-term micronutrient control measures now being implemented that distribute medicinal supplements, or in a few instances through fortification of food products.

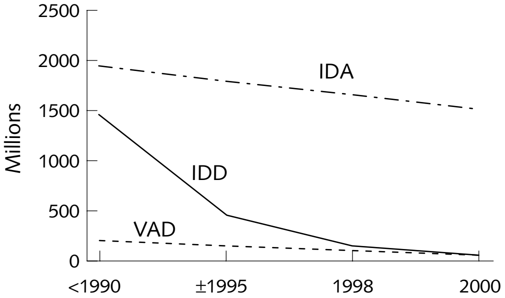

FIG. 2. Trends in incidence of selected micronutrient deficiencies in developing countries, 1990–2000. VAD, Vitamin A deficiency; IDD, iodine-deficiency disorders; IDA, iron-deficiency anaemia. Source: WHO Micronutrient database found at the following Internet address: *www.who.int/nut/data_banks.htm#link2*

Supplements are effective. The medicinal approach, which is cheap in terms of cost of the pills, but expensive in terms of the support devoted to repetitive use of scarce health manpower, has been successful in reducing clinical deficiency signs. Indonesia and Vietnam declared themselves to be free of clinical vitamin A deficiency (xerophthalmia) in part because of the successful broad coverage achieved through periodic delivery of high-dose vitamin A supplements. The current economic crisis in Indonesia, however, has seen the reoccurrence of clinical deficiency, suggesting that dependence on this solution is vulnerable to economic and political instability.

Fortification can work in some places. In developed countries, fortification of a variety of food products has underpinned control of micronutrient deficiencies. I am aware of efforts in the Philippines to fortify several products and of the evidence that this strategy may prove effective, at least in urban areas. The fortification of sugar has successfully raised the level of vitamin A nutrition in some Latin American countries, but fortification is not feasible in much of Africa and parts of Asia, where the food industry is in rudimentary stages of development and there is no structure for quality assurance of fortified products. Fortification of rice, wheat, maize, and other food vehicles has been successful in advanced countries, where central processing and strict quality control is assured. This is not the case for many of those countries where micronutrient deficiencies are most prevalent. Fortification for the control of micronutrient deficiency, therefore, is one important weapon in the mix of strategies needed, but it is not alone sufficient and is not currently feasible in many situations.

Education and awareness of the public are crucial. There is no question that social marketing of micronutrient strategies for social good, from the individual to the national level, is a critical need in all approaches to the control of micronutrient malnutrition. The public must not be considered only the “target” of imposed interventions. Civil society must become engaged in the process, with the goal of their becoming demanding consumers, participating in the action to achieve micronutrient adequacy—with the resultant health benefits—in order to attain adequate food and nutrition security for their household, which is their basic human right.

Is it worth the investment?

Let me illustrate what the payoffs could be by using the example of vitamin A. The lethal consequences of vitamin A deficiency have been convincingly demonstrated in large-scale clinical trials in which vitamin A nutriture was restored in inadequately nourished populations of children and, more recently, of pregnant women. Meta-analysis of all the data from seven community trials conducted in five countries revealed that child mortality was reduced, on average, by 23% [2]. In two of these trials, the two with the greatest efficacy, this was achieved at levels attainable through diets if only the recommended dietary allowances (RDA) were met. This is possible, therefore, without relying on medicinal supplements by providing food with the appropriate quantity and bioavailability of micronutrients.

A recent trial in Nepal demonstrated that gains are not limited to child survival. Maternal mortality among a vitamin A–deficient Nepalese population of pregnant women was reduced by 40% when the RDA was met on a weekly basis by providing either vitamin A or β-carotene [3]. Although these findings need to be confirmed by studies that recognize in their design the appropriate ethical considerations, surely the findings provide a real incentive for agriculture to join other sectors in developing the arsenal of control measures by investing in improving micronutrient nutriture through improved content and bioavailability of staple foods—and other affordable food sources—for the survival of children and mothers, and thus, the health of nations.

Sustainable food-based solutions

Sustainable solutions for deficiencies of iron and zinc, vitamin A, and other micronutrients lie in food-based approaches in which agriculture will play a key role. I am aware of the progress being made in some research centres through germplasm screening of traditional varieties of cassava, sweet potatoes, and other vegetables for their higher content of β-carotene. These varieties can make a substantial contribution in selected populations. I understand that more than 50% of the world’s cultivated land is devoted to wheat, rice, and maize and that by 2020, almost 96% of the world’s rice consumption, two-thirds of its wheat consumption, and almost 60% of its maize consumption will be in developing countries [4]. Clearly, cereals are critical to human nutrition now and will continue to be in the future, and there is an unusual opportunity for agriculture to make a difference through plant-breeding.

Does agriculture have a role? Strategic partnerships are needed

To conclude, I hope that the answer to the question of whether agriculture has a role to play in helping to reduce micronutrient malnutrition is obvious. Strategies are possible to enhance the micronutrient content and bioavailability of plant-based staple foods and other micronutrient-containing foods in whole diets. Maximum efficacy will occur when alliances are formed between agriculturists, whose expertise lies in improving the micronutrient content in staple and other crops and in altering the ratio of enhancers to inhibitors of bioavailability in field crops, and nutritionists, whose expertise lies in diversifying and modifying menus along similar lines that enhance micronutrient availability in households. I am particularly pleased to be at this meeting, which brings the two strategic partners together, and I anticipate productive dialogue over the next few days as these few suggestions for the roles of the CGIAR and the roles of nutritionists are elaborated. I hope that we can join hands in advocacy for the feasibility and long-term sustainability of combating micronutrient deficiencies through food-based approaches. Increased investment by agriculture in quantitative and qualitative improvement of the nutrition of populations is crucial to accelerating global economic growth and national development. The spin-off for the health and quality of life for millions of individuals and communities now trapped in poverty and deprivation is obvious. It is fundamental to achieving the increasingly recognized human right to adequate food and nutrition.

References

1. United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition/International Food Policy Research Institute. Fourth report on the world nutrition situation. Geneva: ACC/SCN, 2000.
2. Beaton GH, Martorell R, Aronson KJ, Edmonston B, McCabe G, Ross AC, Harvey B. Effectiveness of vitamin A supplementation in the control of young child morbidity and mortality in developing countries. ACC/SCN State-of-the-Art Series, Nutrition Policy Discussion Paper No. 13. Geneva: United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition, 1993.
3. West KP, Katz J, Khatry SK, LeClerq SC, Pradhan EK, Shresthra SR, Connor PB, Dali SM, Christian P, Pokhrel RP, Sommer A, on behalf of the NNIPS-2 Study Group. Double blind cluster randomized trial of low dose supplementation with vitamin A or beta-carotene on mortality related to pregnancy in Nepal. BMJ 1999;318:570–5.
4. Rosegrant MW, Paisner M, Witcover J. Global food projections to 2020: emerging trends and alternative futures. IFPRI IMPACT Simulations. Washington, DC: International Food Policy Research Institute, October 1999.

A new paradigm for world agriculture: productive, sustainable, nutritious, healthful food systems

Ross M. Welch and Robin D. Graham

Abstract

Micronutrient malnutrition currently affects over 2 billion people worldwide. Poor health, low worker productivity, high rates of mortality and morbidity, increased rates of chronic diseases (coronary heart disease, cancer, stroke, and diabetes), and permanent impairment of cognitive abilities of infants born to micronutrient-deficient mothers are all consequences of micronutrient malnutrition. Furthermore, these deficiencies are contributing to lethargic national development efforts, continued high population growth rates, and a vicious cycle of poverty for massive numbers of underprivileged people in all nations. Food systems globally are not providing enough balanced nutrient output to meet all the nutritional needs of every person, especially resource-poor women, infants, and children in developing countries. Agriculture is partly responsible. It has never made adequate and balanced nutrient output an explicit goal of its production systems. Many agricultural policies may have fostered a decline in nutrition and diet diversity for the poor during the past four decades. Additionally, the nutrition and health communities have never considered using agriculture as a primary tool in their programmes directed at alleviating poor nutrition and ill health globally. A new paradigm for agriculture and nutrition is now needed. We must consider ways that agriculture can contribute to finding sustainable solutions to food system failures through holistic food-based system approaches, thereby closely linking agricultural production to improving human health, livelihood, and well-being. Such action will rouse support for agricultural research worldwide, because it addresses consumer issues as well as agricultural production issues and is, therefore, politically supportable.

Introduction

The path set down for world agriculture into the twenty-first century was defined barely a decade ago, but we already need new thinking to avert global food system failures. This has much to do with the impact of the Green Revolution and its perceived inadequacies: we have begun to address the environmental concerns about modern, technological agriculture, but evidence is growing that our global food systems are failing to deliver adequate quantities of healthy, nutritionally balanced food, especially to underprivileged people [1, 2]. The consequences are affecting human health, well-being, and productivity and are contributing to stagnating national development efforts in many developing nations.

The old production paradigm

Science-driven progress in agriculture in the last 100 years has resulted in an increasingly technological operation that has shown itself capable of achieving lifts in productivity needed to provide adequate food energy for the world, and even to provide more calories per person. The technology has included new varieties, chemicals ranging from mineral fertilizers to pesticides to synthetic plant hormones, and machines to supplement and replace the labour force. Many countries benefited immensely from this agricultural revolution, as the problems of inherently infertile soils were resolved by the development of nitrogen, superphosphate, and micronutrient fertilizers, creating a surplus of food that has endured since the early 1980s. We call this technological revolution the "production paradigm." It culminated in the Green Revolution, a

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series of highly orchestrated global strategies developed in the face of threatening starvation to expand the global production of staple food crops, especially cereals. This huge international effort began in the 1960s and achieved adequacy in world food calorie and protein production in just two decades, an effort for which one of the leaders, Dr. Norman E. Borlaug, received the Nobel Peace Prize in 1971.

The current paradigm

Even before this monumental international effort for food security got under way, Rachel Carson had published her famous book, *Silent Spring* [3], depicting the threat to our environment from the indiscriminate use of toxic chemicals, much of it in "modern" agriculture. There was also concern that the emphasis on agricultural production was threatening the resource base of land, soil, air, and water through processes such as loss of soil fertility by erosion, acidification, salinization, and desertification.

In the mid-1980s, that approach to agriculture and its research base was largely overrun and a new paradigm installed: high productivity while preserving or improving the resource base of agriculture and the environment—the so-called sustainability paradigm. The Green Revolution failed originally to place enough emphasis on the sustainability of its increased productivity (though it must be remembered that the initial focus was to avert the then imminent prospect of mass starvation in many countries).

A new paradigm is needed

No sooner had the proponents of sustainability been congratulated for getting the philosophy for world agriculture "right," with a remarkable global consensus (though the objectives still have to be realized), than new concerns arose. Like the environmental concerns before them, these have been brewing for some time, but they have been brought into sharp focus by the statistics of the World Health Organization (WHO) and the World Bank [4, 5] in the last few years. Although the world's food supply has been sufficient (wars, food distribution problems, and the like excepted), it is simply not nutritious enough. Micronutrient malnutrition, often called "hidden hunger," has become more conspicuous in many countries since the introduction of Green Revolution cropping systems. Today, micronutrient malnutrition diminishes the health, productivity, and well-being of over half of the global community, with impact primarily on women, infants, and children from low-income families [1, 6].

Some question the Green Revolution's success, because productive cereals, the basis of increased food production in poor countries, have displaced other traditional crops that are higher in iron and other limiting micronutrients needed for healthy lives. In South Asia, where cereal production has increased more than four times since 1970 (while the population has nearly doubled), production of pulses actually declined about 20%. Economically, the World Bank and the US Agency for International Development [7] have estimated that iron deficiency costs India and Bangladesh about 5% and 11% of their gross national product annually, respectively, enough all by itself to prevent these countries rapidly accelerating out of third world status, a prospect which historically if achieved results in a lowering of national birth rates.

During the Green Revolution's push towards food security, little thought was given to nutritional value and human health, and certainly almost none to the concentrations of iron and other micronutrients in the new cereal varieties being bred, or the micronutrient content of the resultant changing diets. However, the prospect of mass starvation, inevitable without the Green Revolution, is far worse than the problems we now need to address. In total, the impact of modern agriculture on improving the lives and well-being of billions of people globally is impressive. Although the impact of agricultural research has been immense, the outcome of these success stories has created even more daunting challenges for agricultural scientists, nutritionists, health-care specialists, policy makers, and their institutions.

The population explosion

The projections to the year 2030 indicate that population stability is expected at that time, with numbers in the range of 8 to 10 billion. The population explosion in the developing world is a phenomenon of our own time—post-World War II—and a feature of the curve is that we have passed the halfway mark in the population bulge, both in time and in numbers. The implications are clear: although the Green Revolution in food production has kept pace with the population increase to the halfway point, a second Green Revolution of similar magnitude is needed to provide food for another three billion people still to come. The achievements to date have been based heavily on increases in productivity of irrigated lands with high potential yield, and as their productivity approaches the potential, it is perceived that further lifts in production must be based, in contrast, more in the low-yield, rain-fed environments that are far below their potential. To succeed is essential if we are to guarantee an acceptable future for our children and grandchildren, no matter what country we now live in. Food security is essential to political stability, on which an acceptable future depends. It is important to note that among those entrusted with the responsibilities of planning international agricultural research, there is quiet but total confidence that it can be delivered, and this confidence needs to be conveyed to the next generation and the budding scientists who will join the effort.

Micronutrients in food systems

Modern agricultural systems are adept at providing calories, but in the process, they have increased hidden hunger among the world's poor by displacing acreage allotted to traditional crops such as pulses, making many micronutrient-rich plant foods less available and more expensive to low-income families [8]. This is no more evident than in South Asia. Green Revolution crops successfully increased the per capita availability of food energy but were associated with a decline in the density of dietary iron in the peoples of South Asia, and the incidence of iron-deficiency anaemia there has increased in pre-menopausal women. The cereals, such as rice, that have displaced traditional micronutrient-rich crops, such as pulses, vegetables, and fruits, contain inherently lower amounts of micronutrients (table 1) and are eaten primarily after milling, whereas pulses are normally consumed whole after cooking; milling removes much of the micronutrients cereals contain (table 2). Furthermore, whole cereal grains contain relatively high levels of antinutrients (substances that reduce the absorption and/or utilization, i.e., bioavailability, of micronutrient metals to humans) and low levels of substances that promote the bioavailability of these nutrients, further reducing the nutritional value of cereal products with respect to micronutrients [16, 17]. Table 3 lists some important antinutrients found in many plant food products.

Animal products (such as beef, pork, lamb, poultry, and fish) and many fruits and vegetables contain high levels of micronutrient metals, such as iron and zinc. Meats are also rich sources of substances known as meat factors that counteract the negative effects of the antinutrients found in many staple plant foods, thereby promoting the bioavailability of iron, zinc, and other micronutrients in mixed diets [16, 18]. Table 4 lists some promoter substances found in abundance in animal protein sources.

TABLE 1. Median concentrations (μg/g dry weight) and range of concentrations of iron, zinc, and copper in rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), field corn (*Zea mays* L.), and soya bean (*Glycine max* L.) grain/seeds from major agricultural production regions within the coterminous United States and range of iron, zinc, and copper concentrations in commercial bean (*Phaseolus vulgaris* L.) seeds

	Iron		Zinc		Copper	
Mature grain/seed	Median	Range	Median	Range	Median	Range
Rice[a]	3	2–10	16	10–22	2	1–5
Wheat[a]	37	24–61	31	13–68	4	2–9
Field corn[a]	20	16–30	21	15–34	1	1–4
Soya bean[a]	70	48–110	45	36–70	13	4–29
Bean[b]		33–80		19–65		5–14

a. Source: refs. 9 and 10.
b. Source: ref. 11.

TABLE 2. Influence of milling on iron and zinc concentrations (μg/g dry weight) in seed/grain of rice, wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), and sorghum (*Sorghum bicolor* Moench)

Crop	Milling fraction	Iron	Zinc
Corn	Whole grain	23	21
	Degermed	11	4
Sorghum	Whole grain	179	36
	64% extraction	54	10
Rice	Brown rice	16	28
	90% extraction	5	17
Wheat	Whole grain	38	37
	70% extraction	22	12

Source: refs. 12–15.

TABLE 3. Important antinutrient substances in plant foods reported to reduce the bioavailability of iron and/or zinc to humans under most, but not necessarily all, circumstances

Antinutrient	Examples of major dietary sources
Phytic acid or phytin	Whole legume seeds and cereal grains
Fibre (cellulose, hemicellulose, lignin, cutin, suberin, etc.)	Whole cereal grain products (e.g., wheat, rice, maize, oat, barley)
Tannins and polyphenolics	Tea, coffee, beans, sorghum, etc.
Haemagglutinins (e.g., lectins)	Most legumes and wheat
Heavy metals (e.g., cadmium, mercury, lead, silver)	Plant foods obtained from crops grown on metal-polluted soils (e.g., cadmium in rice)

Source: modified from ref. 16.

TABLE 4. Promoter substances in plant foods reported to enhance the bioavailability of iron, zinc, and/or vitamin A to humans eating meals containing complex diets under some, but not necessarily all, circumstances

Substance	Micronutrient	Major dietary sources
Certain organic acids (e.g., ascorbic acid or vitamin C, fumarate, malate, citrate)	Iron and/or zinc	Fresh fruits and vegetables
Phytoferritin (plant ferritin)	Iron	Legume seeds and leafy vegetables
Certain amino acids (e.g., methionine, cysteine, histidine, lysine)	Iron and/or zinc	Animal meats (e.g., beef, pork, fish)
Long-chain fatty acids (e.g., palmitic acid)	Zinc	Human breastmilk
Fats and lipids	Vitamin A	Animal fats, vegetable oils
Selenium	Iodine	Seafoods, tropical nuts
Zinc	Vitamin A	Animal meat
Vitamin E	Vitamin A	Vegetable oils, green leafy vegetables

Source: modified from ref. 16.

In many developing nations, animal meats, fruits, and vegetables are not continually available throughout the year (especially to low-income families). Therefore, they contribute insufficiently to meeting the continuous nutritional needs of gravid women, infants, and children, because these foods are seasonal, expensive, or both. For example, many developing nations do not produce enough fruits and vegetables to meet the recommended level of 73 kg/yr per person consumption. Thus, greatly increasing the production of small animals, fruits, and vegetables and the infrastructure to process and provide these foods on a continuing basis to those most in need would have a significant effect on improving the micronutrient status of people in many regions of the world [8].

Under the continuing pressure of population increase, the economic force favouring the dominance of agricultural land by the highly productive and yield-stable cereals will continue. Consequently, we advocate, among others, a strategy of increasing the micronutrient content and bioavailability of cereals themselves (and other staples), and several of the following papers address aspects of this strategy.

What are the ramifications of micronutrient malnutrition to human health, livelihood, well-being, fertility, and, ultimately, the sustainability of national development efforts in third world countries? Hidden hunger results in huge costs to society that greatly impair national development efforts, reducing labour productivity, lowering educational attainments in children, reducing school enrolments and attendance, increasing mortality and morbidity rates, and increasing health-care costs [7].

Even in developed nations such as the United States, health-care costs associated with poor diet are enormous. According to a recent study published by the Economic Research Service of the US Department of Agriculture, poor diet contributes significantly to the four leading causes of death in the United States: coronary heart disease, cancer, stroke, and diabetes [19]. Improving dietary habits alone could save the US population nearly US$1 billion annually in health-care costs and lost productivity resulting from diet-related diseases and poor nutritional health. The US Department of Agriculture and the US Public Health Service have recommended using their food guide pyramid to determine healthful daily food choices. Unfortunately, current per capita supplies of fruits and vegetables fall far short of providing the servings needed to meet the guidelines recommended in the food guide pyramid [20]. This provides evidence that even in the United States, with one of the most abundant and healthful food supplies in the world, the food systems are failing to provide adequate nutrients to insure good health for all.

Commonly, policy makers have viewed malnutrition, including micronutrient malnutrition, as a disease that must be "treated." Accordingly, many nations have adopted solutions to micronutrient malnutrition that only stress supplementation and foodfortification intervention programmes [21]. Although many of these programmes have been successful in the short run, they are all too often unsustainable for economic, political, and logistical reasons [2]. The International Conference on Nutrition held in Rome in December 1992 [4] recognized the urgent need to find sustainable solutions to micronutrient malnutrition. Indeed, the conference called for ensuring that sustainable food-based strategies be given first priority by national policy makers, asking that their policies be directed at additional investment into agricultural research, where necessary, to promote improved micronutrient output of agricultural systems. At the Frontiers of Nutrition and Food Security Colloquium in 1992, organized by the Smithsonian Institution and the International Life Sciences Institute of North America, a noted international human nutritionist, Dr. Barbara Underwood of WHO, emphasized "that food, nutrition and health programs should not exist as vertical programs within the health ministry, nor should agricultural programs be solely production-oriented, thereby ignoring consumption issues, household food security, and community nutritional needs. Indeed …health, nutrition, and food security are inextricably interrelated and must become explicit objectives of development policies, particularly agricultural development policy" [22]. Clearly, there is now a distinct message from the nutrition community to the agricultural community seeking to forge closer linkages between agricultural production and human nutrition and health in ways that will insure adequate, balanced, and enduring nutriment for everyone [23].

In developed nations, agricultural science has provided the tools that have dramatically increased food crop yields and food abundance while reducing the cost of food to consumers. Food surpluses have also accumulated. This success has led to substantially larger but fewer farms and fewer farm families in developed countries. Now, farmers no longer comprise a significant proportion of the voting public within most intranational political boundaries in developed nations; for example, today less than 2% of the US population produces the food needed to nourish its citizens. Consequently, there is much less public concern for agriculture and farming issues than there was a century ago. Public support for agricultural research has been eroded, making government-sponsored funding of agricultural research more difficult to obtain. Currently, leading agricultural institutions in developed nations are faced with expanding their missions to service the concerns of new clients (not just farmers) to justify their existence and glean political support to maintain their agricultural programmes. As a result of national and international movements to redress environmental concerns, many agricultural institutions have initiated environmental research programmes to gain more public support. Importantly, the world community has now given agriculture a new global agenda that will help generate new public support for their agricultural institutions because nutrition and health issues are of growing concern to the public at large and are therefore politically supportable. The time has come to seize this opportunity and begin to form collaborations among agricultural scientists, nutritionists, and health-care officials to eradicate hidden hunger. Clearly, agriculture must address this quandary if we are to find sustainable solutions to micronutrient malnutrition that degrades human health, productivity, and well-being and causes immense suffering among approximately 2 billion people globally.

The food systems paradigm for sustainable production of nutritious food

Clearly, new paradigms for agriculture, nutrition, health, and development must emerge that will meet these new challenges threatening sustainable development efforts in many emerging nations. Holistic food system approaches (directed at empowering people and insuring balanced and adequate nutrition and improved health for all in sustainable ways) hold much promise in providing the methods needed to ensure continued support for agricultural research and in ensuring sustainable agricultural systems. Enduring food-based solutions to malnutrition generate good health and improved productivity while ultimately contributing to lower population growth rates [8]. Insecurity of food and shelter is considered to be causally related to the high birth rate in poor countries. Consequently, the stakes in any attempt to eliminate these deficiencies are of the highest order.

Forging linkages among agriculture, nutrition, and health is necessary to nullify the adverse effects of past policies for global agriculture, nutrition, and national development that have fostered only short-term, unsustainable solutions to starvation, malnutrition, underdevelopment, and high human fertility rates. To do so would be to support a new paradigm for agriculture—the food systems paradigm—an agriculture that aims not only for productivity and sustainability but also for better nutrition, important objectives for the entire human race.

References

1. Mason JB, Garcia M. Micronutrient deficiency: the global situation. SCN News 1993;9:11–6.
2. McGuire J. Addressing micronutrient malnutrition. SCN News 1993;9:1–10.
3. Carson R. Silent spring. Boston, Mass, USA: Houghton Mifflin, 1962.
4. United Nations/World Health Organization. International Conference on Nutrition: World Declaration and Plan of Action for Nutrition. Food and Agriculture Organization and World Health Organization. Rome: FAO, 1992:1–42.
5. World Bank. The challenge of dietary deficiencies of vitamins and minerals. In: Enriching lives: overcoming vitamin and mineral malnutrition in developing countries. Washington, DC: World Bank, 1994:6–13.
6. ACC/SCN (United Nations Committee on Coordination/Sub-Committee on Nutrition). Second report on the world nutrition situation. Vol. I. Global and regional results. Geneva: ACC/SCN, 1992.
7. Sanghvi TG. Economic rationale for investing in micronutrient programs. A policy brief based on new analyses. Washington, DC: Office of Nutrition,

Bureau for Research and Development, US Agency for International Development, 1996.

8. Combs GF, Welch RM, Duxbury JM, Uphoff NT, Nesheim MC. Food-based approaches to preventing micronutrient malnutrition: an international research agenda. Ithaca, NY, USA: International Institute for Food, Agriculture, and Development, Cornell University, 1996.
9. Wolnik KA, Fricke FL, Capar SG, Braude GL, Meyer MW, Satzger RD, Kuennen RW. Elements in major raw agricultural crops in the United States. 2. Other elements in lettuce, peanuts, potatoes, soybeans, sweet corn, and wheat. J Agric Food Chem 1983;31:1244–9.
10. Wolnik KA, Fricke FL, Capar SG, Meyer MW, Satzger RD, Bonnin E, Gaston CM. Elements in major raw agricultural crops in the United States. 3. Cadmium, lead, and eleven other elements in carrots, field corn, onions, rice, spina*ch, and tomatoes.* J Agric Food Chem 1985;33:807–11.
11. Augustin J, Beck CB, Kalbfleisch G, Kagel LC, Matthews RH. Variation in the vitamin and mineral content of raw and cooked commercial Phaseolus vulgaris classes. J Food Sci 1981;46:1701–6.
12. Pedersen B, Eggum BO. The influence of milling on the nutritive value of flour from cereal grains. 5. Maize. Qualitas Plantarum Plant Foods and Nutrition 1983; 33:299–311.
13. Pedersen B, Eggum BO. The influence of milling on the nutritive value of flour from cereal grains. 6. Sorghum. Qualitas Plantarum Plant Foods Nutrition 1983;33: 313–26.
14. Resurreccion AP, Julioano BO, Tanaka Y. Nutrient content and distribution in milling fractions of rice grain. J Sci Food Agric 1979;30:475–81.
15. Widdowson EM. Extraction rates: nutritional implications. In: Spicer A, ed. Bread: social, nutritional and agricultural aspects of wheaten bread. London: Applied Science Publishers, 1975:235–45.
16. Graham RD, Welch RM. Breeding for staple-food crops with high micronutrient density. Agricultural Strategies for Micronutrients No. 3. Washington, DC: International Food Policy Research Institute, 1996.
17. Welch RM, House WA. Factors affecting the bioavailability of mineral nutrients in plant foods. In: Welch RM, Gabelman WH, eds. Crops as sources of nutrients for humans. Madison, Wisc, USA: American Society of Agronomy, 1984:37–54.
18. Welch RM, House WA. Meat factors in animal products that enhance iron and zinc bioavailability: implications for improving the nutritional quality of seeds and grains. In: Cornell Nutrition Conference for Feed Manufacturers. Ithaca, NY, USA: Department of Animal Science and Division of Nutrition, Cornell University Agricultural Experiment Station, 1995:58–66.
19. Frazao E. The American diet: a costly health problem. FoodReview 1996;Jan/Apr:2–6.
20. Kantaor LS. Many Americans are not meeting food guide pyramid dietary recommendations. FoodReview 1996;Jan/Apr:7–15.
21. Maberly GF, Trowbridge FL, Yip R, Sullivan KM, West CE. Programs against micronutrient malnutrition: ending hidden hunger. Annu Rev Public Health 1994;15:277–301.
22. Underwood BA. Frontiers of nutrition and food security in Asia, Africa, and Latin America: a colloquium summation. In: Kotler NG, ed. Frontiers of nutrition and food security in Asia, Africa, and Latin America. Papers and proceedings of a colloquium organized by the Smithsonian Institution and the International Life Sciences Institute of North America. Manila: International Rice Research Institute, 1992:95–9.
23. Buyckx M. The international community's commitment to combating micronutrient deficiencies. Food Nutr Agric 1993;7:2–7.

A conceptual framework for assessing agriculture–nutrition linkages

Lawrence Haddad

Abstract

The pathways through which agriculture affects nutrition are outlined. New evidence from the International Food Policy Research Institute (IFPRI) and the Consultative Group on International Agricultural Research (CGIAR) on specific linkages is reported. Two groupings of impacts of agriculture on nutrition are identified: specific (because food per se is being produced) and generic.

Specific effects include declines in food prices (to what extent do increases in food productivity lead to declines in food prices and better diets?), own-consumption (to what extent does the production of certain foods influence their consumption within the grower households and communities?), processing and preparation (how can nutrient losses be minimized?), and plant-breeding (what can be done to make specific foods more nutritious?).

Generic effects include income generation for those engaged in agriculture and those linked to it, time allocation effects (how compatible are work activities with time investments in nutrition?), impacts on household decision-making (does innovation in the sector draw influence away from nutrition decision makers?), energy and nutrient expenditures (for certain individuals, are more additional nutrients expended than generated?), and health environment effects of agricultural production.

The time is right for international agricultural research to review its potential for increasing its impact on malnutrition. First, micronutrient malnutrition cannot be overcome by food fortification and supplements alone. Second, international agricultural research is being put under increased pressure to demonstrate poverty reduction; improving nutrition reduces poverty. Third, agricultural policy makers and scientists will be placed under increased pressure to be more nutrition sensitive in the context of increasing overnutrition.

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Introduction

The contribution of the international agricultural research community to major increases in agricultural productivity and incomes in the developing world has been well documented [1–4]. The contribution of this community has been further credited with generating the increases in food production that have outpaced population growth and thus averted widespread food shortages [5]. Moreover, publicly funded agricultural research has been found to have an exceptionally high rate of economic return [6].

By way of income generation and food price reduction, it is clear that agricultural research has contributed to significant reductions in malnutrition. For example, a recent study by Smith and Haddad [7] found that increases in per capita food availability were responsible for nearly one-quarter of the decline in child undernutrition rates over the past 25 years. Food availability improved in no small part due to agricultural research, despite rapid population growth in developing countries and severe constraints to increased production through land expansion.

The question the participants at this conference must ask themselves is “Can agriculture—helped by agricultural research—do even more?”* The pessimistic view argues that agricultural research has its hands full in just helping farmers to grow more food. Incorporating nutritional concerns into the design of agricultural research is difficult. Moreover, the effort does not seem to have paid off in terms of improved nutrition outcomes. There are many non-food-related causes of malnutrition, and agriculture cannot be expected to address or even anticipate them. If nutritional concerns are to be incorporated, it should

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* This is not a new question to pose. Using data from urban Colombia, Pinstrup-Andersen [8] showed how research priorities by commodity would vary depending on the nutrition objective selected and on the cost assumption made. Several other conceptual articles on agriculture–nutrition linkages have been written over the years [9–12].

be done by the national agricultural research institutes in collaboration with national nutrition institutes. Few examples exist of successful efforts to get agriculture to be more nutrition sensitive.

The optimistic view argues that agriculture and nutrition are inexorably linked. The efforts of farmers and agricultural researchers should be guided primarily by nutritional concerns. Agricultural, nutritional, and communication experts can work together to address the multiple causes of malnutrition. There are many examples of how the incorporation of nutritional concerns into the design of agricultural research and agricultural interventions has positively influenced nutrition outcomes.

The truth lies somewhere between these two ends of the spectrum. The challenge for the participants at this workshop is to identify the ways an agricultural research design can be modified *ex ante* to enhance nutrition impact. This paper outlines the pathways through which agriculture is thought most likely to affect nutrition, bringing in some new evidence from the International Food Policy Research Institute (IFPRI) and the Consultative Group on International Agricultural Research (CGIAR) along the way. The paper identifies two groupings of impacts of agriculture on nutrition: generic and specific. Generic effects are not sector-specific: any sector that employs a large percentage of a malnourished population in a labour-intensive fashion will generate income and employment and would have such impacts. Specific effects are generated because food—not some other commodity—is being produced.

Agriculture–nutrition links

Specific effects include declines in food prices (to what extent do increases in food productivity lead to declines in food prices and better diets?), own-consumption (to what extent does the production of certain foods influence their consumption within the grower households and communities?), processing and preparation (how can nutrient losses be minimized?), and plant-breeding (what can be done to make specific foods more nutritious?).

Generic effects include income generation for those engaged in agriculture and those linked to it, time allocation effects (how compatible are work activities with time investments in nutrition?), impacts on household decision-making (does innovation in the sector draw influence away from nutrition decision makers?), energy and nutrient expenditures (for certain individuals, do the activities in the sector result in the use of more nutrients than they generate?), and health environment effects of agricultural production (how large are the negative effects on the health environment of the production processes in the sector?).

Specific effects

Impacts on food prices

Lower food staple prices generated by the Green Revolution have had a substantial beneficial impact in improving the food security of the poor. For example, in Bangladesh inflation-adjusted rice prices have fallen by 40% over the past 25 years. All other things being equal, lower rice prices not only allow greater rice consumption, but because expenditures for rice constitute a high proportion of total expenditures, lower rice prices also free up money for greater purchases of non-staple foods and non-food items. Unfortunately, productivity increases for non-staple foods in Bangladesh have not matched those for rice, so that the inflation-adjusted prices of most non-staple foods have risen considerably at the same time as cereal prices have fallen.* Lower cereal prices hurt net producers of cereals, but in general farmers have been more than compensated by increases in productivity, so that overall their incomes have risen [4].

In general, increased food production is good for urban consumers, because it will lead to lower food prices. As markets become increasingly liberalized and open and as transport costs are reduced, price formation depends less and less on local conditions. Hence in the developing countries that are better integrated into the international economy, the price effect of improved agricultural productivity is likely to be diminished. However, because the numbers of urban poor are increasing so rapidly, even small decreases in food prices will have large aggregate impacts [13].

Nevertheless, in many of the poorer countries—particularly the landlocked—transport costs remain very high, and many foods are considered non-tradable. In these situations local increases in production will lead to local decreases in price. Because the livelihood strategies of the rural poor are so complex, it is difficult to predict *ex ante* the total impact of increased food productivity on the poor [4].

Impact on food consumption from own-production

Does what people and their communities grow make a difference in what they and their communities eat? Three examples from recent IFPRI work show the possibilities and highlight the limitations. First, in urban Uganda, an IFPRI-UNICEF study found that pre-school children in families with non-commercial garden plots were much less stunted than their counterparts in families without gardens, after income, assets, education, and a host of other factors had been

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* Bouis H. Impacts of modern varieties of rice on poverty and food security. Paper presented at IRRI's 40th Anniversary Conference, Los Baños, Philippines, April 2000.

controlled for. These garden plots made the difference in the diets of the families [14]. In Bangladesh, Bouis et al. [15] found that innovations in vegetable technology did not result in a significant increase in vegetable consumption of adopting households. The direct impact of new fishpond technologies on diet quality was also negligible, although the fishpond technology will have had a positive impact on diet quality through modest increases in income (see the paper by Bouis [16] in this issue for more information). The latter two examples highlight the need for well-integrated nutrition education expertise if agricultural initiatives that are more nutrition-motivated are to succeed.

A large literature has grown up around the subject of food-based interventions for malnutrition reduction (particularly for the reduction of micronutrient malnutrition). In general, there is a relatively small set of documented interventions, few of which have been assessed in a rigorous way [17]. Some of the interventions show a lot of promise, particularly for vitamin A [18–20]. They share a number of characteristics: nutrition and health expertise in problem assessment and in related disease control (e.g., to control for *Ascaris* and hookworm infestation that affects absorption of nutrients), the utilization of new agricultural and horticultural technologies, a social marketing and nutrition education component, and attention to the institutional factors necessary for such partnerships to form and flourish. The outlook for fruits and vegetables as a way of combating iron deficiency is less positive [17], and for populations that cannot afford animal products and do not have the institutional structures to undertake daily iron supplementation, the options are rather limited [21].

Post-harvest activities and nutrient availability

There are many ways in which post-harvest activities can affect nutrient availability, including increasing the general use of nutrient-rich foods (e.g., β-carotene-rich varieties of sweet potato), increasing the nutrient density of foods consumed by infants, and decreasing nutrient losses from the processing of widely available foods.

Post-harvest activities include storage, commercial processing, in-home processing, and preparation. Food processing includes physical processes (e.g., heat or cold treatment, mechanical separation such as milling, and reduction of water activity), chemical processes (e.g., addition of acid, alkaline, oxidizing, or reducing agents), enzymatic processes (e.g., hydrolysis of proteins or inactivation of toxins), and biological processes (e.g., fermentation and germination) [22].

A good example of work that has the potential to increase the general use of nutrient-rich foods via processing is provided by the work of the Centro Internacional de la Papa (CIP) with sweet potatoes. A series of articles has been written that describe the technical and economic feasibility of deriving and using sweet potato chips and flours in chapati and bread processing, as well as consumer acceptability [23, 24]. The goal of this work is mainly to reduce the costs of production and the cost to the consumer. Sweet potatoes performed well along all of these dimensions. The successful application of such techniques to orange- and yellow-fleshed varieties that are richer in β-carotene has helped to generate a direct nutrition impact in Kenya [19]; see the paper by Hagenimana and Low [25] in this issue for more information).

More work on the nutritional impacts of processing and preparation has been undertaken in the context of complementary feeding. Complementary feeding marks the period during which other foods and liquids are provided to the infant along with breastmilk. Complementary feeding begins when exclusive breastfeeding stops, and it ends when the infant is fed exclusively with foods eaten by the rest of the family [22]. The processing of complementary foods involves cleaning, pounding, grinding, milling, drying, or roasting. Dry heat usually decreases the activity of antinutritional factors and destroys some pathogens, but overtreatment can destroy some vitamins. The extent to which agricultural research—as opposed to food technology research—can contribute to the improved nutrient composition of complementary foods is not clear.

Plant-breeding

This is perhaps the most direct approach to increasing the relevance of agricultural research to nutrition. Breeding maize for higher-quality proteins is an early example of the approach (see the paper by Vasal [26] in this issue for more information). Unfortunately the rapidly changing consensus in the nutrition community as to the limiting factors in the diet (from protein to calories and micronutrients) made the quality protein maize experience somewhat demoralizing for the plant-breeding community [9]. Despite this recent history, a new generation of plant-breeding efforts is now under way (see Welch and Graham [27] for a good summary). The focus this time is not on protein, but on micronutrients. There are three broad goals and two broad technologies. The three broad goals are to increase the micronutrient concentration in the crop, decrease the concentrations of absorption inhibitors such as phytic acid, and increase the concentration of promoter compounds (for iron and zinc in particular), such as sulphur-containing amino acids [28]. The two broad technologies are conventional breeding and use of biotechnology (see the papers in this issue by Bouis et al.[29] for more information on conventional breeding and by Datta and Bouis [30] for more information on the use of biotechnology).

Generic effects

Effects of increased agricultural productivity on income

Agriculture is an important sector in the poorest countries of the world, and for the poorest members of those countries. For countries with a per capita gross domestic product (GDP) below US$2,000 (at purchasing power parity, 1990), large percentages of the labour force remain employed in agriculture. Agriculture is not necessarily the main source of income for these workers and their families, but it does engage a large proportion of working men and women. As such, agriculture is an important source of income for those directly engaged in it. Moreover, as recent research has shown [31], increases in agricultural output lead to large second-round increases in the rural economy. These effects arise in the sectors that supply the agricultural sector with goods and services and via the demand from those rural non-farm sectors that need further goods from agriculture. In some cases, these second-round effects are larger than the initial growth in agricultural output.

These increases in income are important for nutrition, in that they enable people to purchase more non-foods and also a more diverse diet, and this tends to imply a greater dietary quality. Evidence from Bangladesh [32] shows how the consumption of micronutrients increases at a faster rate than calorie consumption as the incomes of poor rural households increase.

It is important not to equate increases in income with increases in nutrition, however. At the macro level, figure 1 shows the enormous range in underweight rates for similar levels of per capita gross national product (purchasing power parity) [7]. At the micro level, recent work reminds us that a large percentage of households that are above the poverty line have stunted children [33].

Changing time allocation patterns

Any activity undertaken by parents or child caretakers is a potential competitor for time devoted to the care of the child. The magnitude of the payoff in increased time for child care (primarily feeding and hygiene behaviours and interactions with the child) in terms of improved cognitive development and achievement is only now being appreciated by the wider development community [34]. Moreover, an increasing number of economic initiatives, such as public works projects and microfinance schemes, are looking for ways of making their activities compatible with the provision of care to young infants [35–37].

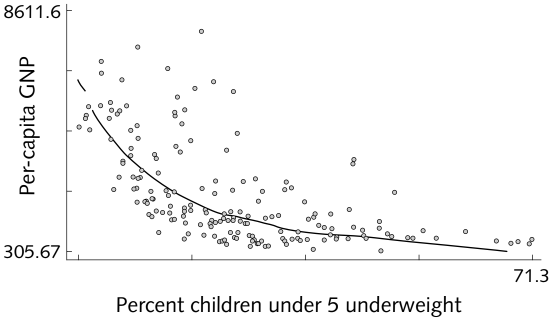

FIG. 1. Per capita gross national product (GNP) and nutrition are linked, but not tightly

Source: ref. 7

One example of the impact of improved care on preschooler weight-for-height is provided by Ruel et al. [38]. Their work in urban Ghana shows that—after a wide range of income and other socio-economic and health factors have been controlled for—children receiving a good level of care do much better in terms of growth rates than children who do not receive good levels of care. Moreover, the effect is even greater for children of women with less formal education.

The provision of care to children takes time, and non-work time is something that poor people have little of. Data from Brown and Haddad [39] show how heavy the time burdens are in poor populations, for both men and women. New technology or institutional arrangements—whether in agriculture or not—will probably affect time allocation patterns of caregivers in unforeseen ways. It is important to try to identify these effects *ex ante*. An example of an intervention that seemed to be able to do this is provided by Paolisso et al. [40]. They investigated the time allocation implications of the introduction of fruit and vegetable technology targeted to women in rural Nepal (the VFC programme). Women increased the amount of time they spent working on VFC crops, but unlike the case with cereals and livestock, they did not have to decrease the amount of time they spent on VFC crops when the number of pre-school children in the household increased. That is because the VFC crop activities were designed *ex ante* to be compatible with child-care responsibilities by being more home-based.

Changes in household decision-making

Household decisions are influenced by bargaining power and fall-back positions of individual family members [41]. Typically, men are seen as having more influence over such decisions than women; men and women often have very different priorities for how household income should be spent. These fall-back positions can be characterized as the economic or social power the individual has should household cooperation break down. These positions can be built up by having good networks, assets, property rights (private and common), employment possibilities, and access to savings and credit services. For example, female-owned assets have a much stronger impact on education priorities within the household than male-owned assets [42, 43]. We need to be aware of how innovations—whether or not they are agricultural—might affect such fall-back positions and therefore how they might affect decision-making within the household.

Impacts on nutrient requirements

A much-overlooked area of research is the impact of new technologies and activities on energy and nutrient expenditure. One of the few social-sciences studies on this subject is by Higgins and Alderman [44]. They asked the question: how does the level of activity in agriculture and nonagricultural activities affect the nutrition status of women in Ghana? They found that women's body mass index (a measure of thinness in adults) was negatively affected by agricultural work and positively affected by non-agricultural work. The significance of this result is magnified by new work linking poor female nutritional status with low birthweight, and by new work linking intrauterine stress to the likelihood of succumbing to diet-related chronic diseases in later life [45, 46].

Health impacts

Productive activities in any sector run the risk of having negative impacts on health. Agriculture is no different. Whether the impacts come from irrigation systems that affect the populations of malaria-carrying mosquitoes or the vectors of schistosomiasis, from the use of inorganic fertilizers that require direct handling for precision fertilization, or from the use of ever-increasing quantities of pesticides because of the build-up of resistance by insects, the dangers are there. For the most part, the international agricultural community is sensitive to these negative externalities and is busy working on methods of insect control and use of fertilizer and water that minimize such negative health impacts [47].

Challenges for the CGIAR

The previous sections of this paper have described the main pathways through which agriculture and nutrition are linked. Is the CGIAR doing enough via these links to enhance the nutritional impact of its work?

First, it is not clear from CGIAR documents how important malnutrition reduction is as a goal for the system. For example, the CGIAR's 1998 annual report [48] mentions malnutrition only twice, and the medium-term plans of the majority of the 16 centres do not mention malnutrition either, although most of them do list poverty and food insecurity as guiding principles for setting research priorities.

Second, a breakdown of CGIAR spending by region indicates that resource allocation does not match the location of undernutrition very well. For example, Asia has 70% of the stunted children in the world but receives 32% of CGIAR resources. Again, however, there may be factors that explain this apparent mismatch. For example, the national agricultural systems might be playing a much larger role in Asia than elsewhere, or perhaps the CGIAR's resource allocation reflects the trends in undernutrition (which are getting worse in sub-Saharan Africa and slowly better in Asia).

Third, a review of the composition of CGIAR resource allocation by commodity (fig. 2) is not very instructive. It is not clear, for example, that the nutritional impact of CGIAR spending would be enhanced by a move away from cereals to vegetables, fruit, and livestock, because of the indirect effects of agricultural productivity on nutritional status.

However, there are a number of indications that the time is right for international agricultural research to review its potential for increasing its impact on malnutrition via all the links outlined above, and that it may be able to have a larger than expected impact.

First, it is becoming clear that micronutrient malnutrition—a problem that affects billions of people and entails huge human costs and large economic costs (up to 5% of GDP by some estimates [49])—cannot be overcome by food fortification and capsule supplements alone. Agriculture and food-based approaches have to be part of a sustainable solution to the micronutrient problem, e.g., for low-weight women just before their child-bearing years [50]. Second, international agricultural research is being put under increased pressure to demonstrate poverty reduction, and we know that malnutrition affects the income-earning ability and economic productivity of both the current and the next generations. Third, in the next 5 to 15 years, agricultural policy makers and scientists will be placed under increased pressure to be more nutrition sensitive as the rates of overnutrition increase rapidly, particularly in Latin America and Asia [50].

There are many ways in which the CGIAR is responding as outlined above. Two areas in which a greater effort would probably have a high payoff are an increase in investments to enhance the productivity of micronutrient-rich non-staple foods if the real price of these

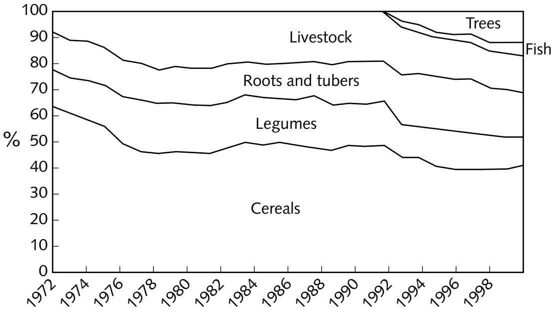

FIG. 2. Resource allocation within the CIGAR, by commodity.

Source: CGIAR Secretariat, Washington, D.C.

foods is increasing over time, as appears to be the case in Bangladesh; and consideration of additional investment in conventional plant-breeding efforts for improving the micronutrient density of staples in the diet of the poor. These efforts are likely to bear fruit 10 years ahead of transgenic work.

This issue highlights existing technologies that can improve the nutritional impacts of agriculture via some of the pathways identified above. The need and the demand for agriculture to play a greater role in promoting improved nutrition are demonstrable. The potential for it to do so is tantalizing.

References

1. Lipton M, Longhurst R. New seeds and poor people. Baltimore, Md, USA: Johns Hopkins University Press, 1989.
2. Walker T, Ryan J. Village and household economies in India's semi-arid tropics. Baltimore, Md, USA: Johns Hopkins University Press, 1991.
3. Hazell P, Ramasamy C. The Green Revolution reconsidered: the impact of high yielding rice varieties in South India. Baltimore, Md, USA: Johns Hopkins University Press, 1991.
4. Kerr J, Kolavalli S. Impact of agricultural research on poverty alleviation: conceptual framework with illustrations for the literature. Discussion Paper. Washington, DC: International Food Policy Research Institute, 1999.
5. Tribe D. Feeding and greening the world: The role of international agricultural research. Oxon, United Kingdom: CAB International in association with the Crawford Fund for International Agricultural Research, 1994.
6. Alston JM, Marra MC, Pardey PG, Wyatt TJ. Research returns redux: a meta-analysis of the returns to agricultural R&D. Environment and Production Technology Division Discussion Paper No. 38. Washington, DC: International Food Policy Research Institute, 1998.
7. Smith L, Haddad L. Explaining child malnutrition in developing countries: a cross-country analysis. Research Report 111. Washington, DC: International Food Policy Research Institute, 2000.
8. Pinstrup-Andersen P, Ruiz de Londono N, Hoover E. The impact of increasing food supply on human nutrition: implications for commodity priorities in agricultural research and policy. Am J Agric Econ 1976(May):131–42.
9. Tripp R. Does nutrition have a place in agricultural research? Food Policy 1990;15(6):467–74.
10. Pinstrup-Andersen P. 1990. Agricultural research and nutrition. Food Policy 1990;15(6):475–8.
11. Kennedy E, Bouis H. Linkages between agriculture and nutrition. Occasional paper. Washington, DC: International Food Policy Research Institute, 1993.
12. Mebrahtu S, Pelletier D, Pinstrup-Andersen P. Agriculture and nutrition. In: Pinstrup-Andersen P, Pelletier D, Alderman H, eds. Child growth and nutrition in developing countries: priorities for action. Ithaca, NY, USA: Cornell University Press, 1995:240–2.
13. Haddad L, Ruel M, Garrett J. Are urban poverty and undernutrition growing? Some assembled evidence. World Dev 1999;27:1891–904.
14. Maxwell D, Levin C, Csete J. Does urban agriculture help prevent malnutrition? Evidence from Kampala. Food Policy 1998;23:411–24.
15. Bouis H, de la Briere B, Guitierrez L, Hallman K, Hassan N, Hels O, Quabili W, Quisumbing A, Thilsted S, Zihad Z, Zohir S. Commercial vegetable and polyculture fish production in Bangladesh: impacts on income, household resource allocation and nutrition. Washington, DC: International Food Policy Research Institute, 1998.
16. Bouis HE. Improving human nutrition through agriculture: the role of international agricultural research. Conference summary and recommendations. Food Nutr Bull 2000;21:549–65.
17. Ruel M, Levin C. Assessing the potential for food-based strategies to reduce vitamin A and iron deficiencies: a review of recent evidence. Washington, DC: International Food Policy Research Institute, FCND Discussion Paper No. 92, July 2000.
18. Smitasiri S, Dhanamitta S. Sustaining behavior change to enhance micronutrient status: community- and women-based interventions in Thailand. OMNI Research Report Series No. 2. Washington, DC: International Center for Research on Women, 1999.
19. Hagenimana V, Anyango Oyunga M. The effects of women farmers' adoption of orange-fleshed sweet potatoes: raising vitamin A intake in Kenya. Research Report Series No. 3. Washington, DC: International Center for Research on Women, 1999.
20. Low J, Kinyae P, Guichuki S, Oyunga MA, Hagenimana V, Kabira J. Combating vitamin A deficiency through the use of sweet potato: results from phase 1 of an action and research project in South Nyanza, Kenya. Lima, Peru, and Nairobi, Kenya: Centro Internacional de la Papa and the Kenya Agricultural Research Institute, 1997.
21. Gillespie S. Major issues in developing effective approaches for the prevention and control of iron deficiency. Washington, DC: International Food Policy Research Institute, 1997.
22. World Health Organization. Complementary feeding of young children in developing countries: a review of current scientific knowledge. WHO/NUT/98.1. Geneva: WHO, 1998.
23. Hagenimana V, Owori C. Sweet potatoes in chapatis processing: feasibility and acceptability in rural areas. J Food Tech Afr 1997;2:4–8.
24. Hagenimana V, Owori C. Feasibility, acceptability, and production costs of sweet potato baked products in Lira Municipality, Uganda. APA Proceedings 1997:209–20.
25. Hagenimana V, Low J. Potential of orange-fleshed sweet potatoes for raising vitamin A intake in Africa. Food Nutr Bull 2000;21: 414–8.
26. Vasal SK. The quality protein maize story. Food Nutr Bull 2000;21:445–50.

27. Welch RM, Graham RD, eds. Sustainable field crop systems for enhancing human health: agricultural approaches to balanced micronutrient nutrition. Field Crops Res 1999;60(1-2):1–188.
28. Ruel M, Bouis H. Plant breeding: a long-term strategy for the control of zinc deficiency in vulnerable populations. Am J Clin Nutr 1998;68(2 suppl):488S–945S
29. Bouis HE, Graham RD, Welch R. The Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project: justification and objectives. Food Nutr Bull 2000;21:374–81.
30. Datta S, Bouis HE. Application of biotechnology to improving the nutritional quality of rice. Food Nutr Bull 2000;21:451–6.
31. Delgado CL, Hopkins J, Kelly V, with Hazell P, McKenna AA, Gruhn P, Hojjati B, Sil J, Courbois C. Agricultural growth linkages in sub-Saharan Africa. Research Report 107. Washington, DC: International Food Policy Research Institute, 1998.
32. Bouis H, Novenario-Reese M. The determinants of demand for micronutrients: an analysis of rural households in Bangladesh. Food Consumption and Nutrition Division Discussion Paper No. 32. Washington, DC: International Food Policy Research Institute, 1996.
33. Appleton S, Song L. Income and human development at the household level: evidence from six countries. Bath, UK: University of Bath, Economics Department, 1999.
34. Engle PL, Menon P, Haddad L. Care and nutrition: concepts and measurement. World Dev 1999;27:1309–37.
35. Colletta N, Reinhold AJ. Review of early childhood policy and programs in sub-Saharan Africa. World Bank Technical Paper No. 367. Africa Region Series. Washington, DC: World Bank, 1997.
36. Adato M, Haddad L, Horner D, Ravjee N, Haywood R. From works to public works: the performance of public works in Western Cape Province, South Africa. Washington, DC: International Food Policy Research Institute, 1999.
37. Zeller M, Sharma M. Rural finance and poverty alleviation. Food Policy Report. Washington, DC: International Food Policy Research Institute, 1998.
38. Ruel M, Levin C, Armar-Klemesu M, Maxwell D, Morris S. Good care practices can mitigate the negative effects of poverty and low maternal schooling on children's nutritional status: evidence from Accra. World Dev 1999; 11:1993–2009.
39. Brown L, Haddad L. Time allocation patterns and time burdens: a gendered analysis of seven countries. Washington, DC: International Food Policy Research Institute, 1995.
40. Paolisso M, Hallman K, Haddad L, Regmi S. Gender and cash crops in rural Nepal: labor responses within the household. College Park, Md, USA: University of Maryland, Department of Anthropology, 1999.
41. Haddad L, Hoddinott J, Alderman H, eds. Intrahousehold resource allocation in developing countries: models, methods, and policy. Baltimore, Md, USA: Johns Hopkins University Press, 1997.
42. Quisumbing A, Maluccio J. Intrahousehold allocation and gender relations: new empirical evidence. Washington, DC: International Food Policy Research Institute, 1999.
43. Doss C. The effects of women's bargaining power on household health and education outcomes: evidence from Ghana. Williamstown, Mass, USA: Williams College, Department of Economics Working Paper, 1997.
44. Higgins P, Alderman H. Labor and women's nutrition. The impact of work effort and fertility on nutritional status. J Hum Resources 1997;32:577–95.
45. Kramer MS. Socioeconomic determinants of intrauterine growth retardation. Eur J Clin Nutr 1998;52(S1):29–33.
46. Barker DJP. Mothers, babies, and disease in later life. 2nd ed. London: British Medical Journal Publishing, 1998.
47. Lipton M, de Kadt E. Agriculture–health linkages. Offset Publication No. 104. Geneva: World Health Organization, 1988.
48. CGIAR (Consultative Group on International Agricultural Research). CGIAR Micronutrients Project Newsletter. Update No. 3. Washington, DC: International Food Policy Research Institute, October 1998.
49. Horton S. Opportunities for investments in nutrition in low-income Asia. Asian Dev Rev 1999;17.
50. Gillespie S, Haddad L. Eradicating malnutrition in Asia and the Pacific by 2020. Washington, DC: International Food Policy Research Institute, 2000.

The Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project: Justification and objectives

Howarth E. Bouis, Robin D. Graham, and Ross M. Welch

Abstract

The general objective of the Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project is to assemble the package of tools that plant breeders will need to produce mineral- and vitamin-dense cultivars. The target crops are rice, wheat, maize, phaseolus beans, and cassava. The target micronutrients are iron, zinc, and vitamin A. The combining of benefits for human nutrition and agricultural productivity, resulting from breeding staple food crops that are more efficient in the uptake of trace minerals from the soil and that load more trace minerals into their seeds, results in extremely high ex ante *estimates of benefit–cost ratios for investments in agricultural research in this area. This finding derives from the confluence of several complementary factors. The rates of micronutrient malnutrition are high, as are the consequent costs to human welfare and economic productivity. High trace mineral density in seeds produces more viable and vigorous seedlings, and efficiency in the uptake of trace minerals improves disease resistance. Trace-mineral-"deficient" soils in fact contain high amounts of trace minerals that are "unavailable" to staple crop varieties presently grown. Adoption of nutritionally improved varieties by farmers can rely on profit incentives; delivery to consumers can rely on existing demand behaviour. Relatively small investments in agricultural research at a central research location may be disseminated widely. Breeding advances are derived from initial, fixed costs, with low recurring costs. The encouraging research results obtained to date under the project would seem to justify a much expanded effort in the future.*

Introduction

Taken together, mineral and vitamin deficiencies affect a greater number of people in the world than does protein–energy malnutrition. In treating iron deficiency in developing countries, Yip [1] argued that if prevalence rates are above 25%, the best approach is to develop programmes to improve the iron status of the entire population. In such situations, which for pre-schoolers and women in developing countries are the rule rather than the exception, this is cheaper than screening for iron-deficient individuals. By increasing the iron content of food staples through plant-breeding, the entire iron-status distribution curve can be shifted to the right, so that targeting a subsequently smaller group of iron-deficient persons could become feasible.

An underlying cause of and fundamental constraint on solution of the micronutrient problem is that non-staple foods, particularly animal products, tend to be the foods richest in bioavailable micronutrients, which the poor in many developing countries desire to eat, but cannot afford. Their diets consist mostly of staple foods, primarily cereals; in fact, per capita direct consumption of staple foods in the aggregate varies little according to income level. For the poor, these staple foods are already primary sources of what micronutrients they are able to consume, particularly minerals.

By breeding staple crop genotypes that load high amounts of minerals and vitamins into their seeds, the plant-breeding strategy seeks to develop staple food crops that, in some sense, fortify themselves. The strategy of breeding for mineral and vitamin enhancement of staple foods has several complementary advantages. No behavioural change on the part of consumers is required. Indeed, the strategy seeks to take advantage of the consistent daily consumption of large amounts of food staples by all family members

Because trace minerals are important not only for human nutrition, but for plant nutrition as well, plant-breeding holds great promise for making a significant, low-cost, and sustainable contribution to reducing micronutrient and mineral deficiencies

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in both humans and crops, and for increasing farm productivity in developing countries in a way that is environmentally beneficial [2–4]. Mineral-packed seeds sell themselves to farmers because, as recent research has shown, these trace minerals are essential in early establishment, in helping plants resist disease, and for the development of deep roots for semiarid conditions [5]. Because of their more efficient uptake of existing trace minerals, these varieties require fewer chemical inputs. Thus, the new seeds can be expected to be environmentally beneficial as well. After the one-time investment is made to develop seeds that fortify themselves, there are low recurrent costs; the costs of supplementation, fortification, and nutrition education remain constant year after year.

With the above as motivation (arguments that are developed in more detail in the following sections of this paper), the Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project was initiated in 1995. The general objective has been to assemble the package of tools that plant breeders will need to produce mineral- and vitamin-dense cultivars. The target crops are wheat, rice, maize, phaseolus beans, and cassava. The target micronutrients being studied are iron, zinc, and vitamin A. For these crops and nutrients, this project is conceived as a pre-breeding study to determine the range of genetic variability available for exploitation by future breeding programmes; the bioavailability of the micronutrients contained in the grain (or seeds or other storage tissue) of the best selections; the genetics, physiology, and biochemistry of the selected traits; and screening protocols for use in subsequent breeding programmes.

The International Food Policy Research Institute (IFPRI) has taken the lead in coordinating the research activities of six partner institutions: the International Center for Tropical Agriculture (CIAT) in Colombia, the International Center for Maize and Wheat Improvement (CIMMYT) in Mexico, and the International Rice Research Institute (IRRI) in the Philippines, within the CGIAR, the Waite Agricultural Research Institute at the University of Adelaide, Australia, and two laboratories of the US Department of Agriculture–Agricultural Research Service (USDA-ARS): the Plant, Soil, and Nutrition Laboratory at Cornell University and the Western Human Nutrition Research Center at the University of California at Davis.

Can a breeding strategy work? Five key questions

A strategy of breeding plants that enrich themselves by loading high amounts of minerals and vitamins into their edible parts has the potential for substantially reducing the recurrent costs that are associated with other strategies, such as fortification and supplementation. However, this approach will be successful only if farmers are willing to adopt such varieties, if the edible parts of these varieties are palatable and acceptable to consumers, and if the incorporated micronutrients can be absorbed by the human body. In examining the feasibility of a plant-breeding strategy, it was imperative to address five core questions.

Is it scientifically feasible to alter the micronutrient density of seeds?

At least three cases of agricultural research projects in developed countries have successfully manipulated the efficiency of mineral uptake of plants or the mineral content of plant seeds, and all have been commercially successful. Zinc-efficient wheat varieties have been developed at the Waite Agricultural Research Institute of the University of Adelaide and are already being grown on a commercial basis in Australia [6]. In the United States, an iron-efficient soya bean has been developed to overcome problems of iron-”deficient” soils, and cadmium levels in durum wheats have been reduced through plant-breeding to meet quality standards in countries importing US wheat. The potential to increase the micronutrient density of staple foods by plant-breeding was reviewed by Graham et al. [7].

What effect will breeding for micronutrient-dense seeds have on plant yields? Will farmers adopt such varieties?

Results from research at Waite and elsewhere had shown that where the soil is deficient in a particular micronutrient, seeds containing more of that nutrient have better germination, better seedling vigour, and/or more resistance to infection during the vulnerable seedling stage [8, 9]. These benefits to crop establishment can result in higher crop yield. Thus, for some elements and agronomic settings, the specific breeding goals for human and plant nutrition largely coincide. There is the expectation, therefore, that the new cultivars with higher contents of micronutrients will have an agronomic advantage to ensure they are competitive in the market place.

A soil is said to be “deficient” in a nutrient when addition of fertilizer containing that nutrient produces better growth. On the basis of a number of soil surveys, particularly in China where the most extensive surveys have been done, it can be estimated that at least 50% of the arable land used for crop production worldwide is low in the availability of one or more of the essential micronutrients.

Zinc deficiency is probably the most widespread micronutrient deficiency in cereals. Sillanpää [10] found that 49% of a global sample of 190 soils in 25 countries were low in zinc. Unlike other micronutrients, zinc deficiency is a common feature of both cold and warm climates, drained and flooded soils, acid and alkaline soils, and heavy and light soils [11].

However, the amount of a mineral micronutrient that is added to a soil to produce better growth is usually small compared with the total amount of that mineral already found in the soil. This is because the major part of the trace mineral in the soil is chemically bound to other elements in the soil and is unavailable to plants. For example, although iron is the fifth most abundant element in the earth's crust, the fraction of soil iron that is in soluble form for absorption by plants may only be 10^{-13} of the total soil iron. Thus, depletion of soil iron is never an issue; instead, the issue is the ability of the plant to mobilize sufficient iron to satisfy its needs [12].

In contrast to the extraction of macronutrients from soil, the depletion of mineral micronutrients may take hundreds or thousands of years or may never occur at all, because of various inadvertent additions and other processes, such as the carrying of minerals in wind-blown dust [13]. An alternative view of plant micronutrient deficiencies, therefore, is that there is a genetic deficiency in the plant, rather than a deficiency in the soil.

Tolerance to micronutrient-deficient soils, termed *micronutrient efficiency*, is a genetic trait of a genotype that causes it to be better adapted to, or to yield more in, a micronutrient-deficient soil than can an average cultivar of the species [14]. Growing zinc-efficient plants on zinc-deficient soils, for example, represents a strategy of "tailoring the plant to fit the soil," in contrast with the alternative strategy of "tailoring the soil to fit the plant" [15]. One mechanism of micronutrient efficiency is the exudation of substances from their roots that chemically unbind trace minerals from other binding elements and so make the trace minerals available to the plant. Mycorrhyzae might also participate in the acquisition of micronutrients. There is substantial genetic variability in the efficiency of uptake of mineral micronutrients from deficient soils and in nutrient loading into seeds.

By far the most extensive survey of efficiency factors has been carried out at the International Rice Research Institute by Ponnamperuma [16]. Over a period of 10 years, some 80,000 lines from the world collection were screened for types tolerant of a number of soil stresses, including micronutrient deficiencies. Tolerant types gave a yield advantage of about two tons per hectare under any of seven different soil limitations. Ponnamperuma noted that zinc deficiency was widespread in wet rice and iron deficiency in dry-land rice.

Micronutrient efficiency can be controlled by major, single-gene inheritance. The concentration and content of mineral micronutrients in seeds are the result of transport via living tissues (the phloem) from vegetative parts of the plant. Thus, seed density depends both on the micronutrient density of vegetative tissues and on the efficiency of the transport process itself. Both can be under genetic control, but there is considerable homeostasis built into the transport process, so that even when the soil and the vegetative plant are high in micronutrients, the levels in the seed are always relatively low. The average genetic variation in micronutrient density is probably of the order of a factor of three, whereas their vegetative parts may vary perhaps one hundred times more than that.

Linkage of zinc efficiency to other efficiency traits (for example, manganese efficiency) is poor, suggesting independent mechanisms and genetic control not linked to gross root-system geometry. Plants with zinc-efficient genotypes absorb more zinc from deficient soils and produce more dry matter and more grain yield, but do not necessarily have the highest zinc concentrations in tissue or grain. Although high zinc concentration in the grain also appears to be under genetic control, it is not tightly linked to agronomic zinc efficiency traits and may have to be selected for independently.

Good nutrition balance is as important to disease resistance in plants as it is in humans. Efficiency in the uptake of mineral micronutrients from the soil is associated with disease resistance in plants, which leads to decreased use of fungicides. Micronutrient deficiency in plants greatly increases their susceptibility to diseases, especially fungal root diseases of the major food crops. The picture emerging from physiological studies of roots conducted over four decades is that phosphorus, zinc, boron, calcium, and manganese are all required in the *external environment* of the root for membrane function and cell integrity, to minimize leaking of cell contents such as sugars, amides, and amino acids. These substances are chemotactic stimuli to pathogenic organisms. It appears that micronutrient deficiency predisposes the plant to infection, rather than that the infection causes the deficiency through its effect on root pruning [17, 18]. Breeding for micronutrient efficiency can confer resistance to root diseases that had previously been unattainable. This means a lower dependence on fungicides, where they are already being used.

Compared with other varieties, micronutrient-efficient varieties grow deeper roots in mineral-deficient soils and are better at tapping subsoil water and minerals [19, 20]. When topsoil dries, the roots in the dry soil zone (which are the easiest to fertilize) are largely deactivated, and the plant must rely on deeper roots for further nutrition. The roots of plants with genotypes that are efficient in mobilizing the surrounding external minerals not only are more disease resistant, but also are better able to penetrate deficient subsoils and so make use of the moisture and minerals contained in subsoils. This reduces the need for fertilizers and irrigation. Plants with deeper root systems are more drought resistant.

Micronutrient-dense seeds are associated with greater seedling vigour, which, in turn, is associated with higher plant yield. An important function of the seed is to supply the young seedling with minerals until it has developed a root system large enough to take over this role, but in nutrient-poor soils, the seed reserves may be insufficient to last until the extra roots are developed to compensate for the low mineral supply. The result is a transient and critical period of deficiency when the seedling is particularly vulnerable. Pathogens and weeds may gain an advantage not otherwise given, so that the plants never regain lost potential.

Will breeding for micronutrient-dense seeds change the processing or consumer characteristics of staple foods?

Mineral micronutrients comprise a tiny fraction of the physical mass of a seed, perhaps 10 parts per million in the case of cereals. Dense seeds may contain perhaps as many as 50 parts per million. Legumes have higher levels and may attain levels of 100 parts per million or more. It is not expected that such small amounts will alter the appearance, taste, texture, or cooking quality of foods.

Increasing the seed content of β-carotene, which is associated with an orange or yellow colour, will alter its colour, which might well reduce consumer preference. However, nutrition education could turn this obstacle to an advantage, as consumers could be taught that deepness of colour is visually representative of a nutrient-dense product.

Will micronutrient intakes be increased to a significant degree? To what extent will the extra micronutrients in staple foods consumed be bioavailable?

As stated above, an underlying cause of and fundamental constraint on solution of the micronutrient malnutrition problem is that non-staple foods, particularly animal products, tend to be the foods richest in bioavailable micronutrients, which the poor in developing countries cannot afford. For the poor, staple foods are already primary sources of what micronutrients they are able to consume, particularly minerals.

A strength of a plant-breeding approach that focuses on food staples, then, is that it relies on existing consumer behaviour. The poor consume large amounts of food staples on a daily basis. This is demonstrated by food-intake data shown in table 1 for survey populations in Bangladesh and the Philippines. The average per capita yearly incomes in these countries range from US$45 in the poorest 20% of households to US$250 in the richest. Thus, they are typical of the middle to lower end of the income distribution in rural areas of these countries. In spite of the fact that staples are non-dense mineral sources with significant antinutrient content, food staples so dominate their diets that they provide from 40% to 55% of the total iron intakes in lower-income households. If a high proportion of the domestic production of food staples can be provided by nutritionally improved varieties, nutritional status can be improved without resort to programmes that depend on behavioural change.*

If a single food staple (such as rice in Bangladesh) provides 50% of the total iron intake in a poor population, a doubling of the iron density in that staple will

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* Likewise, no behavioural change is required of farmers, if nutritionally improved varieties have unique agronomic advantages on trace-mineral-deficient soils, or if these traits are incorporated into highly profitable varieties. Profits then motivate farmers to adopt and produce these nutritionally improved varieties.

TABLE 1. Percent contributions of different food groups to household food expenditure, calorie intake, and iron intake for survey populations in Bangladesh and the Philippines

	Poorest 20% of households		Richest 20% of households		Average for all households	
Food group	Bangladesh	Philippines	Bangladesh	Philippines	Bangladesh	Philippines
% of food expenditure						
Rice, wheat, maize	69	45	54	24	62	33
Meat, fish	9	28	19	39	14	32
Other foods	22	27	27	37	24	35
% of calorie intake						
Rice, wheat	87	84	81	70	84	79
Meat, fish	1	4	4	10	2	6
Other foods	12	12	15	20	13	15
% of iron intake						
Rice, wheat	55	43	43	30	51	36
Meat, fish	3	18	6	36	5	25
Other foods	42	40	52	34	45	39

Source: refs. 21 and 22.

result in a 50% increase in total iron intake, and a tripling of the iron density will mean a doubling of total iron intake.

Iron-deficiency anaemia is widespread among adult women in developing countries. For the lower-income households in table 1, iron intakes for women range from 50% to 75% of the recommended daily allowances. Despite the well-known difficulties of determining useful benchmarks for recommended daily allowances of iron, it would seem evident that a 50% increase in the intake of bioavailable iron would be of considerable benefit to anaemic women with such low iron intakes. Nevertheless, human studies still need to be undertaken to measure the effects of increased iron (or zinc) density in food staples on iron (or zinc) status and consequent improvements in health and productivity.

A key issue is whether the percent bioavailability of total iron (or zinc) intakes will remain constant or decline. The Food and Agriculture Organization/World Health Organization (FAO/WHO) recommend that people who obtain less than 10% of their calories from animal foods need more iron, because perhaps only 5% of total intake is absorbed. There is no reason to think that the degree of absorption of additional iron would be lower than the present rate of absorption. For example, rat studies suggest that the percentage of bioavailable iron (and zinc) remains relatively constant across cereal and bean genotypes with high and low density (see Welch et al. [23] in this issue).

A second key issue is the range of genetic diversity in iron (or zinc) density that can be identified for use in breeding programmes, which will determine the maximum level to which trace mineral density can be increased. Germplasm screening under the CGIAR Micronutrients Project suggests that the trace mineral contents of cereals can be at least doubled, as compared with those of commonly eaten cereal genotypes. This would increase the iron intakes of the populations surveyed in table 1 by about 50%.

Similar arguments apply to those staples in which provitamin A content may be enriched by plant-breeding (wheat, maize, and cassava, for example). Some differences apply, however, as compared with trace minerals. First, no agronomic advantages accrue to higher provitamin A content, so that high density will need to be bred into varieties that are otherwise high-yielding. Second, the colour of the final food product may change so that consumers may need to be educated as to the improved nutritional content, although if education programmes are successful, the colour change becomes an advantage in that it identifies those particular varieties of superior nutritional quality.

A breeding strategy of lowering the level of inhibiting substances (antinutrients) such as phytates in the grain has often been suggested as a way to increase the bioavailability of minerals already consumed. Phytin is the primary storage form of phosphorus in most mature seeds and grains and is an important compound required for early seed germination and seedling growth [24, 25]. Phytin plays an important role in determining the mineral reserves of seeds and, thus, contributes to the viability and vigour of the seedling produced [26]. Selecting for seed and grain crops with substantially lower phytin content could have an unacceptable effect on production, especially in regions of the world with soils of low phosphorus status, poor micronutrient fertility, or both [27].

Such attempts to significantly lower the antinutrient content of seeds and grains require a major shift in seed or grain composition. Because most of the antinutrients known to occur in seeds and grains are major organic constituents of these organs, they may play additional, as yet unrecognized, beneficial roles in plant growth and human health. Therefore, a breeding strategy of attempting to increase iron bioavailability by reducing antinutrient content is not recommended [27].

Certain amino acids (cysteine and lysine, but particularly methionine) enhance iron and/or zinc bioavailability [28]. These amino acids occur in many staple foods, but their concentrations are lower than those found in meat products. A modest increase in the concentrations of these amino acids in plant foods might have a positive effect on iron and zinc bioavailability in humans. Iron and zinc occur only in micromolar amounts in plant foods, so only micromolar increases in the amounts of these amino acids may be required to compensate for the negative effects of antinutrients on iron and zinc bioavailability. These amino acids are essential nutrients for plants as well as for humans, so relatively small increases in their concentrations in plant tissues should not have adverse consequences on plant growth. The optimal breeding strategy from the point of view of bioavailability may be to increase the levels of promoter compounds [27].

Are there other lower-cost, more easily sustainable strategies for reducing micronutrient malnutrition?

A plant-breeding strategy, if successful, will not eliminate the need for supplementation, fortification, and dietary diversification programmes in the future. Nevertheless, this strategy does hold promise for significantly reducing recurrent expenditures required for these higher-cost, short-run programmes by significantly reducing the numbers of people requiring treatment.

Costs of plant-breeding

To obtain a rough estimate of plant-breeding costs, the example of the CGIAR Micronutrients Project may be used. This project is a multidisciplinary effort among plant scientists, human nutritionists, and social scientists. The general objective over five years is to assemble the package of tools that plant breeders will need to produce mineral- and vitamin-dense cultivars. The target crops are wheat, rice, maize, phaseolus beans, and cassava. The target micronutrients being studied are iron, zinc, and vitamin A.

The plant-breeding effort can be seen as a two-stage process. The first five-year phase primarily involves research at central agricultural research stations, at an estimated US$2 million per year for research on all five crops. During this initial phase, promising germplasm is identified, and the general breeding techniques are developed for later adaptive breeding.

During the second phase, the research needs to shift to national agricultural research. The total costs and duration of this second phase are difficult to estimate but will depend on the number of countries involved and the number of crops worked on in each country. The annual cost for each country should not be more than the US$2 million per year estimated for the first phase.

Benefits to human nutrition

The World Bank [29] estimates that at the levels of micronutrient malnutrition existing in South Asia, 5% of the gross national product is lost each year because of deficiencies in the intakes of just three nutrients: iron, vitamin A, and iodine. For a hypothetical country of 50 million people burdened with this rate of malnutrition, deficiencies in these three nutrients could be eliminated through fortification programmes costing a total of US$25 million annually, or 50 cents per person per year. The monetary benefit of this US$25 million investment is quite high in terms of increased productivity; it is estimated to be US$20 per person per year, or a fortyfold return on an investment of 50 cents. These benchmark numbers will be used below as a basis of comparison with the benefits of a plant-breeding strategy.

Calculation of benefit–cost ratios

The details of a formal benefit–cost analysis of a breeding strategy are presented in Bouis [30]. Expressed in present values, the costs are about US$13 million and the benefits US$274 million, giving a benefit–cost ratio of over 20, which is quite favourable, despite the very conservative assumptions made and the long time lag between investments and benefits.

This last point highlights an essential difference between investments in standard fortification programmes and fortification through plant-breeding strategies. Standard fortification programmes must be sustained at the same level of funding year after year. If investments are not sustained, the benefits disappear. Such investments apply to a single geographical area such as a nation-state. By contrast, investments in research in plant-breeding have multiplicative effects: the benefits may accrue to a number of countries. Moreover, the benefits are sustainable: the benefits from breeding advances typically do not disappear after initial investments and research are successful, as long as an effective domestic agricultural research infrastructure is maintained.

Conclusions

The time is long overdue for involving agricultural research directly in the fight against micronutrient malnutrition. Because trace minerals are important not only for human nutrition but also for plant nutrition, plant-breeding holds great promise for making a significant, low-cost, and sustainable contribution to reducing deficiencies of micronutrients, particularly of minerals, in humans and may have important spin-off effects in increasing farm productivity in developing countries in a way that is environmentally beneficial.

The results so far obtained under the CGIAR Micronutrients Project indicate that the breeding parameters are not difficult and are highly likely to be low cost. The following points are seminal:

- Adequate genetic variation in concentrations of β-carotene, other functional carotenoids, iron, zinc, and other minerals exists in the major germplasm banks to justify selection.
- Micronutrient-density traits are stable across environments.
- In all crops studied, it is possible to combine the high micronutrient-density trait with high yield, unlike protein content and yield, which are negatively correlated.
- Genetic control is simple enough to make breeding economical.
- It will be possible to improve the content of several limiting micronutrients together, thus pushing populations towards nutritional balance.
- In elite breeding lines, the bioavailability of the extra nutrient is high for rats and, when the density is high enough for the test, also for human colon cell lines. Tests on human populations are now a high priority.

Moreover, from a broader perspective of food and human nutrition systems, the combining of benefits to human nutrition and agricultural productivity, resulting from breeding staple food crops that are more efficient in the uptake of trace minerals from the soil and that load more trace minerals into their seeds, results in extremely high *ex ante* estimates of benefit–costs ratios for investments in agricultural research in this area. This finding derives from the confluence of several complementary factors:

- » The rates of micronutrient malnutrition are high in developing countries, as are the consequent costs to human welfare and economic productivity.
- » High trace mineral density in seeds produces more viable and vigorous seedlings in the next generation, and efficiency in the uptake of trace minerals improves disease resistance, agronomic characteristics that improve plant nutrition and productivity in trace-mineral-“deficient” soils.
- » A significant percentage of the soils in which staple foods are grown are “deficient” in these trace minerals, which has kept crop yields low. In general, these soils in fact contain high amounts of trace minerals. However, because of chemical binding to other compounds, these trace minerals are unavailable to staple crop varieties presently used.
- » The adoption of nutritionally improved varieties by farmers can rely on profit incentives, either because of agronomic advantages on trace-mineral-deficient soils or incorporation of nutritional improvements in the most profitable varieties being released.
- » Because staple foods are eaten in large quantities every day by the malnourished poor, the delivery of enriched staple foods (fortified by the plants themselves during growth) can rely on existing consumer behaviour.
- » The benefits from relatively small investments in agricultural research may be disseminated widely, potentially accruing to hundreds of millions of people and millions of acres of croplands.
- » Breeding advances are derived from initial, fixed costs, with low recurring costs, and thus tend to be highly sustainable as long as an effective domestic agricultural research infrastructure is maintained.

A plant-breeding strategy, if successful, will not eliminate the need for supplementation, fortification, dietary-diversification, and disease-reduction programmes in the future to combat micronutrient malnutrition. Nevertheless, this strategy holds great promise for significantly reducing recurrent expenditures required for these higher-cost, short-run programmes by significantly reducing the numbers of people requiring treatment. Cost is not a key issue in the decision to pursue a plant-breeding strategy to improve human nutrition. A relatively modest level of resources is required, and the potential payoff is quite high.

References

1. Yip R. Iron deficiency: contemporary scientific issues and international programmatic approaches. J Nutr 1994;124:1479S–90S.
2. Cary EE, Norvell WA, Grunes DL, Welch RM, Reid WS. Iron and manganese accumulation by the *brz* pea mutant grown in soils. Agronomy J 1994;86:938–41.
3. Kannenberg LW, Falk DE. Models for activation of plant genetic resources for crop breeding programs. Can J Plant Sci 1995;75:45–53.
4. Welch RM, Smith ME, Van Campen DR, Schaefer SC. Improving the mineral reserves and protein quality of maize kernels using unique genes. Plant Soil 1993;171:155–6.
5. Welch RM. Importance of seed mineral nutrient reserves in crop growth and development. In: Rengel Z, ed. Mineral nutrition of crops: fundamental mechanisms and implications. New York: Food Products Press, 1999:205–26.
6. Graham RD, Ascher JS, Hynes SC. Selecting zinc-efficient cereal genotypes for soils of low zinc status. Plant Soil 1992;146:241–50.
7. Graham RD, Senadhira D, Beebe SE, Iglesias C, Ortiz-Monasterio I. Breeding for micronutrient density in edible portions of staple food crops: conventional approaches. Field Crop Res 1999;60:57–80.
8. Genc Y, McDonald GK, Graham RD. Effect of seed zinc content on early growth of barley (*Hordeum vulgare* L.) under low and adequate soil zinc supply. Aust J Agric Sci 2000;51:37–46.
9. McCay Buis TS, Huber DM, Graham RD, Phillips JD, Miskin KE. Manganese seed content and take-all of cereals. J Plant Nutr 1995;18:1711–21.
10. Sillanpää M. Micronutrient assessment at the country level: an international study. In: FAO Soils Bulletin 48. Rome: Food and Agriculture Organization, 1990: 1–208.
11. Rahman S, Vance GF, Munn LC. Salinity induced effects on the nutrient status of soil, corn leaves, and kernels. Commun Soil Sci Plant Anal 1993;24:17–8.
12. Han ZH, Wang Q, Shen T. Comparison of some physiological and biochemical characteristics between iron-efficient and iron-inefficient species in the genus *Malus*. J Plant Nutr 1994;17:1257–64.
13. Graham RD. Breeding wheats for tolerance to micronutrient deficient soil: present status and priorities. In: Saunders DA, ed. Wheat for the nontraditional warm areas. Mexico City: Centro Internacional de Mejoramiento de Maiz y Trigo, 1991:315–32
14. Graham RD, Rovira AD. A role for manganese in the resistance of wheat to take-all. Plant Soil 1984;78:441–4.
15. Foy CD. Plant adaptation to mineral stress in problem soils. Iowa State J Res 1983;57:355–91.
16. Ponnamperuma FN. Genotypic adaptability as a substitute for amendments on toxic and nutrient-deficient soils. In: Seife A, ed. Plant nutrition. Proceedings of the Ninth International Plant Nutrition Colloquium. Slough, UK: Commonwealth Agricultural Bureau, 1982:467–73.
17. Sparrow DH, Graham RD. Susceptibility of zinc-deficient wheat plants to colonization by *Fusarium graminearum* Schw. Group 1. Plant Soil 1988;112:261–6.
18. Thongbai P, Hannam RJ, Graham RD, Webb MJ. Zinc nutrition and rhizoctoria root rot of cereals. Plant Soil 1993;153:207–14.
19. Grubb PJ. Root competition in soils of different fertility: a paradox resolved? Phytocoenologia 1994;24:495–505.

20. Brown PH, Zhang Q, Ferguson L. Influence of rootstock on nutrient acquisition by pistachio. J Plant Nutr 1994; 17:1137–48.
21. Bouis HE, Haddad LJ. Agricultural commercialization, nutrition, and the rural poor: a study of Philippine farm households. Boulder, Colo, USA: Lynne Rienner Publishers, 1990.
22. Bouis HE, Novenario-Reese MJ. The determinants of demand for micronutrients: an analysis of rural households in Bangladesh. Food Consumption and Nutrition Division Discussion Paper No. 32. Washington, DC: International Food Policy Research Institute, 1997.
23. Welch RM, House WA, Beebe S, Senadhira D, Gregorio GB, Cheng Z. Testing iron and zinc bioavailability in genetically enriched beans (*Phaseolus vulgaris* L.) and rice (*Oryza sativa* L.) in a rat model. Food Nutr Bull 2000;21:428–33.
24. Welch RM. Effects of nutrient deficiencies on seed production and quality. Adv Plant Nutr 1986;2:205–47.
25. Wise A. Phytate and zinc bioavailability. Int J Food Sci Nutr 1995;46:53–63.
26. Welch RM. Zinc concentrations and forms in plants for humans and animals. In: Robson AD, ed. Zinc in soils and plants. Boston, Mass, USA, and London: Kluwer Academic Publishers, 1993:183–95.
27. Graham RD, Welch RM. Breeding for staple-food crops with high micronutrient density: long-term sustainable agricultural solutions to hidden hunger in developing countries. Agricultural Strategies for Micronutrients Working Paper No. 3. Washington, DC: International Food Policy Research Institute, 1996.
28. Hallberg L. Bioavailability of dietary iron in man. Annu Rev Nutr 1981;1:123–7.
29. World Bank. Enriching lives: overcoming vitamin and mineral malnutrition in developing countries. Development in Practice Series. Washington, DC: World Bank, 1994.
30. Bouis HE. Economics of enhanced micronutrient density in food staples. Field Crops Res 1999;60:165–73.

Breeding for trace mineral density in rice

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Abstract

In 1992 the International Rice Research Institute (IRRI) began to examine the effect of certain soil characteristics on the iron content of rice grains. As part of the Consultative Group for International Agricultural Research (CGIAR) Micronutrients Project, this effort was expanded in 1995 to include analysis of both iron and zinc, in collaboration with the University of Adelaide in Australia. Since then, germplasm screening has shown large genetic variation for iron and zinc concentrations in brown rice. Common cultivars contain about 12 mg of iron and 25 mg of zinc per kilogram. Some traditional varieties have double these amounts. Genetic-by-environmental interactions are sufficiently moderate that breeding for higher iron and zinc content is considered worthwhile. The next major research step will be to further study the genetics of trace mineral accumulation in the grain to determine the best selection techniques for use in breeding. High iron and zinc traits can be combined with improved agronomic traits. This has already been demonstrated in the serendipitous discovery in the IRRI testing programme of an aromatic variety (IR68144-3B-2-2-3) that has a high concentration of grain iron, about 21 mg/kg in brown rice. This elite line has good tolerance to rice tungro virus and to mineral-deficient soils and has excellent grain qualities. The yields are about 10% below those of IR72, but in partial compensation, maturity is earlier. After 15 minutes of polishing, IR68144-4B-2-2-3 had about 80% more iron than IR64, a widely grown commercial variety. It remains to be shown that this extra iron can improve the iron status of iron-deficient human subjects. A human feeding trial is being planned.

Introduction

Other than efforts in the 1960s and 1970s to improve the protein content of rice, there has been little research at the International Rice Research Institute (IRRI) to improve the nutritive value of rice. Research priorities for improving grain quality discussed and recommended at the international rice research conferences held in 1985 and 1990 did not mention nutritive values, but emphasized milling, cooking, and eating qualities as high-priority research items [1, 2]. This was possibly because of IRRI's experience with protein content, for which breeding efforts were not successful. However, rice is the cereal lowest in iron, often containing only 5 or 6 mg of iron per kilogram (parts per million [ppm]) after milling. There appears from other studies to be potential to exploit genetic variation for seed content of iron and other minerals without the generally negative impact on yield commonly seen with protein in many crops; indeed, the relationship with yield may be positive for some minerals when their availability is low in the soil [3]. Although rice is not considered a major mineral source in the diet, any increase in its mineral concentration could significantly help reduce iron and zinc deficiency in humans because of the high levels of rice consumption among the poor in Asia.

Variability in iron and zinc content in rice grain

In 1992 IRRI began to examine the effect of certain soil characteristics on the iron content of the grain. This research was influenced by the efforts of the Philippine Government to eliminate the iron malnutrition problem in the country by artificially enriching milled rice with iron. Varieties were tested under normal and iron toxic soil conditions. Wide differences among varieties were observed for the iron content in grain. In 1995 the work was expanded to include zinc, and

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TABLE 1. Iron and zinc content of varieties of brown rice grown under similar conditions in six different sets

Variety set	No. of samples	Iron Mean ± SE mg/kg (range)	Zinc Mean ± SE mg/kg (range)
Traditional and improved varieties	140	13.2 ± 2.9 (7.8–24.4)	24.2 ± 4.6 (13.5–41.6)
IR breeding lines	350	10.7 ± 1.6 (7.5–16.8)	25.0 ± 7.6 (15.9–58.4)
Tropical japonicas	250	12.9 ± 1.5 (8.7–23.9)	26.3 ± 3.8 (15.0–40.1)
Popular varieties and donors	199	13.0 ± 2.5 (7.7–19.2)	25.7 ± 4.6 (15.3–37.3)
Promising lines (NCT)	83	8.8 ± 1.3 (6.3–14.5)	25.4 ± 4.2 (17.0–38.0)
New plant types	44	16.7 ± 2.1 (11.5–24.0)	29.6 ± 3.2 (23.0–36.0)
Wild rice and derivatives	21	15.6 ± 2.3 (11.8–21.0)	37.9 ± 8.6 (23.0–52.0)
Aromatic rices	51	14.6 ± 3.2 (10.8–23.2)	31.9 ± 6.0 (23.0–50.0)

collaboration with the University of Adelaide was established for mineral analysis according to international standards. Under this collaboration, nearly 7,000 samples now have been analysed, and together with supplementary sets from China and Bangladesh, these data are a valuable database on genetic variation in iron and zinc content in rice grain.

Since the effect of the environment (soil and climate) on the mineral content of the grain was not known, the initial test strains were planted on the IRRI farm under uniform soil and crop-management conditions. From harvesting to analysis, care was taken to prevent any contamination, in particular contamination with soil. Nine sets of plantings were undertaken in different locations and seasons. Brown rice samples were analysed for minerals at the Department of Plant Science, University of Adelaide, Australia. Some varieties with exceptionally high mineral content were observed and were reevaluated in later tests. The data obtained from each screening set are summarized in table 1. Among the 1,138 samples analysed, the iron concentration in brown rice ranged from 6.3 to 24.4 ppm, with a mean value of 12.2 ppm. For zinc, the range was 13.5 to 58.4 ppm, with a mean of 25.4 ppm.

Table 2 shows a comparison of high-iron and high-zinc varieties, selected from the 1,138 varieties analysed in table 1, with IR36 and IR64, the two most popular varieties in Asia. All varieties were grown in the same soil and season. Jalmagna, a traditional variety, had almost double the iron concentration of IR36 and IR64. Its zinc concentration was also high, nearly 40% more than that of IR64. Jalmagna is a floating rice grown in some parts of eastern India. Madhukar had slightly high iron density and very high zinc density. Madhukar is a popular variety in some rain-fed and deep-water areas of eastern India. The soils of this region are slightly alkaline and zinc deficient, and Madhukar is well known as a highly zinc-efficient rice variety. However, other known zinc-efficient rice varieties, such as Kuatik Putih, Bille Kagga, and Getu, did not have high grain zinc concentration. Zuchem, a traditional japonica type rice variety grown at very high altitudes (> 2,000 m above sea level) in Bhutan, expressed both high iron and zinc in grain. Its iron content was not as high as that of Jalmagna. Xua Bue Nuo, a traditional variety from China, also had high iron. Improved varieties with exceptionally high iron or zinc content were not found in this screening series.

It was observed that among the high-iron varieties, there were a number of aromatic rices. Subsequently, a series of seven comparisons of aromatic and non-aromatic varieties was made from seeds grown under similar conditions, available from experiments unrelated to the Micronutrients Project. As compared with non-aromatic rices, aromatic rices were consistently higher in grain iron concentration and often also higher in zinc [4]. It follows that people consuming aromatic rices have higher intakes of iron than those eating non-aromatic types. However, it remains to be shown that this extra iron is present after milling and is absorbed in the gut; these tests are being planned.

Improved rice with enhanced iron and zinc in the grain

A high-iron trait can be combined with high-yielding traits. This has already been demonstrated by the serendipitous discovery in the IRRI testing programme of

TABLE 2. Iron and zinc content of some selected varieties of brown rice

Variety	Iron		Zinc	
	Mean ± SE mg/kg	No. of samples	Mean ± SE mg/kg	No. of samples
Jalmagna	22.4 ± 1.4	5	31.8 ± 7.7	4
Zuchem	20.2 ± 1.8	4	34.2 ± 5.0	3
Xua Bue Nuo	18.8 ± 0.8	2	24.3 ± 0.7	2
Madhukar	14.4 ± 0.5	3	34.7 ± 2.8	3
IR64	11.8 ± 0.5	3	23.2 ± 1.4	3
IR36	11.8 ± 0.9	5	20.9 ± 1.4	4

an aromatic variety—a cross between a high-yielding variety (IR72) and a tall, traditional variety (Zawa Bonday) from India—from which IRRI identified an improved line (IR68144-3B-2-2-3) with a high concentration of grain iron (about 21 ppm in brown rice). This elite line has good tolerance to rice tungro virus and excellent grain qualities. The yields are about 10% below those of IR72, but in partial compensation, maturity is earlier. This variety has good tolerance to soils deficient in minerals, such as phosphorus, zinc, and iron. It has no seed dormancy and excellent seedling vigour, suggesting that it could be a good direct-seeded rice.

Optimal growing conditions and mineral content

Twenty-three varieties, including three commercially grown types, IR36, IR72, and IR74, were grown in the greenhouse with optimal nutrients and with full protection against pests and diseases. The iron content of grains produced ranged from 10.1 ppm in IR36 to 26.4 ppm in Ganja Roozy. Iron was low in all commercial varieties. The zinc concentration ranged from 31.4 ppm in IR36 to 58.9 ppm in Ganja Roozy. The experiment showed that there is a potential to more than double the iron and zinc contents of the grain by genetic improvement.

Response to nitrogen

Three high-yielding varieties were tested under four different levels of added nitrogen (0, 46, 90, and 135 kg/ha). In brown rice, iron increased by an average of 15% with the addition of nitrogen at applications between 0 and 135 kg/ha. This difference was statistically significant. Zinc concentration increased by an average of 10%, although the difference was not statistically significant. A separate study was undertaken to determine the optimal fertilizer combination to maximize genetic variability. All combinations of nitrogen, phosphorus, and potassium were tested. This study confirmed that the addition of nitrogen alone increases the iron concentration in the grain. However, the addition of nitrogen and potassium maximizes the difference in iron content between varieties. Such information contributes to the ease of selection later during breeding.

Effect of soil and climate on grain mineral content

Several tests were conducted to examine the effect of soil and climatic factors on the iron and zinc concentrations in grain. This is an important issue for plant breeders, since we desire nutrient traits that are expressed in all environments. For example, it is well known that soil has a considerable influence on the nutrient content of grains.

In an acid soil site in San Dionisio, Iloilo, Philippines, five breeding lines with high tolerance for acidity, together with IR72, were tested in the 1993 wet season. The soil in this site is deficient in nitrogen, phosphorus, and potassium and is iron toxic. With the addition of phosphorus and potassium, deficiency and toxicity symptoms disappeared, but plant growth was not normal. The addition of all three elements produced nearly normal growth and yield.

Reduced iron toxicity (addition of phosphorus and potassium without nitrogen) produced iron and zinc concentrations that were lower by 25% and 18%, respectively, as compared with the application of nitrogen alone. The addition of nitrogen (in addition to phosphorus and potassium) increased both iron and zinc density, but only to levels that were slightly below those obtained with the application of nitrogen alone. This experiment suggests that the nitrogen level is an important favourable factor determining grain mineral content, even under adverse soil conditions.

Ten varieties, including Jalmagna and Madhukar, were grown on the acid soil in San Dionisio, Philippines, in the 1995 wet season. Nitrogen deficiency was corrected, but phosphorus and potassium deficiencies were not. The results of grain mineral analysis of the harvest were compared with those of the same varieties grown under normal soil conditions on the IRRI farm. Under acid soil conditions, the iron content of acidity-sensitive varieties increased by 20% on average, whereas tolerant varieties showed a slight reduction in iron. This is possibly a reflection of the ability of tolerant varieties to exclude toxic iron (Fe^{2+}). Zinc, on the other hand, increased considerably under acid conditions, independently of the tolerance level of the variety, from a mean of 23 ppm to a mean of 34 ppm. The zinc content in Madhukar was extremely high under acid soil conditions, reaching 55 ppm.

In a third test, four varieties were grown on normal and saline soils in a coastal area in Pili, Iloilo, Philippines, in the 1992 wet season. In salt-sensitive IR29, the iron density increased under saline soil conditions, but only by 4%. In salt-tolerant varieties, there was a 7% reduction in the iron content. Independently of the tolerance for salinity, the zinc content declined with salinity in the soil by 15% on average.

In a fourth experiment, 12 varieties were planted on the IRRI Farm in the 1994 dry season on three different dates at 15-day intervals to test the effects of growing time. The management practices were the same for all three plantings. Mineral analysis revealed only slight differences between the three plantings in the means for both iron and zinc concentrations.

Effect of milling on grain iron content

A comparison between the iron content of high-iron traditional varieties (red pericarp) and that of IR64 and IR68144-3B-2-2-3 (white pericarp) after different polishing times is shown in figure 1. The graph demonstrates a strong interaction between genotype and time of milling. The grain colour appeared to be associated with the iron content. The appearance of the grain of red-pericarp varieties such Jalmagna, Tong Lang Mo Mi, and Xua Bue Nuo became lighter as the polishing time increased. Drastic changes of colour were observed in Jalmagna and Tong Lang Mo Mi after 15 to 45 minutes of polishing time, which corresponded to large declines in iron content. For Xua Bue Nuo, a very slight change in colour was observed, and the iron content declined relatively little.

For IR64, a popular commercial variety with the lowest iron in brown rice, the iron content dropped by more than one-third after 15 minutes of polishing (the time equivalent to that of commercial polishing); after 15 minutes, the iron content remained almost unchanged. A loss in iron content of about one-third at 15 minutes of milling was observed for two high-iron traditional rices, Jalmagna and Tong Lang Mo Mi, but their iron concentrations continued to decrease substantially as the polishing time increased. These observations suggest that much of the iron is in the outer layers of the grain. However, Xua Bue Nuo, a traditional variety from China, and high-iron IR68144-3B-2-2-3 were less affected by polishing time. After 15 minutes of polishing, IR68144-4B-2-2-3 had about 80% more iron than IR64.

Genetic analysis of the high-iron trait

Genetic component analysis was undertaken of the high-iron trait in grain using four traditional high-iron rice varieties (Azucena, Basmati 370, Xua Bue Nuo, and Tong Lang Mo Mi), three advanced lines (IR61608, PP2462-11, and AT5-15), and three IRRI-released varieties (IR36, IR64, and IR72). The results show highly significant differences between the crosses and between the parentals and the F_1 progeny. This clearly indicates a genetic effect on grain iron concentration, suggesting that selection among F_1 progeny is possible. The genetic analysis of variance revealed the presence of additive gene action (fixable genes) in addition to a significant non-additive genetic variance (non-fixable genes or unpredictable genes). Environmental effects are present but are smaller than the genetic effects. The narrow-sense heritability of the trait was found to be moderately low (43%). The large difference between the estimates of narrow-sense and broad-sense heritability (88%) further confirmed the importance of a non-additive type gene action.

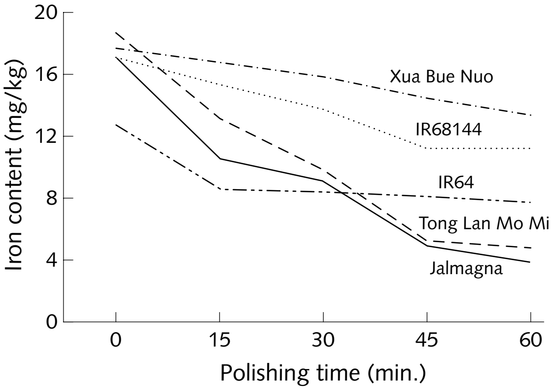

FIG. 1. Iron content of some selected rice varieties after different polishing times (consumption in rice equivalent to 15 minutes of polishing

Analysis of combining ability indicated a high and significant general combining ability. This suggests that some parents may be combined with a range of varieties to produce a high-iron trait in progeny. Specific combining ability (SCA) is also present, indicating that specific combinations between the parents (e.g., Azucena × Basmati 370) would produce higher iron concentration in the progeny. The presence of reciprocal effects suggests the importance of the choice parent. For example, a female parent of Tong Lang Mo Mi would always produce higher-iron progeny than a male parent.

On the basis of the inheritance study, selection during breeding should be undertaken in a later generation (such as F_5) where the dominance effect (unfixable genes) is not present. A bulk breeding method is suggested in early generations, during which selection for other agronomic characteristics should be undertaken, without selection yet for the high-iron trait. An alternative method that might work well is single-seed descent using the F_5 generation. Because of the influence of environment and cultural practices in determining iron concentration, selection should be done in an optimal environment, such as one with application of nitrogen and phosphorus to maximize genetic variability.

Mapping genes for high-iron and high-zinc traits

Three groups of genes were found to be associated with the high-iron trait. These groups of genes were located on chromosomes 7, 8, and 9 and explained 19% to 30% of the variation in iron content. Three groups of genes for aroma were also identified. They were located on chromosomes 5, 7, and 8 and explained 16% to 38% of the variation. Thus, two genes associated with high iron and aroma have two chromosomes in common (7 and 8), although these genes have different locations on the chromosome. This indicates a slight linkage between aroma and the high-iron trait.

Permanent mapping populations of F_8 recombinant inbred lines (RILs) were developed to map high-iron and high-zinc traits. Mapping of genes is an important step in developing marker-assisted selection (MAS) for any trait of interest. This selection technique is rapid, highly reliable, and relatively inexpensive. MAS will be used to select two to three traits at a time. These populations were also used to map tolerance to other abiotic stresses, such as aluminum toxicity, zinc deficiency, and excess water.

The future

Initial evaluations have shown that there are rices with high iron and zinc contents in the grain for use in breeding, although additional evaluation will be valuable. Genetic-by-environmental interactions are sufficiently moderate that breeding for higher iron and zinc content is considered worthwhile. Soil properties and weather (i.e., the environment) affect mineral and vitamin contents in the grain for any particular line (genotype) of a crop. Each genotype has a certain constellation of genes that determine (a) the absolute level of mineral and vitamin content of the grain on average across a range of environments and (b) the extent to which soil properties and climate affect the variation around this mean. If, for all genotypes, (b) is much stronger than (a), then genotypic-by-environmental interactions are so large that breeding is more or less useless. If (a) is much stronger than (b), then this is one condition (among several) that must be met to allow breeding to proceed. The next major step will be to study the genetics in further depth to determine the best selection technique for use in breeding. Current research at IRRI includes the following:

- screening of selected traditional germplasm, wild rices, and new plant types;
- varietal improvement for enhanced micronutrients in rice;
- study of inheritance of high iron and zinc density in grain and formulation of breeding strategy;
- further study of genotypic-by-environmental interactions, including rice processing and parboiling;
- gene tagging and development of molecular marker-assisted selection techniques for both high iron and high zinc in the grain; it is difficult for national agricultural research institute breeders to select for these traits by conventional spectrometric techniques;
- study of the bioavailability of high-iron and high-zinc rice in human feeding trials.

Special acknowledgement

Dr. Dharmawansa Senadhira led IRRI's high-iron rice project from its inception until his untimely death in a road accident in Bangladesh on 7 July 1998. He wrote much of what is contained in this paper for various other purposes, and we, his collaborators, have gathered these together and completed the manuscript, acknowledging his major contribution. We thank Ms. Teresa Fowles, Mr. Lyndon Palmer, Ms. Corinta Quijano-Guerta, and Ms. Normita de la Cruz for the mineral and grain quality analysis; and Mr. Rhulyx D. Mendoza, Neil Monroy, German Jara, Angelito Francisco, and Rosalio Rosario for their assistance in different phases of this study.

References

1. IRRI. Rice grain quality and marketing. Manila: International Rice Research Institute, 1985.
2. IRRI. Rice grain marketing and quality issues. Manila: International Rice Research Institute, 1991.
3. Graham RD, Welch RM. Breeding for staple-food crops with high micronutrient density: long-term sustainable agricultural solutions to hidden hunger in developing countries. Agricultural Strategies for Micronutrients Working Paper No. 3. Washington, DC: International Food Policy Research Institute, 1996.
4. Graham RD, Senadhira D, Ortiz-Monasterio I. A strategy for breeding staple-food crops with high micronutrient density. Soil Sci Plant Nutr 1997;43:1153–5.

Research on trace minerals in the common bean

Stephen Beebe, Alma Viviana Gonzalez, and Judith Rengifo

Abstract

*The common bean (*Phaseolus vulgaris *L.) is the most important grain legume for direct human consumption, being especially important in eastern Africa and in Latin America. The objective of the Centro Internacional de Agricultura Tropical (CIAT) in participating in the Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project has been to assess the feasibility of improving common beans for micronutrient content, especially iron and zinc. In the evaluation of more than a thousand accessions in the cultivated core collection, a mean iron concentration of 55 mg/kg was found, with a range of 34 to 89 mg/kg. Zinc concentrations ranged between 21 and 54 mg/kg, with an average value of 35 mg/kg. These initial data suggest that sufficient genetic variability exists to improve iron content by about 80% and zinc content by about 50%.*

An essential question for the improvement of any trait through plant-breeding is the degree to which the trait is stable across environments. Genetic differences have been expressed over environments and seasons, offering good prospects that genotypes selected in one environment for high iron or zinc will express superior levels of minerals in other environments as well. Correlations among mineral concentrations suggest that the improvement of one mineral may simultaneously improve the contents of other minerals, thus multiplying the impact of the effort. The fact that the bioavailability of iron was higher in white beans in rat studies suggests that a lower tannin content could be beneficial, but the role of tannin is still not well elucidated. The genetics of iron and zinc content appears to be complex, involving between 7 and 11 loci.

Introduction

Food legumes in general contain appreciable quantities of iron and other minerals. Although legumes are often cited as a complement to cereals in terms of amino acid content, they also make a particularly important contribution to micronutrient nutrition. Decreasing per capita consumption of legumes in India is considered to be one possible cause of increasing iron deficiency, illustrating the importance of legumes in the diet. The common bean (*Phaseolus vulgaris* L.) is the most important grain legume for direct human consumption, being especially important in eastern Africa and in Latin America. The objective of the Centro Internacional de Agricultura Tropical (CIAT) in participating in the Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project has been to assess the feasibility of improving the micronutrient content of common beans, especially the iron and zinc contents.

Genetic variability in mineral content

The first essential question regarding whether the micronutrient status of beans can be improved is to determine the degree of genetic variability of the species in mineral content. For this purpose, we evaluated the common bean core collection for mineral content using inductive coupled plasma (ICP) technology at Adelaide University. A core collection is a systematic sample of the germplasm of a species, taken in such a fashion as to represent the broadest possible genetic diversity in a limited and manageable number of accessions. In the evaluation of more than a thousand accessions in the cultivated core collection, a range of 34 to 89 parts per million (ppm) was found, with an average of 55 ppm (table 1). A clear relationship between iron content and geographic distribution was not evident, although accessions from the Andean gene pool tended to have higher iron contents than those from the Mesoamerican pool. The iron-content values from wild and cultivated beans had similar standard deviations, and wild beans had only a narrow advantage in iron content. Initially we thought that use of the wild bean was not warranted in the breed-

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TABLE 1. Mineral contents (ppm) of wild and cultivated common beans

Mineral	Wild (n = 119)		Cultivated (n = 1,031)	
	Mean ± SD	Maximum	Mean ± SD	Maximum
Boron	18 ± 5.9	58	10 ± 1.8	18
Calcium	3,207 ± 1,327	6,450	1,466 ± 412	3,152
Copper	6 ± 2.0	12	9 ± 1.8	14
Iron	60 ± 10.2	96	55 ± 8.3	89
Manganese	23 ± 9.0	74	15 ± 4.4	29
Sodium	16 ± 7.1	38	12 ± 4.0	50
Phosphorus	6,044 ± 705	7,782	3,684 ± 696	7,095
Sulphur	2,354 ± 314	3,073	2,120 ± 259	3,078
Zinc	29 ± 4.5	43	35 ± 5.0	54

ing programme because of its undesirable agronomic characteristics, but recent developments in breeding methods for the use of wild germplasm have induced us to include a wild accession in the populations under study. Given that some of the cultivated accessions with high iron content originated in Peru, we subsequently evaluated additional germplasm from this region, finding accessions with values that averaged as much as 100 ppm over sites and seasons (table 2).

The zinc content of beans is one of the highest among vegetable sources; it is nearly equal to that of dairy products but is far inferior to that of meats. Evaluation of the bean core collection revealed a range of 21 to 54 ppm in zinc content, with an average value of 35 ppm (table 1). Germplasm from Guatemala had especially high values of zinc, but it has not been possible to find germplasm with values that exceed the levels found in the initial evaluation. These initial data suggested that sufficient genetic variability exists to improve iron content by about 80% and zinc content by about 50%.

An essential question for the improvement of any trait is to what degree the trait is stable across environments. In the case of seed mineral content, one might well expect an effect of varying soil type and soil chemistry over sites. Trial plantings were done to assess the stability of mineral content over two growing environments, and two seasons in one of these sites. For both iron and zinc, the varietal mean square was highly significant, although location and location × variety effects were also significant. Visual inspection of the data confirmed that several accessions were superior independently of site and season. This indicates that the superior mineral content selected at one experimental site should not be lost when the materials are planted at other sites, although the degree of expression of the trait will vary.

TABLE 2. Accessions of beans with the highest iron concentration (ppm) over sites and seasons

Accession no.	Darien		Popayan		
	Season 1	Season 2	Season 1	Season 2	Average
G23834E	106	104	111	87	102
G23818B	106	97	106	71	95
G23823E	103	88	101	77	92

One criticism of the breeding approach (or, for that matter, any approach that does not involve improving food intakes) to resolve micronutrient deficiencies is that it addresses deficiencies one element at a time. In fact, this might not be the case. In the core evaluation, we noted that positive correlations existed among several important elements. For our purposes, suffice it to say that iron and zinc had a statistically significant correlation of 0.52*** across different genotypes. Even more convincing are the results of mineral evaluation of recombinant inbred lines (RILs: homozygous lines derived from a simple cross) developed for genetic studies, since these correlations probably reflect co-segregation of genes for traits. The correlations presented in table 3 are derived from a cross of Andean beans, but the same tendency was observed in a Mesoamerican cross. Again, highly significant positive correlations are found among several elements, including iron, zinc, sulphur, manganese, and phosphorus. The implication of these correlations is that some genetic factors for different minerals are co-segregating and that selection for one element (for example, iron) will in fact result in an increase in other elements (such as zinc).

Variability in tannin content

Tannins are widely cited as important antinutrients that precipitate iron in food preparation or in the gut. One possible avenue for the improvement of iron nutrition is to reduce the tannin content or activity. For this purpose, we evaluated the core collection for tannin content. This variability was considered within the context of grain colours, since tannins are closely related to the seed coat pigments, and the possibilities for altering the tannin content must be evaluated within a colour class. For example, white beans have

TABLE 3. Correlation among mineral contents in a cross of two accessions of common beans (G21657 × G21078) of Andean origin[a]

Mineral	Mn	Zn	Ca	Mg	K	P	S
Iron	0.451**	0.663**	0.141	0.113	0.029	0.598**	0.641**
Manganese	0.376**	0.211*	0.268**	0.118	0.356**	0.233*	
Zinc	0.253**	0.144	0.120	0.772**	0.757**		
Calcium	0.247**	–0.257**	0.211*	0.079			
Magnesium	0.543**	0.181	0.077				
Potassium	0.032	0.068					
Phosphorus	0.724**						

a. $*p < .05$; $**p < .01$.

very low tannins, but if this trait is related to lack of pigment, it might not be possible to transfer this trait from white beans into beans of other colours. It was necessary to establish that the low-tannin trait can be obtained in other colours of beans as well. Table 4 indicates the range of tannin contents found within each colour class. There is apparently ample variability even within colour classes to be able to alter the total content of tannin in the seed coat. The darker-coloured beans (red- and black-seeded) in fact had more tannins, but there was more variation within colour classes than between classes. In some degree, this was related to the gene pool as well, especially in black beans: Mesoamerican black beans had high tannin, and Andean black beans had very low values of tannin content.

It can be noted in passing that in one trial to measure bioavailability in rats [1], two white beans in fact had the highest percentages of bioavailable iron: over 70% versus about 50% or less for other accessions. This suggests that lower tannin could in fact be beneficial, although the analysis of all accessions in the trial did not reveal an effect of tannin, possibly because of inadequate variability in tannin content among the other accessions.

One concern about the possibility of lowering tannin content was related to possible collateral effects, since tannins may have other functions, such as serving as resistance factors or flavour components. We have compared data on tannin content with disease reaction data on the core collection, using simple linear correlations. Although the relationship is not consistent, it was found that positive correlations are more common than negative correlations. That is to say, high tannin in the seed coat is often associated with more disease, not less disease. This effect was actually quite strong in the case of common bacterial blight (caused by *Xanthomonas campestris* pathovar phaseoli) and was also observed with reaction to *Rhizoctonia solani*. The most consistent negative correlation (i.e., more tannin associated with fewer symptoms) was observed in relation to an insect pest, *Empoasca kraemerii*. Thus, although the relationship between seed coat tannin and pest resistance is not consistent, there appear to be few negative effects on plant resistance associated with reduced tannin.

Variability in sulphur-containing amino acids

We considered the possibility of genetically increasing sulphur-containing amino acids (SAA) as promoters of iron uptake, looking at the genetic variability of sulphur content in the core, under the assumption that this reflected SAA. Subsequently a subset of the core was analysed for amino acid content by high-performance liquid chromatography (HPLC), and a near-infrared spectrophotometer at the CIAT was calibrated to detect methionine and cystine. The results suggested that some accessions had levels of SAA about 25% above the mean of the core. Furthermore, the genetic component of SAA content was expressed over localities and seasons (table 5). However, we have not pursued

TABLE 4. Variability in tannin content within colour classes of common beans

Seed colour	Mean (range) tannin content (g/g seed coat)
Cream	0.116 (0.036–0.168)
Yellow	0.116 (0.060–0.184)
Pink	0.120 (0.072–0.164)
Red	0.128 (0.048–0.196)
Purple	0.120 (0.048–0.196)
Black	0.128 (0.060–0.188)

TABLE 5. Analysis of variance of methionine + cystine content of 29 varieties of bean grown in three environments

Source	Df	Mean square	*F*	*p*
Locality	2	.01695	38.37	.0001
Rep (Loc)	6	.00136	3.07	.0070
Variety	28	.01222	27.66	.0001
Variety* locality	55	.00071	1.61	.0117
Error	167	.00044		

this. Although legumes are limited in SAA, they have abundant lysine, which has also been reported to improve uptake. The question remains whether lysine can supplant SAA in the uptake promoter role.

Genetics of mineral content

Four populations had been prepared as recombinant inbred lines (RILs) for the development of molecular markers, and three of them have been analysed. Two of these populations were derived from crosses of Mesoamerican parents, and one population was derived from a cross of Andean parents. Thus, the two major gene pools of the common bean were represented. The recombinant lines reveal aspects of the genetics of iron and zinc content in the parental materials. The results from all three populations are similar, and only the results of one population are presented graphically (fig. 1).

In all three populations, both iron and zinc content in the RIL had a continuous distribution, which is to say, mineral content behaves as a quantitative trait. The parental accessions in each case were very close to the extremes of the populations, and very few progeny exceeded the values of the parental genotypes. This suggests that almost all of the favourable alleles came from the high-iron parent. The only exception to this rule was the population of G11350 × G11360, a Mesoamerican cross, in which several progeny were either inferior or superior to the parents in iron content. The number of segregating lines that had iron contents similar to those of the parent with higher iron contents suggests that the number of genes involved could be in the range of four to seven.

Quantitative trait loci analysis of iron and zinc content

Although molecular analysis of the core collection was part of a separate project, the existence of data on mineral contents of the core accessions permitted relationships to be established between specific DNA bands and mineral content. Of the two major gene pools, the Andean pool is quite uniform genetically. However, introgression has occurred from Mesoamerican beans that have been introduced into the Andean zone. Given the relatively uniform background of the Andean beans, this introgression can be traced and quantified by using DNA markers. Subsequently we could use standard QTL (quantitative trait loci) analysis to relate introgressed fragments of Mesoamerican DNA to changes in the mineral contents in the Andean beans.

Small fragments of DNA called primers can be used to “seed” the DNA extracted from an organism to generate larger fragments called RAPD (random amplified polymorphic DNA) that are typical of that organism. Eight primers were used to generate 150 RAPD bands on about 600 traditional farmer varieties of Andean origin. Of these accessions, about 10% displayed evidence of introgression from Mesoamerican beans. A simple *t* test was used to compare the mineral contents in accessions that showed a specific Mesoamerican band versus those accessions that lacked the band. Twenty-five bands so studied showed a significant effect on iron content, and 48 showed effects on zinc content, indicating that the DNA fragments originated close to genes that govern mineral concentrations. Of the 150 bands generated, 47 could be located in the genome on the CIAT mapping population. Seven regions were identified for iron, in chromosomes 3, 4, 8, 9, 10, and 11. Eleven regions were identified for zinc content, which appeared in all chromosomes except 5 and 7. Bands in four regions expressed an effect for both iron and zinc. Thus, loci for mineral content have already been placed on a reliable genetic map that includes RFLP (a molecular marker category) as well, permitting extrapolation to other maps of the common bean.

This preliminary mapping exercise confirms observations on the segregation patterns of the RILs to the effect that mineral content is quantitatively inherited. In the case of iron, the number of loci identified by QTL analysis corresponded rather well to the estimate

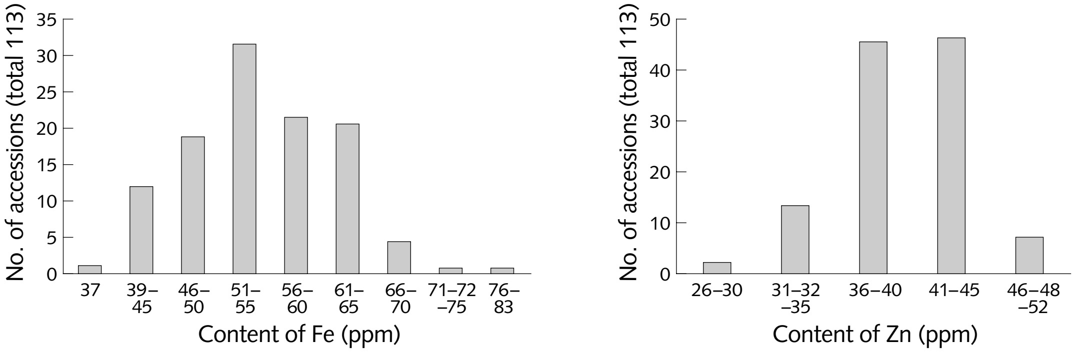

FIG. 1. Distribution of (A) iron and (B) zinc content in recombinant inbred lines of the cross (G21657 × G21078)

based on the segregation pattern, whereas in the case of zinc, the QTL analysis revealed more loci than would have been expected. The loci that were found to be in common could be the basis of the positive correlation that was found between iron and zinc contents in the three populations.

It must be stressed that this is a very preliminary estimate of where QTL are to be found and what their effects might be. Furthermore, all the markers identified are RAPD and therefore are not of adequate quality to use in marker-assisted selection. The search for reliable markers represents another phase in the task of increasing mineral content of the grain.

Conclusions

Studies to date suggest that the iron content of the common bean could be increased by 60% to 80%, while potential gains in zinc content would be more modest, perhaps around 50%. Genetic differences have been expressed over environments and seasons, offering the prospect that genotypes selected in one environment for high iron or zinc will express superior levels of minerals in other environments as well. The genetics of iron and zinc content appear to be complex, involving from 7 to 11 loci. However, allelic variation remains to be explored, and it might yet be possible to identify alleles at specific loci with relatively major effects. Correlations among mineral contents suggest that the improvement of one mineral may simultaneously improve the contents of other minerals, thus multiplying the impact of the effort. The fact that white beans presented higher bioavailability of iron suggests that lower tannin content could be beneficial, but the role of tannin is still not well elucidated.

Reference

1. Welch RM, House WA, Beebe S, Senadhira D, Gregorio GB, Cheng Z. Testing iron and zinc bioavailability in genetically enriched beans (*Phaseolus vulgaris* L.) and rice (*Oryza sativa* L.) in a rat model. Food Nutr Bull 2000;21:428–33.

Breeding for trace minerals in wheat

Ivan Monasterio and Robin D. Graham

Abstract

In the search for genetic material with high iron and zinc concentration in wheat grain, a significant positive correlation has been found between iron and zinc concentrations, suggesting that these two traits may be combined relatively easily during breeding. In future research, the very high values of iron and zinc in the grain seen in wild types and landraces need to be confirmed in trials in which all the best material is planted in the same location and year. In addition, it is important to determine if these high levels of iron and zinc in the grain can be maintained in high-yielding material.

The production of semi-dwarf wheat through the introduction of the rht *genes has resulted in substantial yield increases. However, this is associated with a reduction in iron and zinc concentrations in some bread wheat genotypes, but not in durum wheat. The presence of the 1B/1R translocation in the wheat germplasm of* the *Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) to increase leaf rust resistance may have had a positive effect on the concentration of iron and zinc, but a negative effect was ruled out. There is a strong positive correlation between grain yield and year of release in the CIMMYT wheat varieties. There is a small negative but statistically significant relationship between the time of release and the concentrations of iron, zinc, total phosphorus, and phytate. The positive effect of nitrogen applications on iron and zinc concentrations is more important than declines in these concentrations due to breeding during the last 42 years*

Introduction

The objective of this project was to further our understanding of the possibility of enhancing the micronutrient content in the grain of wheat through plant-breeding. Before a new breeding objective is adopted in a breeding programme, it is necessary first to establish the level of genetic diversity for that trait, identify how many genes are involved, and determine the heritability of the trait. Our research has focused mainly on the first component. In addition, we have been studying the effect of two important genes in the wheat germplasm of the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) that could potentially have an effect on micronutrient concentration in the grain. These are the *rht* genes, which confer the dwarf character to CIMMYT germplasm, and the 1B/1R translocation, which is the transfer of a chromosome segment from rye into wheat. Historical changes in iron and zinc concentration in the grain of wheat of CIMMYT releases between 1950 and 1992 were also part of our study.

Genetic diversity

We first screened 505 lines, trying to sample as much genetic diversity as possible. These materials included wild species, landraces,* high-yielding bread wheat, durum wheat, triticale (a cross between wheat and rye), and also genetic material from special projects such as the water-logging lines, the phosphorus use efficiency lines, and synthetics. Because this initial sample of 505 lines had not all been grown in the same year and location, the results were used to select some of the best and a few of the worst lines.

A resulting subset of 170 lines was grown in a replicated trial in Obregon, Mexico, to confirm which were the best entries in terms of high iron and zinc concentrations in the grain. The results from the replicated trial pointed to three promising future

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* A landrace is a traditional variety that has been grown for generations in a given area.

sources of high-iron and high-zinc lines. These were wild species, landraces, and material from the former pre-breeding unit at CIMMYT. For this subset, the iron density ranged from a low of 25 mg/kg (parts per million [ppm]) to a high of 56 ppm, with a mean of 37 ppm. The range of zinc density was 25 to 65 ppm, with a mean of 35 ppm. Tables 1 and 2 show the 12 lines with highest iron and zinc concentrations, respectively. Note that six lines appear in both tables 1 and 2, suggesting that it may be relatively easy to combine high-iron and high-zinc traits during breeding. In fact, iron and zinc densities (and several other trace minerals) were significantly correlated (correlation coefficient between iron and zinc, 0.7) in these groups of lines.

Subsequently, a second group of 154 lines from the pre-breeding programme was grown in the same location and season and analysed. Six lines had higher iron concentrations than the best found in the previous trial, one with 73 ppm or 30% more iron. Eight lines were identified that had higher zinc concentrations, one with 92 ppm or 41% higher than the best of the previous set.

In addition to lines from the pre-breeding programme, our previous screenings had pointed at land-

TABLE 1. Top 12 entries for iron concentration in the grain, 170 sample replicated trial

ID	Plot no.	Variety	Iron		Type of line[a]	Min	Max
			Mean	SD			
148	PLOT-439	CMH84.3595	56.46	3.60	P		
19	PLOT-84	*Triticum dicoccon* PI254187	55.47	2.26	W		
143	PLOT-434	CMH83.1020-CMH84.1038// CMH83.1020/CMH82A.135	49.19	2.20	P		
32	PLOT-137	TXL92.3.2.2	47.87	4.42	L		
35	PLOT-149	84TK536-003.01-728	46.52	3.21	L		
146	PLOT-437	CMH78.788//AGA/6*YR70/3/ CMH78.788	46.13	0.74	P		
3	PLOT-6	MIAN YANG #11	45.97	0.03	V		
119	PLOT-407	RICARDO E211#1	45.35	4.45	P		
63	PLOT-243	ESDA/VEE#10	44.33	3.71	V		
85	PLOT-330	VEE/MYNA	43.97	1.53	V		
26	PLOT-115	*Triticum dicoccon* PI94677	43.94	3.73	W		
100	PLOT-388	MRGN	43.46	2.88	V		
		n = 170	36.63	4.53		25.13	56.46

a. W, Wild relative; P, pre-breeding unit; L, landrace; V, variety.

TABLE 2. Top 12 entries for zinc concentration in the grain, 170- sample replicated trial

ID	Plot no.	Variety	Zn		Type of line[a]	Min	Max
			Mean	SD			
19	PLOT-84	*T. dicoccu*m PI254187	64.86	4.00	W		
148	PLOT-439	CMH84.3595	53.33	0.63	P		
26	PLOT-115	*T. dicoccu*m PI94677	50.19	4.49	W		
35	PLOT-149	84TK536-003.01-728	49.77	3.06	L		
138	PLOT-428	C306	49.03	4.31	V		
143	PLOT-434	CMH83.1020-CMH84.1038// CMH83.1020/CMH82A.135	48.80	3.03	P		
32	PLOT-137	TXL92.3.2.2	47.79	2.88	L		
144	PLOT-435	CMH79A.955/3*CNO79// HE.1/CN079	46.68	5.85	P		
16	PLOT-61	*T. dicoccu*m PI276011	46.57	2.17	W		
28	PLOT-126	OAXACA92.5.17	44.96	0.35	L		
125	PLOT-413	JUPATECO 73 SUSC	44.60	4.12	V		
3	PLOT-6	MIAN YANG #11	44.52	6.10	V		
		n = 170 Obregon	35.22	5.48		25.21	64.86

a. W, Wild relative; P, pre-breeding unit; L, landrace; V, variety.

races and wild species as promising new sources of genetic material high in iron and zinc. However, the expense of obtaining a large sample of lines that had been grown in the same year and location and that represented the wide diversity in the gene bank was beyond the resources available to the project. Therefore, we opted for further sampling of genetic diversity, but without growing these additional varieties in the same year and location. The seeds of 1,000 additional lines from the CIMMYT germplasm banks and other sources were analysed. CIMMYT records indicated the time period when these seeds had been grown and whether these 1,000 lines had been grown in Obregon or El Batan in Mexico, or elsewhere.

Among lines grown in Obregon out of this sample of 1,000 lines, a set of 30 *T. tauschii* had mean iron concentrations of 76 ppm and a maximum value of 99 ppm. For zinc, this same set of 30 *T. tauschii* had average and maximum concentrations of 50 and 69 ppm, respectively. These values suggest that the grain of *T. tauschii* is a very promising source of iron (table 3).

Among lines grown in El Batan out of the sample of 1,000 lines, we have reference values of iron and zinc concentrations for wheats grown in this soil (from a historical study of CIMMYT releases described later in the paper), but only for the summer months. The reference values for mean concentrations are 52 ppm for iron and 35 ppm for zinc.

For a set of *T. monococcum* grown in El Batan soils during the summer, the maximum concentration found for iron was 70 ppm and the maximum for zinc was 131 ppm. For a set of *T. dicoccoides* and another of *T. dicoccon* grown in El Batan soils in the winter months (reference values are less useful here because of different growing season), the zinc concentrations in *T. dicoccoides* averaged 68 ppm, with a maximum value of 142 ppm. The comparable figures for zinc concentration in *T. dicoccon* were 80 and 135 ppm, respectively (table 3).

The set of 1,000 lines included a group of entries representing a wide range of wild relatives of wheat, all grown in the El Batan screen house: *T. spelta, T. carthlicum, T. araraticum, T. macha, T. polonicum, T. turgidum, T. timopheevii, T. boeoticum,* and *T. monococcum. T. boeoticum* had the highest concentrations of both iron and zinc: 77 and 89 ppm, respectively (table 3).

1B/1R translocation

A chromosome from rye (1R) has been widely introduced into wheat, where it has replaced the 1B chromosome. This was done to introduce a new source of leaf rust resistance that is present in the 1R chromosome. It has been estimated that about 60% of the CIMMYT bread wheat material has this 1B/1R translocation for disease resistance. Research was undertaken to evaluate the effect of the 1B/1R translocation in bread wheat with respect to nutrient concentration in the grain. The fact that rye is a crop that is very efficient in nutrient use suggests that some genes associated with high iron and zinc in the grain might be present in the 1R chromosome.

TABLE 3. Summary of mean and maximum and minimum values found for iron and zinc concentrations in screening trials

Description of wheats analysed	Grown in same location and season?	Location	Season	Iron (ppm)			Zinc (ppm)			Variety with maximum density	
				Mean	Max	Min	Mean	Max	Min	Iron	Zinc
Sample of 505	No	Several		34	59	20	34	67	16		
Sample of 170	Yes	Obregon		37	56	25	35	65	25	CMH84.3595	*T. dicoccon*
Sample of 154	Yes	Obregon		43	73	32	41	92	26		
Subsample of 1,000		Obregon		76	99	59	50	69	38	*T. tauschii*	*T. tauschii*
Subsample of 1,000		El Batan	Winter				68	142		*T. dicoccoides*	*T. dicoccoides*
							80	135		*T. dicoccon*	*T. dicoccon*
Subsample of 1,000		El Batan	Summer		70			131		*T. monococcum*	*T. monococcum*
Study of historical releases		El Batan	Summer	44	57	34	29	37	23		
Subsample of 1,000		El Batan screen house		42	77	26	43	89	22	*T. boeoticum*	*T. boeoticum*

Two different sets of 1B/1R near-isogenics were studied for their contribution to mineral concentration in the grain (near-isogenics are two nearly identical lines, one having the genes to be studied and the other with these genes missing). In the first year, both sets showed a significant increase in iron and zinc concentration of between 6% and 12% in favour of the 1B/1R translocation as compared with the 1B/1B type. Both experiments were repeated a second year, and no significant differences between 1B/1R and 1B/1B in iron and zinc concentrations were found.

Dwarfing genes (*rht*)

The incorporation of the Norin 10 dwarfing genes (*Rht1* and *Rht2*)* in wheat was undertaken with the original objective of reducing lodging (falling over); however, this also resulted serendipitously in the allocation of a higher proportion of the total biomass to the grain. These two changes, improved lodging tolerance and increased yield potential, gave birth to the modern wheat varieties, which in turn initiated what has come to be called the Green Revolution. The effect of the dwarfing genes in terms of dry matter partitioning as well as protein partitioning to the grain has been well documented. There has been an increase in grain yield [1] and a reduction in percent protein concentration in the grain in high-nitrogen environments [2].

New research was undertaken to evaluate the effect of the two dwarfing genes on the mineral concentration in the grain. Again, this was undertaken using two sets of near-isogenic lines. Our results show that *rht* genes resulted in higher yields and lower concentrations of iron and zinc in the grain of bread wheat in some genetic backgrounds, but not in others. There was no effect of the dwarfing genes in bread wheat on iron and zinc concentration in the grain when these lines were grown under drought conditions. In durum wheat there was no effect of the *Rht1* gene on iron and zinc concentration in the grain under irrigated or drought conditions, despite the grain yield increase.

Crop management

Nitrogen and water deficiencies are the two primary stresses limiting global wheat production. We established a replicated trial to evaluate the effect of the presence of these two stresses on iron and zinc concentrations in the grain. The findings indicate that the application of medium to high rates of nitrogen fertilizer increases the iron and zinc concentration. If wheat is grown in a nitrogen-deficient soil, the iron and zinc concentrations in the grain are 8 to 10 ppm lower on average, under irrigated or drought conditions, than in fields where nitrogen fertilizer was applied. Therefore, farmers who grow wheat under nitrogen-deficient conditions (due to the lack of fertilizers, manure, or leguminous rotations) will harvest wheat with lower concentrations of iron and zinc in the grain.

Green Revolution varieties of wheat

A historical set of bread wheat cultivars, which represent progress in the CIMMYT bread wheat-breeding programme from 1950 to 1992, were studied to determine if changes in iron and zinc concentrations had occurred over time. A total of five experiments were established in a period of three years in the Yaqui Valley in northwestern Mexico and in the central highlands. These two locations are agroclimatically representative of 44% of the wheat area in the developing world. The first two released varieties included in the study were Yaqui 50 and Nainari 60, which are traditional tall varieties. The remaining entries were semi-dwarf wheats, representing progress in the period of semi-dwarf improvement at CIMMYT.

As expected, the study found a strong linear relationship between the year of release and grain yield. Seventy-two percent of the variability in grain yield between 1950 and 1992 was explained by the year of release. In absolute terms, the estimated rate of progress in grain yield has been 51 kg/ha/year (a cumulative total of about 2.1 tons/ha over 42 years from a base of about 4 tons/ha) and in relative terms 1% per year. This rate of yield gain is comparable to that of CIMMYT breeding work elsewhere in the world [3].

Regression analysis indicated a small but statistically significant negative trend in iron and zinc concentra-

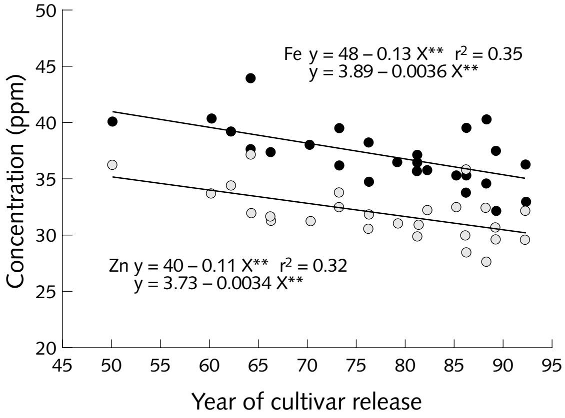

FIG 1. Grain iron and zinc concentrations in a historical set of CIMMYT releases in the Yaqui Valley, Mexico

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* The abbreviation *rht* refers to the description of the loci associated with "reduced height-rht."

tions. Variation around this trend was substantial (fig. 1); only 35% and 32% of the variability in iron and zinc concentration, respectively, was explained by the year of release. Several varieties released by CIMMYT throughout 1960–92 had concentrations of iron and zinc comparable to those found in the first two tall varieties included in the study, whereas the concentrations in the other releases were substantially lower. The estimated reduction in iron and zinc concentration has been 0.13 ppm/year (a cumulative total of about 5 ppm over 42 years from a base of 40 ppm, and 35 ppm for iron and zinc concentrations, respectively) in absolute terms and 0.3% per year in relative terms.

The total phosphorus concentration in the grain was studied, and a significant negative trend with respect to the year of release was also found. Similar to iron and zinc concentrations, only 35% of the variation was explained by the year of release. The rate of reduction in absolute terms has been 11.4 ppm per year (a cumulative total of about 450 ppm over 42 years from a base of about 3,500 ppm) or 0.3% per year. The proportion of phosphorus bound to phytate decreased over time from more than 90% to about 60%.

Conclusions

In our search for genetic material conferring high levels of iron and zinc in the grain of wheat, we have identified the following sources, in order of importance: wild relatives of wheat, landraces, bread wheat, triticales, and durum wheat. There remains a great potential to find even better genetic material, given that less than 1% of the germplasm available at CIMMYT has been screened. A significant positive correlation has been found between iron and zinc concentrations in the grain of wheat, suggesting that these two traits may be combined relatively easily during breeding.

The production of semi-dwarf wheat through the introduction of the *rht* genes has resulted in a yield increase in both bread wheat and durum wheat. However, this is associated with a reduction in iron and zinc concentration in the grain of some bread wheat genotypes, but not in durum wheat. The presence of the 1B/1R translocation in the germplasm of CIMMYT wheat may have had a positive effect on the concentration of iron and zinc in the grain, but a negative effect was ruled out.

There is a strong positive correlation between grain yield and year of release in the CIMMYT wheat varieties. There was a small and weak but statistically significant relationship between time of release and iron, zinc, and total phosphorus concentrations (and phytate) in the grain. The positive effect of crop management (nitrogen applications) on iron and zinc concentrations is more important (approximately twice as large in absolute terms) than declines in these concentrations, because of breeding in CIMMYT material during the last 42 years.

In future research, the very high values of iron and zinc in the grain seen in table 3 need to be confirmed in a trial in which all the best material is planted in the same location and year. In addition, it is important to determine if these high levels of iron and zinc in the grain can be maintained in high-yielding material. We have already started to make crosses between bread wheat and some of the wild species to answer this question.

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References

1. Ortiz-Monasterio JI, Sayre KD, Rajaram S, McMahon M. Genetic progress in wheat yield and nitrogen use efficiency under four N rates. Crop Sci 1997;37:898–904.
2. Ortiz-Monasterio JI, Peña RJ, Sayre KD, Rajaram S. CIMMYT's genetic progress in wheat grain quality under four N rates. Crop Sci 1997;37:892–98.
3. Byerlee D, Traxler G. Estimation of actual spillovers of national and international wheat improvement research. In: Maredia MK, Byerlee D, eds. The global wheat improvement system: prospects for enhancing efficiency in the presence of spillovers. CIMMYT Research Report No. 5. Mexico, DF: Centro Internacional de Mejoramiento de Maiz y Trigo, 1997:46–59.

The potential for increasing the iron and zinc density of maize through plant-breeding

Marianne Bänziger and Jennifer Long

Abstract

The Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) maize-breeding programme has been focusing on identifying white-grained maize germplasm that has the potential to increase kernel iron and zinc concentrations, especially in sub-Saharan Africa. In addition, research at Cornell University has focused on traits such as multiple aleurone layer, which can increase kernel iron and zinc concentrations, and low phytic acid concentration, which holds promise for improving the bioavailability of iron and zinc. More than 1,400 improved maize genotypes and 400 landraces were grown and evaluated to assess grain iron and zinc concentrations. These materials represented all white-grained landraces that belonged to the core collection of CIMMYT's germplasm bank, all white- and yellow-grained CIMMYT maize germplasm pools and populations, all white-grained materials that are currently in the active breeding programme of CIMMYT-Zimbabwe, and 57 white-grained maize cultivars currently grown in southern Africa. After a very thorough evaluation of the genetic variability of iron and zinc potentially available in white-grained tropical maize germplasm, promising genetic variability was found in both improved maize germplasm and landraces.

One difficulty that maize breeders encounter is that grain iron and zinc concentrations are often correlated negatively with grain yield, which may result from the increased carbohydrate content of high-yielding materials, so that a given amount of iron and zinc is diluted. The multiple aleurone trait may be a fast track to overcome this effect. This trait is being introgressed into various materials in both the United States and southern Africa.

Introduction

Many poor people in southern and eastern Africa subsist on a maize-based diet that is low in iron and zinc [1]. As an example of the consequences, 30% of pregnant and lactating women in Zimbabwe are thought to be iron deficient [2]. Improving the nutritional quality of maize could therefore have a significant impact on the nutriture of poor women and children in southern and eastern Africa.

Little is known about the genetic variation of iron and zinc concentrations in the grain of maize and the potential to improve it through plant-breeding. Over the past five years, the maize-breeding programme of the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) has focused on identifying white-grained maize germplasm that has the potential to address iron and zinc deficiencies in humans, especially in sub-Saharan Africa, through increased kernel iron and zinc concentrations. In addition, research at Cornell University has focused on traits such as multiple aleurone layer (MAL), which can increase kernel iron and zinc concentrations [3], and low phytic acid concentration, which holds promise for improving the bioavailability of iron and zinc. Low-phytic-acid maize has reduced levels of phytate, an iron and zinc chelator, in the kernels [4]. Therefore, more iron and zinc can be absorbed from the diet [5, 6]. There is also evidence that lysine, which is present in higher concentrations in opaque or quality protein maize (QPM), promotes iron and zinc absorption [6].

Materials and methods

More than 1,400 improved maize genotypes and 400 landraces were grown and evaluated to assess grain iron and zinc concentrations. These materials represented all white-grained landraces that belonged to the core collection of CIMMYT's germplasm bank, all white- and yellow-grained CIMMYT maize germplasm pools and populations, all white-grained materials

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that are currently in the active breeding programme of CIMMYT-Zimbabwe, and 57 white-grained maize cultivars currently grown in southern Africa. The materials were grown at Glendale, Harare, Kadoma, Matopos, and Rattray-Arnold in Zimbabwe and at Tlaltizapan in Mexico on reddish (Glendale, Harare, Kadoma, and Rattray-Arnold) and black (Matopos and Tlaltizapan) clays. Bordered trials with plant densities of 5.3 plants per square metre were used, and grain micronutrient concentrations, anthesis date, grain yield, and the severity of ear rot and leaf diseases (*Cercospora zea maydis, Exserohilum turcicum*, and *Puccinia sorghi*) were measured. An analysis of variance was conducted for replicated trials. Correlations were calculated between grain iron and zinc concentrations and anthesis date, grain yield, and the severity of disease symptoms.

Germplasm was also being developed at Cornell University to increase the content and bioavailability of iron and zinc in maize. A multiple aleurone layer source, Mo316, was crossed with high-lysine opaque maize in an elite background and with low-phytic-acid maize. Eight lines of low- and high-phytate maize were grown in a greenhouse study to assess early seedling development on phosphorus-deficient soil.

Results and discussion

Table 1 summarizes the maximum and minimum grain iron and zinc concentrations for 1,814 maize germplasms evaluated in a total of 13 trials in Zimbabwe and Mexico. Across trials, grain iron concentrations between 9.6 and 63.2 mg/kg and grain zinc concentrations between 12.9 and 57.6 mg/kg were found. These differences probably were not due to genetic differences alone, but were also influenced by the different locations and years in which the germplasm was grown. For example, it seems that the trials in Mexico had much lower average values for iron and zinc than the trials in Zimbabwe. Within individual trials, high values for grain iron and zinc concentrations averaged 69% and 49%, respectively, above the mean of the trial, indicating considerable variation of grain iron and zinc concentrations in maize.

Among the germplasms evaluated in trials 4 to 13, which were all elite materials, the germplasms highest and lowest in grain iron and zinc concentrations were selected and reevaluated at six locations in Zimbabwe during 1997–98 (table 2). Even though the same germplasm was included, the trials averaged between 13.2 and 18.5 mg/kg for iron and between 19.4 and 24.0 mg/kg for zinc, confirming that the growing conditions at a given location influence grain iron and zinc concentrations. In addition, the same germplasm that produced a range of 16.4 to 63.2 mg/kg for iron and 12.9 to 57.6 mg/kg for zinc when evaluated in trials 4 to 13 (table 1) only ranged between 14.4 and 21.8 mg/kg for iron and between 18.5 and 28.6 mg/kg for zinc when

TABLE 1. Average, minimum, and maximum of 1,814 maize germplasms evaluated in 13 trials in Mexico and Zimbabwe for grain iron and zinc concentrations between 1994 and 1998–99

Trial no.	No. of entries	Site[a]	Year	Mean grain yield (tons/ha)[b]	Iron (mg/kg)			Zinc (mg/kg)		
					Mean	Min	Max	Min	Max	Mean
Landraces from CIMMYT germplasm bank										
1	416	Harare	1998–99	2.89	25.6	17.5	58.5	22.3	14.9	29.7
CIMMYT germplasm pools and populations										
2	50	Tlaltizapan	1994	4.70	14.3	11.3	18.3	23.3	19.0	30.3
3	100	Tlaltizapan	1994	6.20	12.9	9.6	16.9	20.7	14.5	25.4
Active breeding germplasm from CIMMYT-Zimbabwe and released cultivars from southern Africa										
4	100	Harare	1995–96	6.23	25.7	21.9	38.2	23.8	20.3	29.5
5	100	Rattray	1995–96	8.42	32.3	26.8	57.3	22.1	18.1	26.5
6	147	Matopos	1995–96	na	23.2	19.1	30.2	23.5	18.6	30.6
7	195	Harare	1995–96	na	24.4	19.1	38.5	21.4	15.8	57.6
8	181	Harare	1995–96	na	23.3	17.6	61.8	20.4	14.1	28.2
9	119	Harare	1995–96	na	22.3	18.7	26.2	20.3	15.6	24.0
10	140	Harare	1995–96	na	26.4	19.8	63.2	21.7	17.3	37.0
11	155	Harare	1995–96	na	22.7	18.0	47.1	20.5	12.9	31.0
12	91	Harare	1995–96	na	22.0	16.9	33.5	21.6	16.7	46.0
13	20	Harare	1996–97	5.09	19.6	16.4	22.9	19.8	14.7	24.0

a. Tlaltizapan is in Mexico; the other sites are in Zimbabwe.
b. na = not available.

TABLE 2. Average, minimum, maximum, and statistics of 90 maize germplasms evaluated at six locations in Zimbabwe for grain iron and zinc concentrations during 1997–98[a]

Site	Mean grain yield (tons/ha)	Iron (mg/kg)					Zinc (mg/kg)				
		Mean	LSD$_p$ = 0.05	Min	Max	p	Mean	LSD$_p$ = 0.05	Min	Max	p
Harare, N applied	8.02	18.5	3.4	14.4	26.0	< .001	21.9	3.4	16.7	31.5	< .001
Harare, N stress	3.20	13.2	3.3	11.1	19.8	< .001	23.7	3.3	18.4	31.2	< .001
Matopos	1.40	17.5	4.6	13.8	20.7	< .01	24.0	4.6	18.8	29.1	< .01
Rattray	7.12	18.1	2.9	14.6	22.8	< .001	19.7	2.9	15.3	25.8	< .001
Kadoma	9.62	17.6	3.2	14.3	25.3	< .001	19.4	3.2	15.0	23.3	< .001
Glendale	7.65	18.1	4.2	13.2	25.7	< .001	23.8	4.2	17.8	30.8	< .001
Across sites	6.17	17.2	3.0	14.4	21.8	< .001	22.0	3.7	18.5	28.6	< .001

a. The p values show the significance of genotypic differences. LSD (least significant difference) is a t test for comparing the statistical significance of differences between two adjacent lines when the lines are ranked from minimum to maximum.

reevaluated across six locations (table 2). Thus, some of the variation presented in table 1 was probably due to environmental effects. From the results in table 2, genetic variation in grain iron and zinc concentrations in elite white-grained maize germplasm was found to be around 30% above the mean of the trial.

In the search for maize materials that could provide even more iron and zinc, a representative sample of all white-grained landraces currently held in the CIMMYT maize germplasm bank was evaluated in 1998–99 (table 1, trial 1). These are non-elite materials that have not been improved through a formal breeding process. The kernel concentrations in these materials varied from 17.5 to 58.5 mg/kg for iron and from 14.9 to 29.7 mg/kg for zinc. The best of these materials are currently being evaluated in multilocation trials. If the results of the multilocation trials confirm the potential of these landraces, they will be crossed with more elite germplasm, particularly those with already high iron and zinc concentrations.

One difficulty that maize breeders encounter is that grain iron and zinc concentrations are often correlated negatively with grain yield, indicating that many low-yielding maize germplasms express high grain iron and zinc concentrations (table 3). A selection of such materials would be undesirable. This correlation may result from the increased carbohydrate content of high-yielding materials, which dilutes a given amount

TABLE 3. Correlations between grain yield and grain iron and zinc concentrations in various trials evaluated in Mexico and Zimbabwe between 1994 and 1998–99

Trial no.	No. of entries	Site[a]	Year	Iron	Zinc
Landraces from CIMMYT germplasm bank					
1	416	Harare	1998–99	–0.22	–0.32
CIMMYT germplasm pools and populations					
2	50	Tlaltizapan	1994	–0.32	–0.39
3	100	Tlaltizapan	1994	–0.17	–0.29
Active breeding germplasm from CIMMYT-Zimbabwe and released cultivars from southern Africa					
4	100	Harare	1995–96	–0.15	–0.03
5	100	Rattray	1995–96	0.09	–0.11
13	20	Harare	1996–97	–0.20	–0.21
Selected germplasm from trials 4 to 13, evaluated at 6 locations					
	90	Harare, N applied	1997–98	–0.60	–0.44
	90	Harare, N stress	1997–98	–0.16	–0.28
	90	Matopos	1997–98	0.16	–0.15
	90	Rattray	1997–98	–0.52	–0.35
	90	Kadoma	1997–98	–0.46	–0.23
	90	Glendale	1997–98	–0.40	–0.40

a. Tlaltizapan is in Mexico; the other sites are in Zimbabwe.

of iron and zinc. In our studies, dilution effects in the opposite direction were also seen when yields were compromised by disease susceptibility or early maturity (results not shown). Disease-susceptible germplasm and early-maturing germplasm had significantly lower grain yields, resulting in lower carbohydrates and increasing grain iron and zinc concentrations. Because the correlation between yield and mineral density is never close to –1.0, however, there seems to be sufficient potential to select for high-yielding maize germplasm that also possesses high iron and zinc concentrations. The multiple aleurone trait may be a fast track to overcome the negative correlation between grain yield and kernel iron and zinc concentrations. Because most of the iron and zinc in maize kernels is localized in a single cell layer in the endosperm, the aleurone layer, an increase in the number of cell layers increases the ratio of iron- and zinc-rich cells to regular endosperm cells. Data from Welch et al. [3] show promising results in this regard, and the multiple aleurone trait is being introgressed into various materials both in the United States and in southern Africa.

Another avenue that is being explored is maize germplasm with high iron bioavailability. Low-phytic-acid maize has been shown to have higher iron bioavailability [5]. In low-phytic-acid strains, inorganic phosphorus replaces phytic acid, with total phosphorus remaining about constant. Because of this change in the form of phosphorus, effects on seedling vigour, particularly under the phosphorus-deficient soil conditions found in much of the developing world, must be examined. In a preliminary study, low-phytic-acid 1-1 (*lpa 1-1*) mutant lines were evaluated for performance under phosphorus-deficient conditions. The *lpa 1-1* lines had significantly lower shoot dry weights than high-phytate (wild-type) lines two weeks after emergence, whereas there were no longer significant differences between shoot dry weights at 3.5 weeks post-emergence. Thus, the high-phytate plants grew more vigorously early in development. The *lpa 1-1* maize shoots, on the other hand, had significantly greater concentrations of calcium, phosphorus, manganese, and zinc than high-phytate maize shoots two weeks after emergence and significantly higher calcium, phosphorus, copper, and manganese concentrations at 3.5 weeks after emergence. We conclude that low-phytic-acid maize seems to show a different response to phosphorus-deficient soils, and this needs to be further evaluated to preclude negative consequences of the low-phytic-acid trait for maize production.

Conclusions

After a very thorough evaluation of the genetic variability in iron and zinc potentially available in white-grained tropical maize germplasm, we found promising genetic variability in improved maize germplasm as well as in landraces. Materials selected for high iron and zinc should therefore be further evaluated for their nutritional value for human consumption. Additional research is needed on traits that improve the bioavailability of iron and zinc in maize.

References

1. Centro Internacional de Mejoramiento de Maiz y Trigo. 1997/98 world maize facts and trends. Mexico City: Centro Internacional de Mejoramiento de Maiz y Trigo, 1999.
2. Bhebe S, Sikosana PLN, Katuli DS. A prevalence survey of iron deficiency and iron deficiency anemia in pregnant and lactating women, adult males and preschool children in Zimbabwe. Harare, Zimbabwe: Ministry of Health and Child Welfare, 1997.
3. Welch RM, Smith ME, Van Campen DR, Schaefer SC. Improving the mineral reserves and protein quality of maize (*Zea mays* L.) kernels using unique genes. Plant Soil 1993;155/156:215-8.
4. Raboy V. Low-phytic-acid grains. Food Nutr Bull 2000; 21:423–7.
5. Mendoza C, Viteri F, Lonnerdal B, Raboy V, Young K, Brown KH. Effect of genetically modified, low-phytate maize on iron absorption from tortillas. FASEB J 1997;11:A607.
6. Graham RD, Welch RM. Breeding for staple food crops with high micronutrient density. Working Papers of Agricultural Strategies for Micronutrients No. 3. Washington, DC: International Food Policy Research Institute, 1996.

Zinc and iron concentrations in seeds of wild, primitive, and modern wheats

I. Cakmak, H. Ozkan, H. J. Braun, R. M. Welch, and V. Romheld

Abstract

In the case of cultivated modern wheats, the variation in zinc and iron concentrations in seeds is relatively small. Moreover, environmental and management factors exert a greater effect on variation of micronutrient concentrations of modern cultivated wheats than genetic factors. Wild wheats might serve as an important source of new genetic material for increasing micronutrient concentrations in seeds. To investigate this, we studied the variation in zinc and iron concentrations in seeds of wild and primitive diploid wheats and wild tetraploid wheats. The variation was particularly large in the case of zinc. The highest concentrations of zinc were found in the seeds of ssp. boeoticum *(178 mg/kg) and ssp.* dicoccoides *(159 mg/kg). The results demonstrate that the genetic variation in the concentrations of zinc and iron in cultivated modern tetraploid and hexaploid wheats is extremely low when compared with the variation found in wild diploid and tetraploid wheats. This suggests that wild wheats, particularly chromosomes 6A and 6B in the wild tetraploid wheats, can be considered a major source of genetic diversity for increasing zinc and iron density in the seeds of modern wheats. In view of the fact that the concentrations of protein in seeds are strongly and positively correlated with the concentrations of iron and particularly of zinc, selection and/or breeding for high zinc and iron levels in seeds may result in simultaneously high levels of protein.*

Introduction

Zinc and iron deficiencies are the most prevalent micronutrient deficiencies in soils and plants, resulting in large decreases in crop production and quality [1]. One approach to increasing zinc and iron concentrations in seeds is fertilization of plants via soils or foliar sprays. However, in most cases, zinc or iron concentrations in seeds do not improve to the desired levels, and in any event, there is no direct economic motivation for farmers to improve the nutritional quality of seeds through fertilization, although this may improve crop yields.

An alternative approach is to exploit the genetic variation in concentrations of these micronutrients in seeds through plant-breeding. In the case of cultivated modern wheats, however, the variation in zinc and iron concentrations in seeds is relatively small. Moreover, environmental and management factors exert a greater effect on the variation of micronutrient concentrations of modern cultivated wheats than genetic factors [2, 3]. However, as indicated by Cakmak et al. [4] and by Monasterio and Graham [5], wild wheats might serve as an important source of new genetic material for increasing micronutrient concentrations in seeds. Wild and primitive wheats are rich in genetic diversity for a number of agronomically valuable traits [6, 7].

To investigate this, we studied the variation in zinc and iron concentrations in seeds of wild (ssp. *urartu* and ssp. *boeoticum*) and primitive (ssp. *monococcum*) diploid wheats and wild tetraploid (ssp. *dicoccoides*) wheats. In addition, we identified the role of genes of some wild tetraploid wheats that are associated with high zinc and iron concentrations in modern wheats. Selected *dicoccoides*-modern wheat substitution lines were used in this last study. Seed samples were obtained from Israel (from Dr. M. Feldmann), Germany (from Dr. A. Börner), and Japan (from Dr. N. Watanabe). For each country except Turkey, seeds were obtained from plants that were grown under similar greenhouse conditions. As indicated in table 1, the

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TABLE 1. Concentration and content (total amount) of zinc and iron in seeds of different wild, primitive, and modern wheats

			Zinc				Iron			
			Concentration (mg/kg)		Content (μg/seed)		Concentration (mg/kg)		Content (μg/seed)	
Species	*n*	Origin	Mean	Range	Mean	Range	Mean	Range	Mean	Range
T. boeoticum	12	Israel, Germany	89	45–177	1.3	0.7–3.0	79	41–92	1.1	0.4–1.5
T. monococcum	13	Israel	56	29–89	1.3	0.2–2.5	48	34–85	1.2	0.6–3.0
T. dicoccoides	19	Israel	91	20–159	3.1	0.5–5.3	34	24–49	1.1	0.4–2.3
T. dicoccoides	20	Germany	62	43–107	2.2	1.3–3.9	45	28–78	1.6	2.0–2.9
T. dicoccoides	7	Japan	69	42–126	2.2	1.1–4.0	43	34–66	1.3	0.6–2.1
T. durum	11	Israel	31	18–50	1.6	0.6–2.7	32	10–50	1.6	0.5–2.7
T. durum	4	Turkey	26	25–28	0.9	0.9–1.0	39	33–46	1.4	1.2–1.6
T. durum[a]	3	Turkey	9	9–10	0.4	0.4–0.4	35	33–37	1.7	1.6–1.7
T. aestivum	16	Israel	27	15–61	1.2	0.6–3.1	34	24–51	1.5	1.0–2.2
T. aestivum	8	Turkey	26	23–28	0.8	0.7–0.9	42	36–46	1.2	1.1–1.4
T. aestivum[a]	34	Turkey	9	8–12	0.4	0.3–0.5	33	29–38	1.3	0.9–1.6

a. Grown in zinc-deficient soils in Turkey.

seeds from Turkey were grown under field conditions in the same zinc-deficient or zinc-sufficient soils.

Wild and primitive wheats

The results for 25 wild diploid wheat (ssp. *boeoticum* and ssp. *urartu*) accessions and 46 wild tetraploid (ssp. *dicoccoides*) wheat accessions presented substantial variation in seed concentrations of iron and zinc. The variation was particularly large in the case of zinc. The accessions of wild tetraploid wheats from Israel differed by factors of 8 and 13 in concentration and content of zinc, respectively (table 1). Large differences were also found for iron, but the extent of the variation with iron was smaller. The highest concentrations of zinc were found in the seeds of ssp. *boeoticum* (178 mg/kg dry weight) and ssp. *dicoccoides* (159 mg/kg dry weight). Also in a set of ssp. *dicoccoides* accessions grown in El Batan, Mexico, Monasterio and Graham found accessions with very high concentrations of zinc in seeds [5]. The maximum concentration of zinc found in seeds of ssp. *dicoccoides* accessions in El Batan was 142 mg/kg dry weight. The fact that in each country *dicoccoides* accessions showed very high variation and concentrations of zinc suggests that high zinc concentrations in seeds of ssp. *dicoccoides* are genetically determined and not related to environmental conditions.

High concentrations of zinc in seeds of wild diploid wheats are partly related to smaller seed weight of these wheats. Among all wheats tested, the wild diploid wheats with the highest zinc concentrations had the lowest seed weights, indicating a role of "concentration effects" in high-zinc seeds. However, in the case of wild tetraploid wheats, the seed weights were markedly greater than in diploid wheats, and, therefore, most of the ssp. *dicoccoides* accessions showed the highest amount of zinc per seed among all wheats tested in this study. Although the correlation between zinc and iron concentrations was not always high, the accessions of ssp. *dicoccoides* also showed higher concentrations and contents of iron.

Modern tetraploid and hexaploid wheats

The concentrations of zinc and iron in seeds of the modern tetraploid (ssp. *durum*) and hexaploid (ssp. *aestivum*) wheats were much lower and less variable than those of the wild tetraploid and diploid wheats, particularly under zinc-deficient soil conditions (table 1). Clearly, domestication of wheat has resulted in lower seed concentrations of zinc and iron. The lower levels of zinc and iron in modern wheats as compared with the wild wheats might be related to the increased grain yield, or harvest index, of modern wheats, which causes a dilution of nutrients in seeds. However, in our study the accessions of the wild tetraploid wheats (ssp. *dicoccoides*) with higher zinc concentrations also had higher seed weight. Therefore, the very high concentrations and contents of zinc and iron found in some wild tetraploid wheat accessions cannot be attributed to a concentration effect. The existence of exceptionally large variation in concentration and content of zinc and iron in seeds of wild tetraploid wheats indicates that high micronutrient concentrations of wild tetraploid wheats are genetically controlled and not related to lower seed weight. In addition, in contrast to zinc, the variation in concentrations of other trace minerals in seeds, such as potassium, magnesium, and manganese, was very low and not relevant.

Unfortunately, we have no data about grain yield, which can also affect micronutrient concentrations in seeds. However, Graham et al. [8] reported that in wheat there is not always a negative linkage between yield capacity and concentration of micronutrients in seeds. In addition, Deckard et al. [9] showed that increases in nitrogen concentration (and also protein concentration) in modern cultivated wheats by transfer of genes from wild tetraploid wheats (ssp. *dicoccoides*) are not related to grain yield.

The results demonstrate that the genetic variation in concentrations of zinc and iron in cultivated modern tetraploid and hexaploid wheats is extremely low when compared with the variation found in wild diploid and tetraploid wheats. This suggests that wild wheats, particularly the wild tetraploid wheats (ssp. *dicoccoides*), can be considered as a major source of genetic diversity for increasing zinc and iron density in seeds of modern wheats.

Wheat-dicoccoides substitution lines

Given the above results, we studied the role of genes from wild tetraploid wheat (ssp. *dicoccoides*) in determining zinc and iron concentrations of the modern wheats. Two *dicoccoides* substitution lines sets were used: Chinese Spring (CS)-*dicoccoides* and Langdon (LNG)-*dicoccoides*. CS and LNG are modern hexaploid and tetraploid wheats, respectively. These sets were grown under same soil conditions in a greenhouse and obtained from Dr. M. Feldmann (Israel) and Dr. B. Friebe (Kansas State University, USA).

Depending on the parent cultivars, several critical chromosomes were found to exert a pronounced effect on the concentrations of zinc and iron. In the case of CS substitution lines, the 6B, 6A, and 5B chromosomes resulted in large increases in zinc and iron concentrations in comparison with their recipient parent. The increases were 3.2-fold for the 6B and 2.6-fold for the 5B and 6A chromosomes, particularly chromosomes 6B and 5B of the *dicoccoides* accession used in the development of CS substitution lines.

In the case of the LNG-DIC chromosome substitution lines, the 6B chromosome was also a very critical chromosome, increasing both zinc and iron concentrations in seeds. The LNG-DIC substitution lines have been studied very extensively by Dr. Joppa's group. In these studies, the 6B chromosome is associated with high protein concentration in the seed [9–11]. Many other reports have shown a consistently significant correlation between the concentrations of protein, zinc, and iron in seeds [2, 8, 12]. Thus, further research is warranted on the possible linkage between the inheritance of high zinc and iron concentrations and protein.

Conclusions

Our results indicate that the wild tetraploid wheats (ssp. *dicoccoides*), particularly their chromosomes 6A and 6B, are highly promising sources of genes that determine high levels of zinc and iron in seeds. In view of the fact that the concentrations of protein in seeds are strongly and positively correlated with the concentrations of iron and particularly of zinc, selection and/or breeding for high zinc and iron levels in seeds may result in a simultaneously high level of protein.

References

1. White JG, Zasoski RJ. Mapping soil micronutrients. Field Crop Res 1999;60:11–26.
2. Peterson CJ, Johnson VA, Mattern PJ. Influence of cultivar and environment on mineral and protein concentrations of wheat flour, bran, and grain. Cereal Chem 1986;63:118–86.
3. Rengel Z, Batten GD, Crowley DE. Agronomic approaches for improving the micronutrient density in edible portions of field crops. Field Crops Res 1999;60:27–40.
4. Cakmak I, Tolay I, Ozdemir A, Ozkan H, Kling CI. Differences in zinc efficiency among and within diploid, tetraploid and hexaploid wheats. Ann Bot 1999;84:163–71.
5. Monasterio I, Graham RD. Breeding for trace minerals in wheat. Food Nutr Bull 2000;21:392–6.
6. Sharma HC, Waines JG, Foster KW. Variability in primitive and wild wheats for useful genetic characters. Crop Sci 1981;21:555–9.
7. Ciaffi M, Lafiandra D, Porceddu E, Benedettelli S. Storage protein variation in wild emmer (*Triticum turgidum* ssp. *dicoccoides*) from Jordan and Turkey. I. Electrophoretic characterization of genotypes. Theor Appl Genet 1993;86:474–80.
8. Graham R, Senadhira D, Beebe S, Iglesias C, Monasterio I. Breeding for micronutrient density in edible portions of staple food crops: conventional approaches. Field Crops Res 1999;60:57–80.
9. Deckard EL, Joppa LR, Hammond JJ, Hareland GA. Grain protein determinants of the Langdon Durum-*dicoccoides* chromosome substitution lines. Crop Sci 1996;36:1513–6.
10. Joppa LR, Cantrell RG. Chromosomal location of genes for grain protein content of wild tetraploid wheat. Crop Sci 1990;30:1059–64.
11. Cantrell RG, Joppa LR. Genetic analysis of quantitative traits in wild emmer (*Triticum turgidum* L. var. *dicoccoides*). Crop Sci 1991;31:645–9.
12. Feil B, Fossati D. Mineral composition of triticale grains as related to grain yield and grain protein. Crop Sci 1995;35:1426–31.

Carotenoids in staple foods: Their potential to improve human nutrition

Robin D. Graham and Julia M. Rosser

Abstract

As part of the Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project, we have investigated the content of carotenoids in staple foods, particularly wheat. Wheat varies widely in carotenoid content, depending on the variety and type. Durum (pasta) wheat is generally higher in carotenoid content, because the market has continued to demand strong pigment in pasta and noodle products, whereas in bread wheat the market demands flour as white as possible. Consequently, twentieth-century wheat breeders have consciously selected wheat varieties low in carotenoid content, although older, high-carotenoid bread wheats are still available and the trait is not lost. The entire carotenoid biosynthetic pathway exists in wheat grains, so varieties high in β-carotene and/or other carotenoids can be reintroduced if and when education in nutrition creates the demand. Numerous high-yielding maize varieties high in β-carotene already exist and have been used to eliminate vitamin A deficiency in livestock. A β-carotene–rich rice has been genetically engineered recently. Although the carotenoid content of beans has not yet been explored, high–β-carotene lines of cassava exist, and the trait is easily handled in a breeding programme. Yellow types of most staples are known, for example, sorghum, potatoes, and sweet potatoes. The amounts present are such that we can assert that vitamin A deficiency could easily be eliminated globally by delivering the required amounts via food staples. Moreover, there are strong signs that other benefits in eye health, enhanced absorption of iron from non-haem sources, anticarcinogenic effects, enhanced aroma, and better storage life may also result.

Introduction

The world is awash with carotenoid pigments manufactured by all green plants in order to, among other things, protect chlorophyll from photodestruction by solar radiation at wavelengths it cannot utilize. The carotenoids absorb this green light and fluoresce it again at longer wavelengths so that it can then be absorbed by chlorophyll and converted to usable energy, namely, sugar. So fundamental is this photoprotective role that many herbicides act by inhibiting carotenoid synthesis [1]. Many non-photosynthetic tissues, notably storage tissues that constitute our staple foods, also contain carotenoids. In storage roots it is obvious that the pigments are not needed for harvesting light but may well perform a role as antioxidants, contributing to storage life.

There are two major classes of carotenoid pigments in plants: the carotenes, which are hydrocarbon chains with no hydroxyl side chain, and the xanthophylls, which are similar in structure but have hydroxyl side chains on their terminal rings. Figure 1 shows the structure of lycopene, α- and β-carotene, zeaxanthin and lutein, and retinol (vitamin A). The relation of retinol to βcarotene is obvious: cleavage of the β-carotene molecule exactly in the middle at the double bond yields two 20-carbon molecules of retinol.

Because α-carotene is not symmetrical like β-carotene, only one molecule of retinol is produced when it is cleaved in the middle, so α-carotene is only half as efficient as β-carotene in producing vitamin A in the human body. Because these carotenes are highly reactive antioxidants, not all of the ingested carotene will survive to be cleaved to produce vitamin A. It is generally considered that the human body can generate one molecule of retinol from each six molecules of β-carotene metabolized, and that conversion of α-carotene to retinol is about half as efficient as that of β-carotene. Lower conversion rates have been reported. There are four other carotenes that can be converted to retinol, but at even lower efficiencies than α-carotene and β-carotene.

The biosynthetic relationships among the carotenoids are shown in figure 2. Lycopene is the red pigment of tomatoes, and two separate pathways continue on

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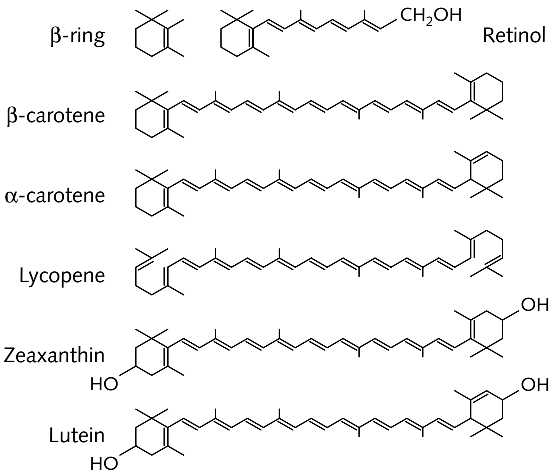

FIG. 1. Structures of important carotenoid pigments in plants and of retinol, showing that a β-ring is characteristic of both retinol and α- and β-carotene. Retinol is produced from α-carotene and β-carotene in the mammalian liver and intestinal mucosa

from it, leading to most of the important carotenes and xanthophylls in plant chloroplasts.

Millions of people in developing countries who rely heavily on grain products to meet their energy and protein requirements suffer from vitamin A deficiency, resulting in blindness, poor immune function, and early death [2]. In the lowest socio-economic strata of society, the relatively low cost of staples as a source of energy means that they constitute most of the diet. With some exceptions, this would appear to be because the major staples—wheat, rice, maize, cassava, potatoes, and sorghum—are white, starchy foods with few provitamin A carotenoids present. It appears that this may not always have been the case. Yellow types of all these staples are known, at least in the germplasm banks of the world, and appear to be more the norm for staples before the rise of modern plant-breeding efforts in the twentieth century. In some cases, yellow types are still common. Yellow cassava is known in northern Brazil and preferred as a fresh vegetable to the white types that are used for flour. Yellow maize, containing large amounts of β-carotene, is quite common and was bred in the United States some 40 years ago to cure hogs of vitamin A deficiency. However, like other staples, it is often not the choice for human consumption, perhaps because it is identified with animal feed, or because white flour is seen to be uncontaminated by soil, faecal material, or cheaper diluents.

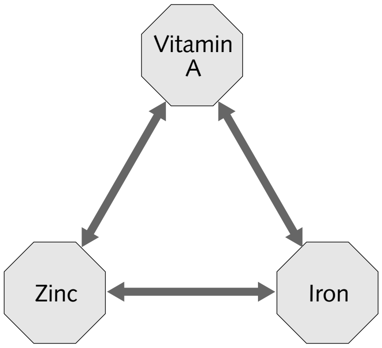

FIG. 3. Potential interactions in the absorption and metabolism of iron, zinc, and vitamin A in humans

Recent reports [3–5], suggesting that a relatively small supplement of vitamin A or β-carotene can double the absorption of endogenous non-haem iron from cereal meals, greatly increase the significance of carotenoids in staples. Carotenoids may be important not only in controlling vitamin A deficiency itself, but also in controlling the more ubiquitous and insidious iron-deficiency anaemia. Thus, a survey of the carotenoid content of current cultivars and germplasm bank resources of the major staples is needed to assess the potential to deliver health-related carotenoids to resource-poor populations who are isolated either geographically or socio-economically and heavily dependent on staples for food. This paper addresses the situation in the cereals, with emphasis on wheat.

Nutrient interactions involving iron, zinc, and vitamin A

The potential for synergistic interactions among three nutrients is shown in figure 3. Each corner of the triangle represents the main effect of one nutrient of this particular group of three nutrients that are of interest because they are among the most widely

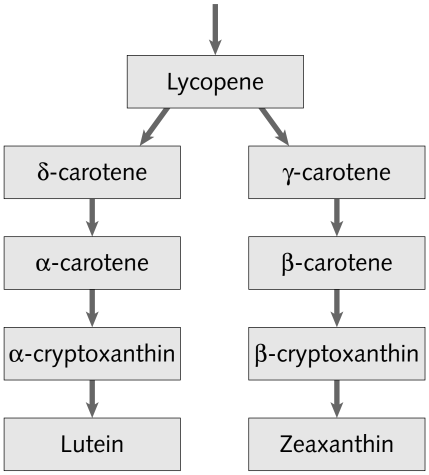

FIG. 2. Both α- and β-carotene are derived from lycopene via separate biosynthetic pathways. Through hydroxylation, the carotenes are converted to the oxygenated group of carotenoids known as xanthophylls

deficient in human populations [2, 6–8] and their density can be increased in staples by plant-breeding. Each side of the triangle represents the first-order interaction of a pair of nutrients, and there is the potential for a second-order interaction among all three nutrients. An interaction is recognized when the response of an individual to one nutrient is not constant but varies depending on the level of another nutrient. In terms of nutrition and health, the essential roles (main effects) of these three nutrients are well known and do not need to be repeated here.

Zinc–vitamin A interactions

Evidence of interactions between vitamin A and zinc emerged in the late twentieth century (see reviews by Christian and West [9], and Solomons and Russell [10]). In their summary figure, Christian and West [9] indicated a role of zinc in synthesis of retinol-binding protein (RBP), increasing lymphatic absorption of retinol and its inter- and intracellular transport, whereas vitamin A affects the synthesis of a zinc-dependent binding protein and thus the absorption and lymphatic transport of zinc. The interaction of delivering these two essential nutrients together to patients deficient in both was shown by Udomkesmalee et al. [11], in that they observed strong synergistic effects of adding both nutrients together on eye parameters and RBP. They concluded that the dual treatment was so effective that supplementation with only one dose containing twice the recommended daily allowance of each was sufficient to normalize the cohort. We argue that plant-breeding can also double the normal *daily* dose of these nutrients delivered by today's staples.

Iron–zinc interactions

Interactions of the mineral–mineral type among chemically relatively similar members of the transition metal series in both plants and animals have been characterized much earlier than the zinc–vitamin A type just mentioned (see Hill and Matrone [12]). Both synergistic and antagonistic interactions occur, but the competition of Fe^{2+} with Zn^{2+} for the bond with plasma transferrin is an antagonistic interaction that is well documented [13]; however, this effect is less likely to be significant if the subject is deficient in these nutrients. Recently, evidence of synergy in absorption generated by genetically different beans was identified (see King et al. [14] in these proceedings). The amount of iron absorbed by young women from two different beans of similar iron density was greater for the beans with the higher zinc density, and this could not be explained alternatively by the levels of phytate or tannins. Such a synergistic effect strongly indicates breeding for staples dense in both iron and zinc in order to address iron-deficiency anaemia effectively.

Vitamin A–iron interactions

Interest in this interaction has been kindled by the recent article by Garcia-Casal et al. [3], who showed that just 500 IU of vitamin A or β-carotene added to a 0.1-kg meal of cereal (wheat, rice, or maize) doubled the iron absorption from the gut of human subjects in Venezuela. Earlier work [5, 15, 16] suggests that this effect occurs in the presence of non-haem, phytate-bound iron and may be due to reduction and/or chelation of iron by the carotenoid, enhancing transport of iron from the lumen of the gut to the mucosal cell membrane. It appears that in the presence of high levels of phytate and tannins in the diet, vitamin A or β-carotene will enhance the bioavailability of iron in humans, but in the absence of these antinutrients, no enhancement was found [Welch RM, House WA, Glahn R, Garvin D, personal communication, 11 September 1999]. A further question arises as to whether the xanthophylls that are not precursors to vitamin A might also function to give this synergistic response, and perhaps function even better than β-carotene, if complex formation is the mechanism, as suggested by Garcia-Casal et al. [3].

A putative second-order interaction

Although the study may be technically difficult, a three-way interaction, in which the response to one nutrient depends on the levels of the other two nutrients, can be predicted. Given the synergies in all three first-order interactions, a person with a deficiency of all three nutrients can be expected to respond dramatically to relatively small supplements of the three nutrients given together until normal homeostasis is reached. This is because the absorption efficiency is likely to be very high for each, and with more of each available to catalyse the primary functions of the other, symptoms will be quickly suppressed. Put differently, the body has less tolerance to a deficiency when it occurs together with a deficiency of one or more synergistic nutrients. This principle is consistent with the finding of Udomkesmalee et al. [11], surprising to them, that only a relatively small supplement of both nutrients, zinc and vitamin A, was needed to normalize the diagnostic indices.

Genetics

Little definitive information on the genetics of inheritance of carotenoid content is available, except for carrots, in which three major genes controlling primary colour classes and other conditioning loci have been described [17]. Three basic biosynthetic enzymes are involved [18]. Seven major biosynthetic steps, and more than 20 genes, have been well characterized in the synthesis of carotenoids in tomatoes [19]. Hauge and Trost [20] described a major gene for carotene content in maize that is incompletely dominant and designated it the Y (yellow) locus.

Carotenoids of wheats

In order to breed wheat varieties with an enhanced carotene content, we need to understand the development of carotenoids in the wheat grain and the genetic variation in the biosynthetic process that could be exploited. The use of bread wheat as a staple in many regions where vitamin A deficiency is prevalent indicates that there is a need for identification and quantification of the carotenes present in wheat germplasm.

The most accurate method of identification of the many carotenoids that are present in biological material is high-performance liquid chromatography (HPLC). This accuracy is needed because each carotene has a different provitamin A activity, indicating its usefulness in the treatment of deficiencies. HPLC is especially valuable in the analysis of carotenes that are light, heat, and oxygen sensitive. A method of extracting carotenoids from wheat grain flour was established by comparing a number of solvents and extraction procedures to find the most efficient method that was also compatible with HPLC analysis. HPLC was used to distinguish between xanthophylls and the provitamin A carotenes. All procedures were conducted under nitrogen gas to prevent oxidation of carotenes.

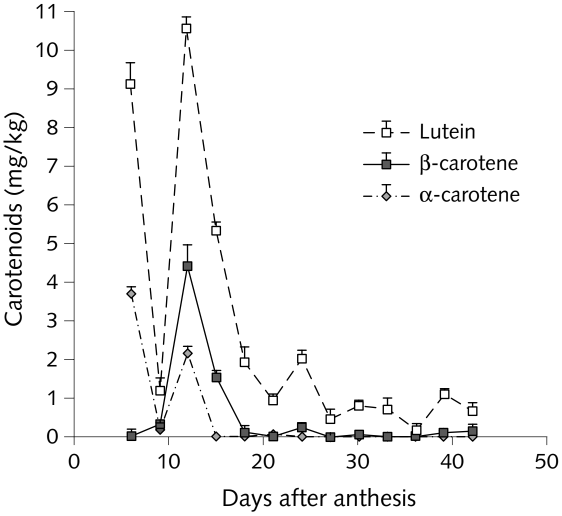

FIG. 4. Time trend of synthesis and metabolism of various carotenoids in the caryopsis of wheat (var. Krichauff) from anthesis to maturity

The appearance of carotenoids in the wheat grain during development and maturation was studied by the sequential harvest of grains from anthesis to full grain hardness. Figure 4 shows that total carotenoids reach a maximum 12 to 15 days after anthesis, and thereafter the concentrations decline. Both α-carotene and β-carotene decline to low levels at maturity, while lutein remained at measurable levels. This proves that the whole biosynthetic pathway exists in the endosperm of wheat and that recombination of genetic loci involved in the expression of each of the enzymes should be able to enhance the levels shown by 10 to 100 times. If the hydroxylation enzymes were suppressed, more carotenoid would be left as provitamin A, and the daily requirement should be deliverable in the normal daily intake of wheat products.

Bread and durum (pasta) wheats were analysed by HPLC; the range of concentrations found is represented in figure 5. These amounts are perhaps 20 times less than in a range of vegetables and fruits,* but the greater consumption of staples would make them more equal suppliers of carotenoids in the diet.

The carotenoid-dense lines of durum wheats, if all carotenoid were present as β-carotene, would be enough to supply the daily requirement (1–2 mg/kg of wheat products.

Carotenoids of rice

Ye et al. [21] have produced yellow endosperm transgenic rice grain containing β-carotene. Four genes

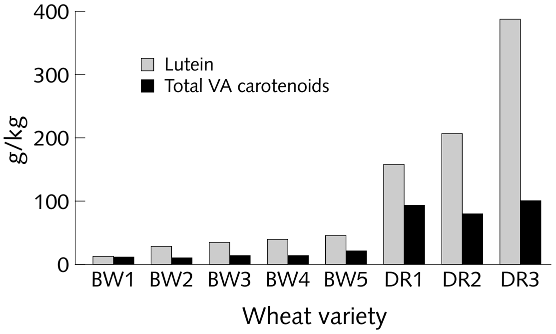

FIG. 5. Carotenoid concentrations of five bread wheats (BW) and three durum wheats (DR), representing the range of values found in collections from the germplasm banks in the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) and the International Center for Agricultural Research in the Dry Areas (ICARDA)

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* Rosser JM, Khachik F, Graham RDG. Paper presented at the 12th International Carotenoid Symposium, Cairns, Australia, 18–23 July 1999.I moved this from the refs. (no. 21). Is there a published version?

in two constructs, two from daffodil and two from the bacterium *Erwina uredovora*, were added to the rice line to complete the biosynthetic pathway to β-carotene. The resulting transgenic rice line synthesized enough β-carotene in the endosperm to meet part of the vitamin A requirements of people dependent on rice as a staple in South Asia. The insertion of these genes into rice to express β-carotene was necessary because parts of the pathway had been lost, while their own evidence suggests that downstream parts of the pathway were still expressed.

Recently, "yellow" rice that may supply the missing genes naturally was discovered in the International Rice Research Institute (IRRI) germplasm bank. On the advice of Prof. Lita del Mundo of the University of the Philippines, Los Baños, a search was made for amarillo (Spanish for yellow), and two entries were found, one from the Philippines and one from Cuba. The HPLC analyses of the pigments is under way. The endosperm is vitreous; one line appears to have pigment through half and the other through 90% of the endosperm, the rest being white "belly" or starchy endosperm. If so, further enhancement of expression should be possible by recombination between the two lines, and incorporation into the new high-iron, high-zinc, high-yielding variety should not take more than a few years.

Carotenoids of maize

White maize is frequently preferred for human consumption, and yellow types are preferred for animal feed. The stigma associated with this appears to be one barrier to the adoption of yellow maize for human consumption. Other colours are acceptable for human consumption, notably the highly prized blue maize in Mexico.

In maize, the total carotenoids varied by a factor of 2.5 between the means of six high-carotene and six low-carotene inbred lines, and their provitamin A activity varied by a factor of 4.4; even wider variation was found between means of single crosses made within these groups (table 1). Yellow corns have been recognized for decades as the main source of provitamin A for hogs and other farm animals relying on winter feed rations, and some effort has been put into breeding for this trait already [22]. Where yellow maize is already accepted in the marketplace, further enhancement of its provitamin A content could have an immediate positive impact on dietary intakes [23].

Conclusions

Carotenoids are abundant in the plant kingdom, not only in green tissues but in storage tissues as well, including most of the major staples. Both the provitamin A carotenes and the non-provitamin A xanthophylls abound, and moreover it appears from current research that both groups are essential to good vision and perhaps to anticarcinogenesis.

In the twentieth century, pure white varieties of the major cereals have been bred to meet market expectations by selecting for poor expression of the enzymes of the carotenoid biosynthetic pathway, but older varieties and landraces exist, so that breeders could, if required, "turn the clock back."

The germplasm resources are such that it should be possible for breeders to produce, by conventional means, cereals with sufficient provitamin A and other essential carotenoids to satisfy the daily requirements of resource-poor people whose diet is severely restricted in other sources of these nutrients

Among the three micronutrients—iron, zinc, and carotenoids (deficiencies of which are major global public health issues currently)—there are important synergies in absorption, transport, and function that strongly indicate substantial benefits to enhancing all three nutrients together. The genetic resources to meet this challenge are available and are not beyond a moderately well-funded breeding programme for

TABLE 1. Provitamin A content of corn (mg/kg) calculated from the contents of β-carotene + β-zeacarotene + cryptoxanthin, presented as the means of six high- and six low-carotene inbreds, and of the means of nine single crosses made within each group [22]

Parental carotene concentration	Selfed[a]	Single crosses	High–low single cross
High	6.5	7.5	4.1
Low	1.3	1.7	

a. Selfed refers to a variety crossed with itself.

References

1. Ben-Aziz A, Koren E. Interference in carotenogenesis as a mechanism of action of the pyridazinone herbicide Sandoz 6706. Accumulation of C-40 carotenoid precursors, inhibition of β-carotene synthesis, and enhancement of phytoene epoxidation. Plant Physiol 1974;54:916–20.
2. World Health Organization. Trace elements in human nutrition and health. Geneva: WHO, 1996.
3. Garcia-Casal MN, Layrisse M, Solano L, Baron MA, Arguello F, Lloera D, Ramirez J, Leets I, Tropper E. Vitamin A and β-carotene can improve nonheme iron absorption from rice, wheat and corn by humans. J Nutr 1998;128:646–50.
4. Garcia-Casal M, Layrisse M. Food iron absorption: role of vitamin A. Arch Latinoam Nutr 1998;48:191–6.
5. Layrisse M, Garcia-Casal M, Solano L, Baron M, Arguello F, Llovera D, Ramirez J, Leets I, Tropper E. The role of vitamin A on the inhibitors of nonheme iron absorption: preliminary results. J Nutr Biochem 1997;8:61–7.
6. World Health Organization/United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition. Second report on the world nutrition situation. Global and regional results. Vol. 1. Geneva: WHO, 1992:1–80.
7. World Bank. Enriching lives: overcoming vitamin and mineral malnutrition in developing countries. Development in Practice Series. Washington, DC: World Bank, 1994.
8. Gibson RS. Zinc nutrition in developing countries. Nutr Res Rev 1994;7:151–73.
9. Christian P, West KP Jr. Interactions between zinc and vitamin A: an update. Am J Cli*n* Nutr 1998;68:435S–41S.
10. Solomons NW, Russell RM. The interaction of vitamin A and zinc: implications for human nutrition. Am J Clin Nutr 1980;33:2031–40.
11. Udomkesmalee E, Dhanamitta S, Sirisinha S, Chatroenkiatkul S, Tuntipopipat S, Banjong O, Rojroongwasinkul N. Effect of vitamin A and zinc supplementation on the nutriture of children in Northeast Thailand. Am J Clin Nutr 1992;56:50–7.
12. Hill CH, Matrone G. Chemical parameters in the study of *in viv*o and *in vitr*o interactions of transition elements. Fed Proc 1970;29:1474–81.
13. Georgievskii VI, Annenkov BN, Samokhin VT. Mineral nutrition of animals. London: Butterworths, 1982.
14. King JC, Donangelo CM, Woodhouse LR, Mertz SD, Shames DM, Viteri FE, Cheng Z, Welch RM. Measuring iron and zinc bioavailability in humans. Food Nutr Bull 2000;21:434–9.
15. Laryisse M, Garcia-Casal M. Strategies for the prevention of iron deficiency through foods in the household. Nutr Re*v* 1997;55:233–9.
16. Taylor P, Martinez-Torres C, Mendez-Castellano H, Jaffe W, Lopez de Blanco M, Landaeta Jimenez M, Leets I, Tropper E, Ramirez J, Garcia-Casal MN, Layrisse M. Iron bioavailability from diets consumed by different socioeconomic strata of the Venezuelan population. J Nutr 1995;125:1860–8.
17. Gabelman WH, Peters S. Genetical and plant breeding possibilities for improving quality of vegetables. Acta Horticult 1979;93:243–63.
18. Camara B, Schantz R, Moneger R. Enzymology and genetic regulation of carotenoid biosynthesis in plants. In: Bills DD, Kung S-Y, eds. Biotechnology and nutrition. Boston, Mass, USA: Butterworth-Heinemann, 1992:301–14.
19. Porter JW, Spurgeon SL, Sathyamoorthy N. Biosynthesis in carotenoids. In: Nes WD, Fuller G, Tsai LS. Isopentenoids in plants: biochemistry and function. New York: Marcel Dekker, 1984:161–83.
20. Hauge SM, Trost JF. An inheritance study of the distribution of vitamin A in maize. J Bio*l* Chem 1928;80:107–15.
21. Ye X, Al-Babili S, Klöti A, Zhang J, Lucca P, Beyer P, Potrykus I. Engineering the pro-vitamin A (β-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. Science 2000;287:303–5.
22. Brunson AM, Quackenbush FW. Breeding corn with high provitamin A in the grain. Crop Sci 1962;2:344–7.
23. Simon PW. Genetic improvement of vegetable carotene content. In: Bills DD, Kung S-Y, ed. Biotechnology and nutrition. Boston, Mass, USA: Butterworth-Heinemann, 1991:291–300.

Iron, carotene, and ascorbic acid in cassava roots and leaves

A. L. Chavez, J. M. Bedoya, T. Sánchez, C. Iglesias, H. Ceballos, and W. Roca

Abstract

The cassava core collection (601 genotypes) was evaluated for root and leaf contents of micronutrient minerals, ascorbic acid, and carotene. Wide genetic variability was observed for all measurements, indicating that there is good potential for exploiting and improving the nutritive value of cassava. There seems to be little correlation between the levels of any micronutrient in roots and leaves. There was no clear association between carotene and ascorbic acid concentrations. A genetic study of the progeny of a cross between yellow and white parents indicated control of the yellow trait by only two genes. The stability of vitamins after three commonly used processing procedures was evaluated in a sample of 26 genotypes. A higher proportion of the original vitamin content survived boiling, whereas solar drying resulted in the highest losses. Carotene was more stable than ascorbic acid. In a limited number of lines, there was some indication that higher vitamin content was associated with decreased post-harvest physiological deterioration. Since it is well established that β-carotene and ascorbic acid can enhance the absorption and internal transport of dietary iron and zinc from plant sources, yellow varieties of cassava have potential to address not only vitamin deficiencies per se, but also iron-deficiency anaemia and zinc deficiency. Further, the use of the leaves as a vegetable, as is done in several African countries, can complement the use of the root as a staple because of the high nutrient density of the leaves. The potential to improve the nutritive potential of cassava is exciting.

Background information

Cassava has traditionally been regarded as the poorest in nutritional quality of the staple foods. This is probably because of the low protein content of its storage roots, the primary edible product. However, cassava has considerable nutritional potential because its leaves can be used as well, and they have high protein concentration. Because both leaves and storage roots are used fresh, they also have the potential to supply both water-soluble and fat-soluble vitamins. The ongoing objective of the project is to assess the amounts of micronutrients in cassava and the degree of genetic variability that could be exploited to improve the micronutrient density and balance of nutrients through breeding. Cassava is an important staple food for 500 million people and is outstandingly adapted to poor soils and environments. Cassava will grow and can be relied on to produce food under conditions in which other staples would fail. Cassava is tolerant of acid and alkaline soils, low fertility, pests and diseases, and seasonal drought. High-cyanide types are resistant to animals, and the roots can be stored in the ground before harvesting for a considerable time as a drought reserve. All these features together justify an examination of how its nutritional value can be harnessed and improved.

Because yellow and orange types were known in Brazil and most staples have little carotenoid content, it was decided to begin with a study of the provitamin A content of cassava that is associated with root pigmentation. Subsequently, the mineral and vitamin C concentrations in roots and leaves were investigated, as well as vitamin A in leaves, and finally, a study of the effects of processing on vitamin A and C content was completed. The results are surprising.

Methods

The core collection

Of the 6,017 entries in the cassava germplasm bank, 601 clones have been selected to constitute the core collection. Selection was based on geographic and agronomic data from the site of collection and known relationships among the clones. Any kind of genetic variation survey can be carried out on this much smaller collection with a high probability that most

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variation will be represented in it. A survey of germplasm for any trait is thus efficiently managed. High values from a particular group in the core collection can be explored further by studying related material in the main collection to find more superior types.

Minerals

Because both genotype and soil type influence the mineral content of plant tissues, it was necessary to grow the core collection together at one site in order to compare the genetic differences without bias. Leaves were collected, dried, ground to powder, and sent to the analytical laboratory where the samples were analysed by inductively coupled plasma atomic-emission spectrometry [1]. All sample processing was carried out to avoid contamination from soil, which has iron concentrations up to 10,000 times higher than in plants.

Measurements of carotene and ascorbic acid concentrations

For carotene, the extraction procedure outlined by Safo-Katanga et al. [2] was adjusted by extracting root parenchyma with petroleum ether. The extraction protocol for leaves had to be modified because of the presence of tannins and chlorophyll. The adjusted protocol included several washing steps with methanol in order to minimize the interference from the other pigments that were present in the leaves. A random sample of 5 g was taken from the roots or leaves 10 to 11 months after planting. Quantification was performed by ultraviolet spectrophotometry. The protocol for the determination of ascorbic acid by Fung and Luk [3] was adjusted for cassava leaf and roots.

Stability of vitamin content after processing

The stability of vitamin content after solar drying of cassava flour, oven drying of cassava flour, and boiling fresh roots for 30 minutes was measured on 26 genotypes.

Correlation between vitamin content and PPD

Post-harvest physiological deterioration (PPD) was first measured (six days after harvest) on several genotypes whose root concentrations of ascorbic acid and carotene were known. The correlation between vitamin concentration and PPD was then measured.

Results

Trace mineral concentrations

Roots averaged 9.6 mg/kg of iron, 6.4 mg/kg of zinc, and 590 mg/kg of calcium on a dry matter basis (table 1). Mineral concentrations in the leaves were much higher, averaging 94.4 mg/kg of iron, 51.6 mg/kg of zinc, and 12,324 mg/kg of calcium. These leaf concentration figures are much higher than those in most staples. Although the leaves are eaten as a vegetable with high water content and low mineral density, they supply high levels of minerals per calorie. The protein concentration in the leaves was 30%, and therefore leaf protein was an important supplement to protein from the roots, where the concentration was low. Considerable genetic progress could be made in improving protein in the roots, because the baseline is so low that doubling the concentration is unlikely to have a high yield cost.

Carotene and ascorbic acid concentrations

The inheritance of carotene concentration in cassava was studied in an F_2 population of a white × yellow cross [4]. The intensity of the root colour was found

TABLE 1. Trace mineral content of leaves and roots of cassava: minimum, maximum, and mean contents of 20 genotypes from the CIAT core collection (mg/kg dry weight)

	Leaves			Roots		
Element	Min	Max	Mean	Min	Max	Mean
Iron	61.5	151.0	94.4	7.7	12.6	9.6
Manganese	50.3	87.2	67.9	0.8	3.2	1.2
Boron	50.2	85.5	66.1	2.0	3.2	2.4
Copper	6.2	8.1	7.3	1.4	3.0	2.2
Zinc	39.2	63.7	51.6	4.4	8.6	6.4
Calcium	8,233	16,295	12,324	379	945	590
Magnesium	4,786	9,735	7,198	806	1,479	1,153
Sodium	9.2	15.8	11.4	25.8	173.1	66.4
Potassium	8,465	11,837	10,109	7,574	10,389	8,903
Phosphorus	2,631	3,504	3,071	1,012	1,556	1,284
Sulphur	2,563	2,987	2,714	202	382	273

to be highly correlated with carotene concentration (table 2). However, the range of genotypic variability in carotene content was quite high—0.6 to 2.4 mg of carotenes per 100 g of fresh root—even for deep yellow and orange roots. In fact, the range of carotene concentration within any particular root colour class (white, cream, yellow, deep yellow, or orange) was sufficiently high that a quantitative evaluation of carotene concentrations of clones preselected according to root parenchyma colour is justified. The inheritance of carotene concentration appears to be determined by two genes, one controlling the transport of the product of precursors to the roots, the other responsible for the accumulation process (table 3). The genes have epistatic effects (influence one other). Other major genes not segregating in the evaluated cross will have to be studied in the future, as well as genes with minor effects.

The ascorbic acid concentration in leaf tissue ranged from 1.7 to 419 mg/100 g fresh weight (table 4), and the best lines had more than double the mean concentration. The concentrations of ascorbic acid in the roots were about a tenth of those in the leaves, but the best line had a concentration more than four times the median or mean concentrations. Both distributions were strongly skewed. However, there was no correlation between the ascorbic acid concentrations in the leaves and the roots (*r* = .045 based on 514 data points).

The carotene concentration in leaf tissue ranged from 23 to 86 mg/100 g fresh weight (table 4), and, not unlike ascorbic acid, the best lines had nearly double the mean concentration. The concentrations of carotene in the roots were about a tenth of those in the leaves, but the best line had a concentration more than 40 times the median or mean concentrations, indicating considerable potential for selection and breeding. Both distributions were strongly skewed. However, again as for ascorbate, there was no correlation between the carotene concentrations in the leaves and the roots, nor was there any correlation between ascorbic acid and carotene, suggesting that the levels of these vitamins are independently inherited.

TABLE 2. Average carotene concentration in cassava roots classified according to root colour

Root colour	Numerical scale	Carotene (mg/100 g)	SD
White	1	0.13	0.48
Cream	2	0.39	0.28
Yellow	3	0.58	0.28
Deep yellow	4	0.85	0.17
Orange	5	1.26	0.11

Stability of vitamin content after different processing procedures

The effects of different processing methods on carotene content were studied in a group of 28 genotypes. On average, boiling reduced carotene content the least (34%), followed by oven-drying to produce flour with a 44% reduction. The production of sun-dried flour reduced the carotene concentration to the lowest level

TABLE 3. Segregation for root colour and carotene concentration (fresh weight basis) in a cross between contrasting parents

Genotype	Expected genotype	No. of individuals (observed)	No. of individuals (expected)	Carotene (mg/100 g)
CM 2772-3 (yellow)	Y1y1Y2Y2			0.42
CG 1372-6 (white)	y1y1Y2y2			0.08
White	y1y1Y2__	20	19.50	0.09
Cream	Y1y1Y2y2	10	9.75	0.28
Yellow	Y1y1Y2Y2	9	9.75	0.38

Source: ref. 4.

TABLE 4. Range, mean, and standard deviation of concentrations (mg/100 g fresh weight) of ascorbic acid and carotene in leaves and roots of more than 500 cassava lines from the core collection grown together at CIAT in 1998

	Leaves			Roots		
Micronutrient	Range	Mean	SD	Range	Mean	SD
Ascorbate	1.7–419	120	84	1–40	9.5	6.5
Carotene	23–86	48.3	8.6	0.1–1.0	0.23	0.14

(73% reduction), which indicates that carotenes are photolabile. Although the correlation among different processing methods across genotypes was significant, genotype-specific effects were sufficiently strong, however, genotypes with the highest carotene concentration in the fresh root controls were not the ones with the highest concentration after processing. Therefore, after routine screening for high β-carotene in fresh roots, a test of stability after different processing methods should also be carried out routinely. Although the carotene levels declined significantly during processing, considerable amounts of carotenes remained, particularly when oven-drying was carried out. These results support the findings of McDowell and Oduro [5]. *Gari* (a dry flour produced from cassava roots) obtained from yellow-root cultivars had concentrations of carotene up to 1.13 mg/100 g.

It is, of course, also important to study how much carotene left after processing is bioavailable, once the cassava product is consumed. The recommended daily intake of vitamin A is 800 retinol equivalents (RE) for an adult woman [6], or 4.8 mg/day on the basis of a 6 to 1 conversion ratio of β-carotene per retinol equivalent.

The carotene content was considerably stabler than that of ascorbic acid after the different processing procedures evaluated. On average, 50% of the original carotene content remained after boiling or drying the roots, whereas only 14% of the ascorbic acid was recovered after the same treatments. The ascorbic acid content showed a strong dependency on the processing method. The highest level of vitamin C (36.6% of the original) was retained after boiling, whereas oven and solar drying reduced the vitamin C content to 6.2% and 0.005% of the original levels, respectively.

Correlation between vitamin contents and PPD

In general, there were poor correlations between postharvest physiological deterioration (PPD) (measured in 30 genotypes after six days of storage) and vitamin concentrations in roots. The correlations between PPD and vitamin C or carotene concentrations in roots were –0.30 and –0.27, respectively. Although the correlations were statistically significant, they were nonconclusive. To further test the hypothesis that vitamin concentrations can help to reduce PPD (through their antioxidant capacity), an additional study was carried out with 400 genotypes. The correlation coefficient between carotene content and PPD remained negative, but was smaller (–0.16). However, for carotene concentrations below 0.5 mg/kg, there was no correlation between the two traits. At root concentrations higher than 0.5 mg/kg, PPD was always lower than 30%, suggesting a threshold effect.

Conclusions

It appears that cassava's reputation for poor nutritive value need not be so. First, there is substantial genetic variation that can be exploited to improve its micronutrient density and probably its protein content as well. Second, the use of the leaves as a vegetable along with the roots as staple, as is practised in Africa, can do much to balance the diet, especially for protein, micronutrients, and calcium. Third, cassava, because of its high-carotene germplasm, can deliver varieties with superior concentrations of iron, zinc, and provitamin A, to exploit the synergies that operate in absorption, internal transport, and function among these three micronutrients [7]. Like maize, but not wheat and rice, cassava is in a favourable position, in that it has high-carotene types to develop immediately. To do so requires the education of all sectors of the food system about the advantages of yellow staples over white. Cassava is further enhanced nutritively compared with the cereals, in that it also supplies significant vitamin C, which also enhances the absorption of iron in the human gut. Thus, although the iron concentration in cassava roots is not very high, if it is delivered in a root with high levels of zinc, carotene, and vitamin C, it should have high bioavailability. The challenge is to optimize this nutritive genetic potential and prove its efficacy.

References

1. Zarcinas BA, Cartwright B, Spouncer LR. Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. Commun Soil Sci Plant Anal 1987;18:131–46.
2. Safo-Katanga O, Aboagye P, Amartey SA, Olaham JH. Studies on the content of yellow-pigmented cassava. In: Terry ER, Doku EV, Arene OB, Mahungu NM, eds. Root crops production and uses in Africa. Ottawa, Canada: International Development Research Center, 1984:103–4.
3. Fung Y-S, Luk S-F. Determination of ascorbic acid in soft drinks and fruit juices. Part 1. Background correction for direct ultraviolet spectrophotometry. Analyst 1985;110:201–4.
4. Iglesias C, Mayer J, Chavez L, Calle F. Genetic potential and stability of carotene content in cassava roots. Euphytica 1997;94:367–73.
5. McDowell I, Oduro KA. Investigation of the beta-carotene content of yellow varieties of cassava. J Plant Foods 1981;5:169–71.
6. National Research Council. Recommended dietary allowances. Washington, DC: National Academy Press, 1989.
7. Graham RD, Rosser JM. Carotenoids in staple foods: their potential to improve human nutrition. Food Nutr Bull 2000;21:404–9.

Potential of orange-fleshed sweet potatoes for raising vitamin A intake in Africa

Vital Hagenimana and Jan Low

Abstract

The potential to use orange-fleshed (β-carotene-rich) sweet potatoes as an effective entry point for improving vitamin A and caloric intake in sub-Saharan Africa appears to be high, since non-orange-fleshed cultivars are widely grown throughout the continent, easy to raise, and typically under women's control. The paper describes the collaborative effort of the Kenya Agricultural Research Institute, the Centro Internacional de la Papa (CIP), and CARE to promote adoption of early-maturing orange-fleshed sweet potatoes in a two-year research-intervention pilot project. A community-based approach was undertaken, whereby group members actively participated in the research process, developing nutrient-rich processed products (weaning and adult foods) that combined the introduced germplasm with locally available foods. The results suggest that improving women's access to resources (particularly to productivity-enhancing technologies and to knowledge) and utilizing crops under their control are essential features for demonstrating positive nutritional and adoption outcomes within a relatively short time. Findings comparing control and intervention groups indicate that an "enhanced extension package," emphasizing improved child-feeding practices and introducing new food-processing techniques, in addition to providing higher-yielding varieties, is essential to ensure that the introduced varieties are incorporated into the diets of young children.

Introduction

The sweet potato research and development programme of the Centro Internacional de la Papa (CIP) in sub-Saharan Africa has the three objectives of improving food security, nutrition, and income generation for small farmers in the region. Millions of poor, small-scale farmers, mostly women, produce sweet potatoes, primarily for home consumption and, to a lesser extent, for commercial sales in local or urban markets. The increasing importance of the sweet potato in sub-Saharan Africa is largely attributable to its relatively high productivity across a range of environments, short cropping season, and flexible planting and harvesting schedules.* Periodic droughts and the rising costs of grain production have also contributed to the increasing importance of sweet potatoes for both food security and income generation.

Sweet potatoes have considerable potential for reducing vitamin A deficiency throughout Africa. However, most of the varieties currently grown in sub-Saharan Africa have white or cream flesh and supply little or no β-carotene [1–5]. New high-yielding, orange-fleshed varieties of sweet potato may be introduced that are rich in provitamin A, are well adapted to local farming systems, and meet local standards of culinary quality.

A number of high-yielding cultivars that are high in both provitamin A and dry matter have been identified in different agroecological zones of East Africa [6, 7]. The levels and stability of provitamin A have been evaluated [5, 8], and their potential use in locally processed foods has been assessed and validated [9–12]. The work is being conducted in close collaboration with partners in national agricultural research and extension systems, universities, and non-governmental organizations in East Africa.

The ability of orange-fleshed sweet potatoes to contribute to a considerable improvement in vitamin A intake is demonstrated by the data in table 1 that show the provitamin A concentrations of 17 varieties of sweet potato ranging from white to orange in colour. Regular intake (100 g per day or one half-cup) of yellow- or orange-fleshed sweet potato roots having moderate β-carotene concentrations (e.g., 3 mg/100 g on a fresh weight basis) provides the recommended

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* Ewell PT. Sweet potato in Africa: research priorities to stimulate increased marketing. Paper presented at the International Workshop on Methods for Agricultural Marketing Research, 16–20 March 1993, Indian Agricultural Research Institute Campus, New Delhi, India.

TABLE 1. Carotenoids and vitamin A values of 17 sweet potato cultivars evaluated in Kenya in 1996[a]

Cultivar	Colour of flesh	Total carotenoids (mg/100 g fresh root)	β-Carotene (mg/100 g fresh root)[b]	β-Carotene-5, 6-monoepoxide (μg/100 g fresh root)	β-Carotene (% of total carotenoids)	Vitamin A value (RE/100 g fresh root)
Naveto (CIP440131)	White	< 0.1	< 0.1	1.5 ± 0.3	0.1	0.1 ± 0.0
LM88.002 (CIP188001.1)	White	0.1 ± 0.0	< 0.1	0.1 ± 0.0	4.5	0.9 ± 0.6
KSP 11	White	0.2 ± 0.0	< 0.1	< 0.1	12.5	3.3 ± 0.3
TIS 2534 (CIP440062)	White	0.1 ± 0.0	< 0.1	0.1 ± 0.0	12.1	2.8 ± 0.3
Ex-Diani	White	0.2 ± 0.0	< 0.1	0.1 ± 0.1	10.1	3.2 ± 0.6
Philippine (CIP440160)	Dark cream	0.2 ± 0.0	< 0.1	0.3 ± 0.2	3.2	0.9 ± 0.3
TIS 70357 (CIP440078)	Cream	0.2 ± 0.0	< 0.1	0.2 ± 0.0	15.8	6.6 ± 1.2
NG 7570 (CIP440377)	White	0.2 ± 0.0	< 0.1	0.1 ± 0.0	9.9	3.4 ± 0.8
Capadito (CIP420053)	Pigmented	0.2 ± 0.0	< 0.1	ND	15.0	6.0 ± 1.0
KEMB 10	Cream	0.4 ± 0.0	0.1 ± 0.0	2.3 ± 0.2	39.6	21.1 ± 1.8
Maria Angola (CIP420008)	Pale orange	0.4 ± 0.0	0.1 ± 0.0	0.5 ± 0.1	28.4	18.5 ± 1.6
Kakamega 4 (SPK 004)	Orange	2.6 ± 0.2	1.5 ± 0.1	68.0 ± 0.0	59.0	258.2 ± 23.3
Zapallo (CIP420027)	Pale orange	4.3 ± 0.0	2.9 ± 0.5	111 ± 19.3	67.7	493.8 ± 80.2
Japon Tresmesino Selecto (CIP420009)	Intermediate orange	5.5 ± 0.3	4.6 ± 1.4	90.2 ± 2.7	82.7	768.4 ± 228.8
Unknown	Pale orange	7.5 ± 0.7	6.2 ± 0.0	98.5 ± 5.8	83.1	1,047.3 ± 15.8
W-220 (CIP440015)	Intermediate orange	8.4 ± 0.4	6.0 ± 0.5	208.9 ± 56.9	71.7	1,021.3 ± 82.1
TIB 11 (CIP440057)	Orange	8.8 ± 0.7	8.0 ± 0.3	91.0 ± 4.7	90.8	1,338.2 ± 56.9

a. Plus–minus values are means ± SD.

b. Values less than 0.05 mg/100 g fresh root are indicated as 0.0.

daily amount of vitamin A for children under five years of age [13]. Six of the 17 varieties shown in table 1 have adequate β-carotene concentrations, even when processing losses are taken into account.*

Introduction of these new varieties must be linked to education on nutritional quality and on new forms of utilization to promote their adoption and use. There are three major pathways through which the sweet potato–based intervention can achieve its goal of increased production and intake of vitamin A–rich foods: access to improved planting material, empowerment through knowledge, and enhanced purchasing power.

Access to improved planting material

Women farmers receive planting material of high-yielding β-carotene-rich varieties and are directly involved in varietal evaluation. Rapid multiplication, staggered planting, improved agronomic practices, and out-of-ground storage techniques are introduced to ensure year-round availability of orange-fleshed sweet potatoes in the diets of both adults and young children. Production of other locally available nutrient-rich crops is also encouraged.

Empowerment through knowledge

Health and nutrition knowledge surveys in many parts of sub-Saharan Africa have noted several major areas in which caregiver awareness of basic child-feeding practices is severely lacking, including the duration of exclusive breastfeeding, the preparation of appropriate complementary foods, the correct timing of the introduction of different foods into the young child's diet, and the frequency of feeding of young children at specific ages.

Key to the knowledge empowerment process is the interactive development among researchers, extension personnel, and caregivers who are cognizant of the daily constraints faced by the principal caregiver, including financial constraints (lack of purchasing power), time constraints (lack of time for complex food procurement and preparation), and cultural constraints (beliefs, preferences, and pressure from influential relatives). Promotional campaigns at the community, district, and provincial levels can facilitate widespread acceptance of improved child-feeding practices centered on the use of sweet potato–based weaning foods.

Enhanced purchasing power

There are two principal mechanisms through which dietary diversification can be achieved at the household level. The first is the direct production of crops containing significant quantities of the desired nutrient.

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* Although the standard conversion rate of 6 units of β-carotene to 1 RE is used in calculating the final column of table 1, recent evidence suggests that the conversion factor from β-carotene to RE for sweet potato is between 12 and 26 to 1 [14]. In addition, processing results in 25 to 30% loss of β-carotene content [5].

The second is through market purchase. Sweet potato is well known for being a crop that can give acceptable yields without significant use of inorganic or organic fertilizers. Many of the other micronutrient-rich foods have to be purchased in the market. Sweet potatoes, freshly grated, boiled, and mashed or in flour form, can substitute for up to one-third of the wheat flour in processed products such as bread or doughnuts. These β-carotene-enriched products can be consumed at home or sold in the local market. Enhancing the purchasing power of caregivers vastly improves their capacity to capitalize on whatever new knowledge they have obtained.

In this framework, orange-fleshed sweet potatoes are the entry point for improving calorie and vitamin A intake among young children. However, it is expected that the intakes of other vitamin A–rich foods will also increase significantly because of the impact of increased knowledge regarding which foods to produce and feed to young children, combined with greater capacity to buy vitamin A–rich foods through the sale of processed products.

The final step is to ensure that the increased vitamin A intake translates into improved vitamin A status. The results of a clinical trial in Indonesia [15] showed that the incorporation of β-carotene sources (mainly in the form of orange-fleshed sweet potatoes) into meals given to three- to six-year-olds significantly increased serum retinol concentrations (i.e., improved vitamin A status). The same study also demonstrated that the greatest rise in serum retinol occurred when meals contained added β-carotene sources and added fat, and the children were dewormed. Added fat improves vitamin A absorption, and local sources of fat can be easily incorporated into the development of sweet potato–based foods. Since the absorption of ingested vitamin A is hindered by poor health status, food-based strategies should include a health-care component, whenever feasible,

A case study of the introduction of orange-fleshed sweet potatoes

An action research project [16, 17] was recently implemented by the Kenya Agricultural Research Institute (KARI), in collaboration with Centro Internacional de la Papa and CARE International. Orange-fleshed varieties of sweet potatoes that were both high-yielding and rich in β-carotene were introduced to women farmers. The results demonstrated that orange-fleshed sweet potatoes were highly acceptable to producers and consumers, both when eaten alone and when used as ingredients in processed foods. Taste tests revealed that adults preferred varieties with a high content of dry matter (greater than 27%), whereas children preferred weaning foods made from varieties with a low content of dry matter [16]. The orange colour of the flesh is not in itself a barrier to acceptance.

The intervention sites were in rural western Kenya, an area in which farmers have traditionally produced sweet potatoes for home consumption and sale. The trial intervention worked with 20 women's groups in two Districts (Ndhiwa/Nyarongi and Rongo in South Nyanza Province) and compared two extension packages to promote the adoption and consumption of varieties of orange-fleshed sweet potatoes rich in β-carotene. Both packages included agricultural extension support to promote cultivation of the new orange-fleshed sweet potato varieties to improve vitamin A intake. In addition, one of the packages also included nutrition education, training in processing methods, and home visits to reinforce the group lessons and identify additional barriers to adopting new infant-feeding practices and other processed products using sweet potatoes as a base. Home visits provided an opportunity to reconcile any conflicts between the practices promoted through the nutrition education programme and cultural beliefs or patterns. Without an opportunity to discuss and understand these issues, the women were much less likely to change their child-feeding practices permanently.

The primary nutrition indicator used in this study was the frequency with which children under five years of age consumed vitamin A–rich foods, as measured by an index developed by Helen Keller International (HKI).* The index was used in two ways. First, it was applied to assess whether vitamin A deficiency was an important public health problem in the research area. Second, it was used to assess changes in vitamin A intake patterns by comparing baseline scores and post-intervention scores among the children of women in the intervention and control groups.

In Ndhiwa/Nyarongi, the area of the study with the higher probability of severe vitamin A deficiency, the HKI scores increased significantly in the intervention group from pre- to post-intervention, while those in the control group decreased. The overall change was a highly significant 93% increase over the pre-intervention level. Both the animal and plant food components of the HKI score increased, with the increase in the plant component being due in large part to higher consumption of orange-fleshed sweet potatoes, as well as mangoes and dark-green leafy vegetables. The results from Ndhiwa/Nyarongi indicated that the promotional activities (nutrition education and food processing for

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* The method is based on the caregiver's recall of the number of days per week that children under five years of age consumed animal and plant foods rich in vitamin A. There are two cut-off points according to the HKI guidelines: communities with a mean animal source index of less than 4 days/week or a mean weighted total food frequency index of less than 6 days/week are considered at risk of vitamin A deficiency.

sale as well as home consumption) were critical for significantly increasing HKI scores.

In Rongo, the area of the study with a lower probability of inadequate vitamin A intake, the increases in the HKI scores that occurred as a result of the intervention were not statistically significant. This may suggest that promotional efforts are unlikely to significantly increase the consumption of vitamin A–rich foods in areas where the consumption is already adequate.

Substituting orange-fleshed sweet potatoes for other ingredients dramatically increased the β-carotene content in other common products consumed by both children and adults. Flat fried bread (*chapati*), doughnuts (*mandazi*), and small buns are commonly sold in medium-sized rural markets. As typically produced with wheat flour, these products contain approximately 100 mg of β-carotene equivalents per 100 g of food product. Substituting orange-fleshed sweet potatoes for wheat flour in either boiled and mashed or flour form raised the β-carotene content to 800–3,200 mg/100 g.

Moreover, a cost analysis indicated that the profitability of selling these processed products increased, principally as a result of lowering production costs. The food products made from the orange-fleshed varieties were well accepted by consumers. Once the women sell the products, they are most likely to use the derived income to meet other basic household needs of the family.

This research was not only about demonstrating the efficacy of nutrition outcomes. It emphasized exploring how those results could be achieved. The intervention demonstrated the potential for linking an agricultural innovation (orange-fleshed sweet potatoes) with simple processing technologies (flour, mandazis, chapatis, buns), micro-scale enterprise development, and increased knowledge of women farmers about the relationships between production, processing, marketing, food preparation, and the health and nutrition of their families.

The potential for this intervention to be sustained over time is high. First, farmers in sub-Saharan Africa typically exchange planting material for sweet potatoes (vines) free of charge. Since seed is not required for plant establishment, traditional dissemination methods can be rapid and continual. Organized multiplication and dissemination programmes, however, can massively accelerate the spread of new material. Second, the improved material introduced has a higher yield than the local material, and it survived the drought that occurred in the second year of the project. Thus, the varieties are likely to be sustained in the community for agronomic reasons. Finally, because women in these areas controlled both the consumption and the production of sweet potatoes, they were able to use the crop to improve the quality of their children's diet as well as to retain any income earned by selling the processed product or fresh root. Although men are likely to become more involved in sweet potato production as commercial markets for the crop continue to grow in western Kenya, women are unlikely ever to be excluded from sweet potato production for home use and from periodic selling from plots under their management. Thus, the potential is high for women to continue applying what they have learned through project participation.

Discussion and conclusions

Given that the number of children in sub-Saharan Africa affected by chronic malnutrition (stunting) increased by an alarming 62% between 1980 and 1995 [18], the need for addressing malnutrition on the continent is acute. The use of improved, higher-yielding food crops and increased incomes for purchasing better-quality diets and improved health care is critical to address this situation. Sweet potatoes are grown in every country south of the Sahara [19]. Moreover, several eastern and southern African countries have had major increases in sweet potato production in the 1990s [20]. The most dramatic increase has been seen in drought-prone Malawi, where a concerted effort by governmental and international agencies to massively distribute improved varieties of cassava and sweet potato has been under way since 1993–94. By 1997–98, the annual per capita consumption of sweet potatoes had risen to 79 kg, with sweet potatoes rapidly emerging as a major food staple alongside maize.* Unfortunately, no β-carotene-rich varieties were included in this distribution effort.

Higher-yielding, early-maturing varieties with significant β-carotene content address the need for enhanced dietary quality as well as improved calorie availability. Because of the poor health infrastructure and limited financial resources of many poor rural households both within and outside of sub-Saharan Africa, it is critical that alternatives to supplements and fortification be explored. If the findings of the proposed research demonstrate that improvement of dietary quality through the introduction of an agricultural technology combined with a set of improved child-feeding practices is a cost-effective and sustainable approach for reducing vitamin A deficiency, the transferability of these findings to other settings is likely to be high.

The intervention trials in western Kenya demonstrated the success of linking the promotion of orange-fleshed sweet potato production and processing through agricultural and extension activities to the promotion

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* Phiri MA. Grain legumes issues and options for research in Malawi. Paper presented at the international training course on Methods for Analyzing Agricultural Markets, Nairobi, Kenya, 9–15 November 1998.

of increased consumption of vitamin A–rich foods through health and nutrition education. Such dietary interventions address the underlying causes of malnutrition and poverty, empowering women by providing them with greater access to improved technologies and existing knowledge. If the new dietary habits and agricultural practices are adopted, the benefits for vitamin A status are likely to be sustained over time. Given the ease of sweet potato production and use, there is a high potential for this type of intervention as part of an integrated strategy to combat micronutrient malnutrition in sub-Saharan Africa. Expanding and replicating the approach and methods used in the study for a large sample and in other African countries where vitamin A deficiency is prevalent could lead to significant gains in reducing vitamin A deficiency.

References

1. Purcell AE. Carotenoids of goldrush sweet potato flakes. Food Technol 1962;16:99–102.
2. Purcell AE, Walter MW Jr. Carotenoids of centennial variety sweet potato, *Ipomoea batata*s. J Agric Food Chem 1968;16:769–70.
3. De Almeida-Muradian LB, De Penteado MVC, De Ferreira VLP. Relationship between carotenoid content and Hunter color parameters of Brazilian sweet potato. Rev Espanol Ciencia Technol Alimen 1992;36:611–9.
4. Takahata Y, Noda T, Nagata T. HPLC determination of beta-carotene content in sweet potato cultivars and its relationship with color value. Jpn J Breed 1993;43:421–7.
5. Hagenimana V, Carey EE, Gichuki ST, Oyunga MA, Imungi JK. Carotenoid contents in fresh, dried, and processed sweet potato products. Ecol Food Nutr 1999; 37:455–73.
6. Gichuki ST, Hagenimana V, Low J, Oyunga MA, Carey EE, Kabira JN. Involving women groups in the evaluation of introduced high beta-carotene sweet potato varieties. Proceedings of the 4th Triennial Congress of the African Potato Association, 23–28 February 1997, Pretoria, South Africa: Agricultural Research Council, 1997:228–33.
7. Carey EE, Hagenimana V, Kosambo L, Oyunga MA, Benesi I, Smit N, Ocitti P, Obwoya C, Turyamureeba G, Ndolo PJ, Low J. Using orange-fleshed sweet potato varieties to combat vitamin A deficiency and enhance market opportunities for smallholder farmers in sub-Saharan Africa. In: Akoroda MO, Teri JM, eds. Food security and crop diversification in SADC countries: the role of cassava and sweet potato. Proceedings of the Scientific Workshop of the Southern African Root Crops Research Network (SARRNET), Pamodzi Hotel, 17–19 August 1998, Lusaka, Zambia. Lilongwe, Malawi: SARRNET, 1999:15–-68.
8. K'osambo LM, Carey EE, Misra AK, Wilkes J, Hagenimana V. Influence of age, farming site, and boiling on provitamin A content in sweet potato *(Ipomoea batata*s (L.) Lam.) storage roots. J Food Compos Anal 1998;11:305–21.
9. Omosa M. Current and potential demand for fresh and processed sweet potato products in Nairobi and Kisumu, Kenya. Social Science Department Working Paper No. 1997-1. Lima, Peru: Postharvest Management, Marketing Program, Centro Internacional de la Papa, 1997.
10. Hagenimana V, Owori C. Feasibility, acceptability, and production costs of sweet potato-based products in Uganda. CIP Program Report 1995-96. Lima, Peru: Centro Internacional de la Papa, 1997:276–81.
11. Hagenimana V, Karuri EG, Oyunga MA. Oil content in fried processed sweet potato products. J Food Proces Preserv 1998;22:123–37.
12. Fawzia A, Karuri EG, Hagenimana V. Sweet potato ketchup: feasibility, acceptability, and production costs in Kenya. Afr Crop Sci 1999;J7:81–9.
13. Tsou SCS, Hong TL. The nutrition and utilization of sweet potato. In: Hill WA, Bonsi CK, Loretan PA, eds. Sweet potato technology for the twenty-first century. Tuskegee, Ala, USA: Tuskegee University Press, 1992: 359–66.
14. de Pee S, West CE, Permaesih D, Martuti S, Muhilal, Hautvast JGAJ. Orange fruit is more effective than are dark-green, leafy vegetables in increasing serum concentrations of retinol and beta-carotene in schoolchildren in Indonesia. Am J Clin Nutr 1998;68:1058–67.
15. Jalal F, Nesheim MC, Agus Z, Sanjur D, Habicht JP. Serum retinol concentrations in children are affected by food sources of beta-carotene, fat intake, and anthelminthic drug treatment. Am J Clin Nutr 1998;68:623–9.
16. Low J, Kinyae P, Gichuki ST, Oyunga MA, Hagenimana V, Kabira JN. Combating vitamin A deficiency through the use of sweet potato. Results from Phase I of an action research project in South Nyanza, Kenya. Lima, Peru: Centro Internacional de la Papa, 1997.
17. Hagenimana V, Oyunga MA, Low J, Njoroge SM, Gichuki S, Kabira J. The effects of women farmers' adoption of orange-fleshed sweet potatoes: raising vitamin A intake in Kenya. ICRW/OMNI Research Program, Research Report Series 3. Washington, DC: International Center for Research on Women, 1999.
18. United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition (ACC/SCN). Third report on the world nutrition situation. Geneva: World Health Organization, 1997.
19. Scott GJ, Ewell PE. Sweet potato in African food systems. In: Scott G, Ferguson PI, Herrera JE, eds. Product development for root and tuber crops. Vol. III-Africa. Proceedings of the Workshop on Processing, Marketing, and Utilization of Root and Tuber Crops in Africa, held 26 October–2 November 1991 at the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. Lima, Peru: Centro Internacional de la Papa, 1992:91–103.
20. Scott GJ, Maldonado L. Sweet potato for the new millennium: trends in production and utilization in developing countries. Lima, Peru: Centro Internacional de la Papa, 1999.

Genetic variation in total carotene, iron, and zinc contents of maize and cassava genotypes

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Abstract

Deficiencies of vitamin A, iron, and zinc are widespread in sub-Saharan Africa, where the diets are mainly plant-based and the intakes of animal products are low. The overall objective of this investigation was to determine the extent of genetic variation of these micronutrients in 16 yellow-seeded improved maize varieties, 109 maize inbred lines (60 from mid-altitude and 49 from lowland/savannah agroecologies), and 162 cassava clones resistant to the cassava mosaic disease. The yellow-seeded improved maize varieties were analysed for physical and chemical characteristics and total carotene content; the maize inbred lines and cassava clones were analysed for iron and zinc content. The results showed statistically significant and large genotypic differences in total carotene content among the 16 yellow-seeded improved, open-pollinated maize varieties. The total carotene content ranged from 143 to 278 µg/g. Significant genotypic variation was also observed for iron and zinc concentrations in maize inbred lines and cassava storage roots. Iron concentration ranged from 15 to 159 ppm for mid-altitude and from 14 to 134 ppm for lowland maize inbred lines; zinc concentration ranged from 12 to 96 ppm for mid-altitude inbreds and from 24 to 96 ppm for lowland inbred lines. For cassava storage roots, the range was 4 to 95 ppm for iron and 4 to 18 ppm for zinc. A strong and positive relationship was observed between iron and zinc concentrations for both mid-altitude and lowland maize inbred lines, but this relationship was weak for the cassava clones. The potential exists for improving carotene, iron, and zinc contents in maize and cassava genotypes through plant-breeding.

Introduction

Maize and cassava provide a large proportion of the daily intake of energy and other nutrients, including micronutrients, for poor populations in many areas of sub-Saharan Africa that have limited access to animal foods [1]. Cassava plays an important role in food security by providing a stable food base in areas prone to drought and during periods of civil disturbances because of its flexibility in time of planting and harvesting and its tolerance to poor soil and pest or disease problems. Root crops are often considered to be primarily sources of low-cost energy, but not important sources of other nutrients. However, protein content and essential vitamins and minerals vary considerably among roots and tubers [2]. Developing cultivars of maize and cassava with high available micronutrient content could significantly improve the health and nutritional status of the poor, especially women and children. Because consumers in some areas of West Africa prefer maize with yellow endosperm and add palm oil during the processing of cassava to *gari* (roasted cassava granules) to impart a yellow colour, the problem of vitamin A deficiency can be addressed through consumption of yellow-coloured genotypes of both maize and cassava.

A breeding programme was initiated at the International Institute of Tropical Agriculture (IITA) in 1998 to develop maize varieties and cassava clones with high levels of provitamin A carotenoids, iron, and zinc. Selection of maize and cassava for improved micronutrient content is dependent on knowledge of the extent of genetic variation expressed in a given environment. A second requirement for selection of superior genotypes with high micronutrient content is that the trait is maintained across different environments. The objective of the research reported here was to determine the extent of genetic variation for total carotenoid, iron, and zinc in maize and cassava genotypes.

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Materials and methods

Maize genotypes

Sixteen yellow-seeded, improved, open-pollinated maize varieties were grown in a replicated field trial at the IITA research farm, Ibadan, Nigeria, under uniform conditions during the first rainy season (March to August) in 1998. The genotypes were selected for potential variability in carotenoid content based on kernel colour. Within each variety, bulk pollen was used to avoid pollen contamination from other varieties. In addition, 109 elite inbred lines developed at IITA for the mid-altitude and lowland agroecologies of West and Central Africa were grown in a field trial at Ibadan under irrigation during the 1995 dry season (November to April). The trial was not replicated. The inbred lines were planted in December 1995 and harvested in May 1996. Seeds of inbred lines were produced by self-pollination in order to avoid contamination. At maturity, the maize was hand harvested, and ears with poor seed sets were discarded. The ears were artificially dried at 40°C until the moisture was reduced to a range of 11% to 12%. The ears were hand shelled to minimize physical damage and were stored at 10°C and brought up to 25°C before analysis. Samples of the inbred lines were bulked and kept in cold storage (4°C) until needed for analysis. They were brought up to 25°C before analysis.

Cassava genotypes

A total of 142 improved cassava clones and 20 African landraces of cassava selected for various agroecologies of sub-Saharan Africa and resistant to cassava mosaic disease were grown in a replicated field trial at the IITA research farm at Ibadan, Nigeria, in 1997 and harvested 12 months after planting. Random samples of five storage roots of each clone were peeled, shredded, and dried in an oven at 40°C until they attained constant weight. Samples were ground to pass through a 1.0-mm sieve and stored in an airtight container before analysis for iron and zinc content.

Results and discussions

Table 1 shows the total carotenoid and fat contents of the 16 improved maize varieties. Significant differences among varieties were observed for total carotenoids and fat content. The fat content ranged from 3% to 7%, and the total carotenoid content varied from 143 to 278 µg/g, with an overall mean of 200 µg/g. Our results are in agreement with those of Carballido et al. [3], who reported a range of 82 to 280 µg/g for total carotenoids in hybrid corn grown in different regions.

TABLE 1. Total carotenoid and fat contents of 16 adapted improved maize varieties

Genotype	Fat (%)	Carotenoids (µg/g)
IK 91 TZL COMP3-Y-C1	5.2	143
TZB-SR-SGY	4.1	159
TZSR-Y-1 C4	4.8	164
TZESR-Y-1	3.6	172
TZUTSR-W-SGY	4.3	173
TZEE-Y	3.7	179
AK 9331-DMR-SR	3.9	186
SUWAN-2-SR	3.8	194
EV 8728-SR	3.1	204
ACR 91 SUWAN-1-SR	5.2	210
MAKA-SR	5.2	212
POOL 26 SEGUA	3.8	216
AK94-DMR-ESR-Y	5.6	222
AK 9528-DMR	4.6	228
DMR-LSRY	4.1	266
STR-SYN-Y	7.1	278
Mean	4.55	200
LSD	0.33	3.41

The maize kernel contains two fat-soluble vitamins: provitamin A carotenoids and vitamin E. Carotenoids are found mainly in yellow maize genotypes, in amounts that can be genetically controlled, whereas white maize varieties have little or no carotenoid content. Most of the carotenoids are found in the hard endosperm, and only small amounts are found in the germ [4]. Weber [5] analysed 15 yellow corn inbred lines and found total carotenoid concentrations ranging from 30 to 77 µg/g. The carotene content fraction constituted half of the total carotenoids in some inbred lines. In others the carotene content exceeded the xanthophyll levels, indicating that inbred lines could be selected for high percentages of carotenes or xanthophylls. When the distribution of carotenoids in hand-dissected corn kernel fractions (horny endosperm, floury endosperm, and germ) was analysed in four inbred lines [5], 74% to 86% of the carotenoids were found in the horny endosperm, 11% to 20% in the floury endosperm, and only 1% to 4% in the germ.

Our results show that genotypic variation for total carotenoid content exists among varieties. Further studies on β-carotene content and its conversion to vitamin A are needed. In addition, exotic germplasms need to be screened to identify suitable sources of yellow genes that can be used in a breeding programme.

Statistically significant ($p < .01$) genotypic differences in iron and zinc concentrations between mid-altitude and lowland inbred lines of maize were observed. The iron content varied from 15 to 159 ppm, whereas the zinc content ranged from 12 to 96 ppm for mid-altitude inbred lines; the iron and zinc concentrations of the lowland inbred lines ranged from 14 to 134 ppm and from 24 to 96 ppm, respectively (table 2). There appeared to be more genetic variation for iron than for zinc. The frequency distributions for lowland and mid-altitude inbred lines indicate that a tremendous potential for developing inbred lines high in iron and zinc concentrations exists. A strong and positive relationship was observed between iron and zinc concentrations for the mid-altitude maize inbred lines ($r = 0.88$, $p < .01$) and for the lowland inbred lines ($r = 0.62$, $p < .01$). An in-depth study involving replicated field trials will be undertaken to verify the observed results.

Significant differences ($p < .01$, $r^2 = 0.70$) among cassava clones were observed for iron and zinc concentrations. Iron concentration varied from 4 to 49 ppm and zinc concentration from 4 to 18 ppm (table 2). For iron, 15% of the clones were more than two standard deviations above the overall mean. For zinc, 12% of the clones were more than two standard deviations above the overall mean. However, a very weak relationship ($r = 0.18$, $p < .01$) was found between iron and zinc contents in cassava.

Looking ahead

This investigation shows that genotypic variation exists for total carotenoid content among maize genotypes and for iron and zinc content among maize and cassava genotypes. Although some of the yellow-seeded improved maize varieties have high concentrations of total carotenoids, it will be necessary to determine the proportion of carotenoids with provitamin A activity and their bioavailability and stability during processing and storage before such varieties are promoted for production and consumption. A positive relationship was found between iron and zinc concentration, suggesting that selecting for high iron concentration in maize grain and cassava roots will not have a negative effect on zinc or vice versa. Therefore, it can be concluded that a potential exists for developing maize genotypes and cassava clones high in both iron and zinc.

Although the present results are encouraging, this study should be considered preliminary, because more in-depth studies are under way to identify the best sources of micronutrients in African landraces and improved and introduced germplasm of both maize and cassava. Determination of the genetic relationships for micronutrient content will optimize the use of these genetic resources in the breeding programme. Research will be undertaken to determine the mode of inheritance of micronutrient concentrations in maize and cassava. Such information is important to combine increased levels of provitamin A, iron, and zinc in a single genotype or clone through hybridization and introgression of the germplasm sources and selection.

There is also the need to develop a simple visual method that can be used by breeders in selecting for high micronutrient content. Information is also needed on the expression and stability of high concentrations of carotene, iron, and zinc under different environmental conditions and their stability under different processing and storage methods. In addition, the bioavailability of these micronutrients in promising genotypes will be investigated using animal models and chemical methods. Antinutritional and other factors, which have been implicated as promoters or enhancers of iron and zinc absorption, will also be investigated.

TABLE 2. Simple descriptive statistics (mean, standard deviation, minimum, and maximum) for iron and zinc concentrations (ppm) of maize and cassava

Crop	Mineral	*n*	Mean	SD	Min	Max
60 maize mid-altitude inbred lines	Iron Zinc	60 60	39.84 24.63	37.05 17.93	14.70 11.65	159.43 95.62
49 maize lowland inbred lines	Iron Zinc	49 49	87.30 49.82	30.72 17.40	13.60 23.50	133.82 94.94
2 cassava clones (storage roots)	Iron Zinc	162 162	18.76 9.86	6.10 2.66	3.50 4.32	48.85 17.97

References

1. Allen LH. The Nutrition CRSP: What is marginal malnutrition and does it affect human function? Nutr Rev 1993;51:255–67.
2. Horton D. Underground crops. Long-term trends in production of roots and tubers. Morrilton, Ark, USA: Winrock International, 1988.
3. Carballido A, Lorento V, Centeno M. Composition of maize. Anal Bromatol 1971;23:291.
4. Food and Agriculture Organization. Maize in human nutrition. Food and Nutrition Series No. 25. Rome: FAO, 1992.
5. Weber EJ. Carotenoids and tocols of corn grain determined by HPLC. Journal of the American Oil Chemists Society 1987;47:337–9.

Low-phytic-acid grains

Victor Raboy

Abstract

*As one approach to the improvement of the nutritional quality of crops for both foods and feeds, low-phytic-acid (*lpa*) mutants of maize and other cereals have been isolated. An important advantage of* lpa *mutants is that the bioavailability of a range of minerals may be improved, although phytic acid can also function as an antioxidant. Livestock producers are primarily concerned with excretion of feed phytic acid phosphorus by livestock and fish. This contributes to water pollution and is a major environmental issue in developed countries. In these mutants, phytic acid phosphorus is reduced by 55% to 66%, which is matched by an equal increase in inorganic phosphorus. Greater reductions in phytic acid, as high as 95% to 99%, may be desirable and are possible. The first two studies of an* lpa *maize in human nutrition found increased fractional absorption of iron and zinc in the* lpa *maize as compared with the control maize.*

Yields of the best lpa *lines, first developed in the mid-1990s, now range between 5% and 15% below those of the highest-yielding commercial varieties. Because of benefits for animal nutrition,* lpa *crops could become highly profitable for use as animal feeds. All* lpa *lines to date have been developed using classical genetic methods; these classically obtained mutants affect the expression of a given gene throughout the tissues and organs of a plant. BY using a biotechnology approach, it may be possible to achieve optimal levels of phytic acid reduction and target the desired effect to the seed, thereby reducing any undesirable agronomic effects of whole-plant mutants.*

Introduction

In this paper I will briefly review genetics and breeding research addressing one aspect of grain nutritional quality that has relevance for the agriculture of both developed and developing economies, and for both feed and food uses of grains. This research addresses the amount and form of the major phosphorus-containing compound in seeds, referred to as phytic acid.

In mature seeds of most traditional crops, about 75% of the total phosphorus is found as phytic acid [1]. Seeds produced by cereal grains typically contain 2.5 to 4.0 mg of total phosphorus per gram dry weight and thus might contain 2 to 3 mg of phytic acid phosphorus, or from 7 to 10 mg of phytic acid, per gram dry weight. At physiological pH, phytic acid is a polyanion, each molecule containing six to eight negative charges distributed among its six phosphate esters. This relatively small molecule with a high charge density is a strong chelator of positively charged mineral cations such as calcium, iron, and zinc. Once consumed, seed-derived dietary phytic acid may continue to bind the seed-derived minerals, but it also may bind other "endogenous" minerals encountered in the digestive tract. These salts are largely excreted by humans and non-ruminant animals, which typically lack the ability to digest and utilize phytic acid.

In terms of human health and nutrition, dietary phytate can have both negative and positive outcomes [2]. It can contribute to mineral depletion and deficiency in populations that rely on whole grains and legume-based products as staple foods [3]. This negative impact may be "global," in that phytic acid will bind to, and lead to depletion of, several nutritionally important minerals. However, phytic acid can also function as an antioxidant and anticancer agent and may have other beneficial effects on health [4, 5]. Any consideration of the role of dietary phytic acid in nutrition and health must take both pro- and anti-health roles into account [2].

Whereas human nutritionists are mostly concerned about the consequences of the chelation of minerals by phytic acid, animal nutritionists and livestock producers are primarily concerned with the excretion of feed phytic acid phosphorus by poultry, swine, and fish. This contributes to water pollution and is a major

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environmental issue in the United States, Europe, and elsewhere [6, 7]. New and more stringent standards are being mandated for phosphorus management in livestock production.

The 75% of grain and legume total phosphorus found as phytic acid phosphorus represents a significant fraction of all phosphorus removed from the soil by grain and legume crops. It represents a sum equivalent to about 50% of all phosphorus applied as fertilizer worldwide [8]. It also represents an amount that would satisfy a major fraction of an animal's dietary requirement for phosphorus, if available. Until the advent in the 1990s of the research reported here, that portion of grain total phosphorus found as phytic acid phosphorus and fed to non-ruminants was simply wasted.

Low-phytic-acid mutants

As one approach to the improvement of the nutritional quality of crops for both foods and feeds, my group at the US Department of Agriculture-Agricultural Research Service (USDA-ARS) has been isolating low-phytic-acid mutants (*lpa*) (table 1). Seeds homozygous for an *lpa* mutant contain normal levels of seed total phosphorus but greatly reduced levels of phytic acid phosphorus. At the start of this research, there was essentially no Mendelian genetics of grain or legume seed phytic acid; there were no "phytic acid mutants." There had been numerous studies of the quantitative variation in seed phytic acid among lines of a given crop species [1]. Substantial variation in the concentration of seed phytic acid was typically observed, but in crops grown under standard production conditions, the proportion of seed total phosphorus found as phytic acid phosphorus largely remained constant. We sought mutants whose seed contained normal levels of total phosphorus but greatly reduced levels of phytic acid phosphorus.

Maize low-phytic-acid mutants

We began by generating a population of ethylmethane sulphonate-induced mutants in maize and screening it for mutants whose seed contained substantial reductions in phytic acid phosphorus. Two heritable mutants were found in the first round of screening (table 1) [9]. In these mutants, phytic acid phosphorus was reduced by 55% to 66%, which was matched by an equal increase in inorganic phosphorus. In these seeds, inorganic phosphorus may represent up to 50% of total seed phosphorus. Initial studies indicated that one of these mutants, *lpa1-1,* was a good candidate for use in breeding.

The first *lpa1-1* inbred lines were developed in the mid-1990s and were used to produce 14 pairs of near-isogenic hybrids (isogenic lines differ only by a narrow range of selected traits/genes, in this case differing only in grain phytic acid and inorganic phosphorus levels). These were then used for the first studies of the effect of *lpa1-1* on germination, yield, and other agronomic characteristics [10]. Little or no difference in germination, stand establishment, stalk lodging,

TABLE 1. Description of selected low-phytic-acid mutants

Species and mutant[a]	Approximate reduction in phytic acid phosphorus[b]	Other observations
Maize		
lpa1-1	55%–65%	Reduced phytate matched solely by increased inorganic phosphorus
lpa2-1	50%	Reduced phytate matched by increased inorganic phosphorus and other inositol phosphates
M2 91286-15	95%	Lethal as homozygote. Reduced phytate matched solely by increased inorganic phosphorus
M2 92166-3	95%	Lethal as homozygote. Reduced phytate matched solely by increased inorganic phosphorus
Barley		
lpa1-1	50%	Reduced phytate matched solely by increased inorganic phosphorus
lpa2-1	50%	Reduced phytate matched by increased inorganic phosphorus and other inositol phos-
phates		
M2 635	75%	Reduced phytate matched solely by increased inorganic phosphorus
M2 955	95%	Viable as homozygote. Reduced phytate matched solely by increased inorganic phosphorus
Rice		
1pa1-1	45%	Reduced phytate matched solely by increased inorganic phosphorus

a. Mutants given italicized gene symbols s*uch as* lpa*1-1 or* lpa2-1 have been mapped to chromosome position, and allelism tests have been conducted to determine allelic relationships. Other mutants for which we have incomplete mapping or allelism test data are referred to using their laboratory designations, such as M2 91286-15 or M2 *635*.

b. Normal, wild-type seeds of these species typically contain from 7 to 10 mg/g of phytic acid. The amount of phytic acid in any given mutant can be calculated by multiplying this range by the indicated level of reduction.

plant height, ear height, flowering date. or "stay green" score was observed between normal (non-mutant) and mutant isolines of a given hybrid. On average, a 6% yield loss was observed in the *lpa1-1* hybrids as compared with the normal hybrids.

Animal nutrition studies with maize lpa1-1

Normal isohybrids and *lpa1-1* were compared first for use in chick feeds [10]. General measures of performance, such as bird weight or feed/gain ratio, indicated that the *lpa1-1* grain was more nutritious than normal grain. The mean weight of birds consuming *lpa1-1*–containing diets was 16% greater than that of birds fed normal diets. Feed/gain ratios were 8% to 9% lower in *lpa1-1* feeds than in normal feeds, indicating greater weight gain per unit of feed. Bone phosphorus was 10% higher, and blood phosphorus was 28% to 36% higher, in *lpa1-1*–fed birds than in those consuming normal feed. Bone calcium was 11% to 13% higher, and blood calcium was 29% to 36% higher, in birds consuming *lpa1-1* feed than in those consuming normal feed. Faecal phosphorus was reduced by 9% to 40%. According to a variety of these bioassay measures, phosphorus availability in *lpa1-1* grain was estimated to range from 70% to 91% in *lpa1-1* grain, as compared with 30% to 47% in normal grain. These results indicate that reductions in grain phytic acid phosphorus can have a positive impact on calcium nutrition as well as on phosphorus nutrition. Additional studies with poultry, swine, and fish have since yielded similar results. These studies revealed a simple quantitative relationship. Increasing reductions in grain phytic acid phosphorus in various *lpa* lines lead in a linear fashion directly to corresponding increases in the retention and utilization of grain phosphorus.

Human nutrition studies with maize lpa1-1

The first study of a low-phytic-acid maize in human nutrition assayed the potential effect of reduced phytic acid consumption on iron nutrition [11]. Tortillas were prepared from normal, non-mutant maize and from *lpa1-1* maize. These tortillas were extrinsically radiolabelled with iron and fed to 14 non-anaemic men. Iron absorption was 49% greater from *lpa1-1* tortillas than from normal tortillas (8.2% of intake vs. 5.5% of intake). Although these fractional absorption levels are low, this was a statistically significant improvement in iron uptake, and supports the potential benefits of reduced phytic acid consumption in improving iron nutrition.

A more recently conducted study looked at the effect of *lpa* maize on zinc nutrition [12]. During cooking, ^{67}Zn and ^{70}Zn stable isotopes were incorporated into *lpa1-1* and normal polenta (corn cakes), respectively. Five healthy adults (aged 23 to 39 years) consumed the *lpa1-1* polenta on the first day and the normal polenta on the second day. The fractional absorption of the ^{67}Zn in the *lpa1-1* food was 0.30 ± 0.13 (mean ± SD), whereas the fractional absorption of the ^{70}Zn in the non-mutant food was 0.17 ± 0.11. This result further supports the potential value of reduced dietary phytic acid intake.

A field project is currently under way in rural Guatemala (principal investigator, Dr. Michael Hambidge, University of Colorado). Families will consume either normal or *lpa1-1* maize over an extended period of time (two months or more). Zinc nutritional status and homeostasis will be studied in children. Pending funding decisions, we would also like to monitor iron and calcium status and to include adult women and men in the study. An important aspect of this study is that it will examine steady-state nutritional status in individuals consuming greatly different levels of phytic acid over an extended period of time. It will therefore attempt to distinguish between chronic and acute effects of phytic acid intake.

Current research directions for maize

A growing number of maize-breeding programmes are working with *lpa1-1* and similar mutants. This trait is being introduced into a variety of maize types, including yellow and white, and temperate and tropical types. Breeding for high yield in an *lpa* background is an important part of these programmes. However, very little research has been reported to date with respect to stress tolerance and susceptibility to pests and diseases of low-phyticacid lines. Breeding for adequate and stable yield in a wide variety of environments should have at least as high a priority as breeding for high yield.

We, and others, continue to isolate and study additional maize low-phytic-acid mutants, many of which have greater reductions in grain phytic acid than does *lpa1-1*. The 66% reduction in phytic acid phosphorus in *lpa1-1* as compared with wild type (table 1) represents a valuable first step, but greater reductions may be desirable and possible. We have isolated maize mutants for which there is a 95% to 99% reduction in seed phytic acid (table 1), but all such mutants isolated to date are lethal as homozygotes.

It is possible that reductions in phytic acid consumption approaching 90% or greater will be necessary to have a positive impact on iron nutrition. In the case of zinc nutrition, further reductions in grain phytic acid might be necessary to achieve optimal phytic acid:zinc molar ratios. Some argue that phytic acid reductions greater than a certain threshold are required before nutritional benefits can be realized. Perhaps there is a significant quantitative component to the impact of dietary phytic acid on iron and zinc nutrition, or on mineral nutrition in a global sense. Perhaps stepwise decreases in grain phytic acid will translate in a linear fashion directly into increases in iron and zinc retention and utilization, or the retention and utilization of minerals globally. Testing these assumptions or paradigms is one of the objectives of the current field project in Guatemala.

All low-phytic-acid lines to date were developed using classical genetics methods: mutant induction, isolation, and standard plant-breeding methods. In addition to their desirable seed-specific phenotype, these classically obtained mutants affect the expression of a given gene throughout the tissues and organs of a plant. These whole-plant effects could contribute to the solution of yield and productivity problems, such as disease or stress susceptibility. The most effective approach to developing a high-yielding, disease- and pest-resistant, low-phytic-acid maize may therefore require the use of contemporary molecular genetics approaches. We, and others, are mapping and cloning the genes altered in these mutants, and other genes that play a role in these pathways. Using a biotechnological approach, we may be able to achieve optimal levels of phytic acid reduction, and target the desired effect to the seed, or to a specific tissue or cell within the seed, thereby reducing undesirable effects of whole-plant mutants.

Low-phytic-acid barley

A number of low-phytic-acid mutants have now been isolated in barley (table 1) [13, 14]. The results of these studies are very similar to those observed with maize, in that we have isolated a large number of mutants (more than 20) that are *lpa1*-like, with reductions of grain phytic acid ranging from 50% to 95%. One important difference is represented by the barley mutant termed M2 955, in which seed phytic acid is reduced by more than 95% (table 1). M2 955 is viable, but the two maize mutations that cause such large reductions in seed phytic acid, maize M2 91285-15 and M2 92166-3, are lethal. Although M2 955 does not appear to be valuable in agronomic terms (its yield is significantly reduced as compared with that of non-mutant checks), it provides a very powerful tool for nutrition research. With it we now can produce near-isogenic barley lines that are essentially identical in every way, except that their grain phytic acid phosphorus ranges from levels typical of non-mutant grain, through intermediate levels of reduction in *lpa1-1* and M2 635, to nearly absent in M2 955. With such lines, definitive studies can be conducted that test the putative negative impact of phytic acid on mineral nutrition, or its putative positive roles.

Low-phytic-acid rice

We have made less progress with rice than with maize or barley. To date we have isolated only one rice mutant, which has a reduction in seed phytic acid of about 45% [15]. To evaluate its agronomic value, and to get a better idea of what can be achieved in rice, we need a much larger collection of mutants. Developing such a collection of mutants is our current main research objective with respect to rice.

Rice is primarily consumed as white rice after milling. Most phytic acid and minerals are located in the rice aleurone layer, which is removed during milling. Therefore, it might seem pointless to isolate a low-phytic-acid rice. However, a low-phytic-acid rice bran would be of greater value in non-ruminant livestock feeds, including poultry, swine, and fish feeds, than would brans derived from normal rices. The enhanced value and use of such a side product would represent a non-trivial increase in efficiency of resource use.

However, a low-phytic-acid rice may in fact prove beneficial for human nutrition. First, it may be of value for whole-grain rice foods. More importantly, these mutants may alter the distribution of phosphorus and minerals in the mature grain. A block in phytic acid synthesis might perturb the deposition of zinc and iron in the aleurone layer, elevating the level of these minerals in the central endosperm. Studies are under way to test this hypothesis. Even a small increase in the mineral content of rice endosperm could prove beneficial in human nutrition terms.

Conclusions

The primary goal of the maize-breeding community in the United States is to improve this crop as a feed grain. The traits of greatest importance here include optimized amino acid balance, high oil content, and high available phosphorus (or low phytic acid). Maize breeders seek to combine or “stack” nutritional quality traits to produce an optimal feed grain. This approach might have application in the improvement of grains as human foods, in the area of mineral nutritional quality. An important advantage of *lpa* mutants is that the bioavailability of a range of minerals may be improved. Therefore, it may be important to breed for increased iron and zinc levels, along with reduced phytic acid. Any strategy of reducing grain or legume phytic acid must take the needs of the target population into account. Dietary phytic acid may have a net beneficial effect as an antioxidant and anticancer agent, or a negative effect on mineral nutrition, depending on the population. Therefore, a number of genotypes with varying degrees of phytic acid content may need to be developed to fit particular nutritional circumstances.

Many questions remain concerning the agronomic performance of *lpa* crops, particularly under adverse growing conditions. With our best-yielding *lpa* lines, in general, yield reductions ranging from 5% to 15% have been observed. As breeding programmes with the *lpa* trait progress, yields of such lines will continue to increase, although they may never equal that of the best high-yielding lines. Nevertheless, because of benefits for animal nutrition, *lpa* crops could become profitable varieties available for use as animal feed. Because of benefits for human nutrition and for the environment that are not easily captured by private markets, it behooves policy makers to consider introduction of these varieties into public breeding programmes in developing countries as well.

References

1. Raboy V. Accumulation and storage of phosphate and minerals. In: Larkins BA, Vasil IK, eds. Cellular and molecular biology of plant seed development. Dordrecht, Netherlands, and Boston, Mass, USA: Kluwer Academic Publishers ,1997:441–77.
2. Harland BF, Morris ER. Phytate: a good or a bad food component? Nutr Res 1995;15:733–54.
3. Brown KH, Solomons NW. Nutritional problems of developing countries. Infect Dis Clin North Am 1991;5:297–317.
4. Graf E, Eaton JW. Suppression of colonic cancer by dietary phytic acid. Nutr Cancer 1993;19:11–9.
5. Graf E, Epson KL, Eaton JW. Phytic acid: a natural antioxidant. J Biol Chem 1987;262:11647–50.
6. Cromwell GL, Coffey RD. Phosphorus—a key essential nutrient, yet a possible major pollutant—its central role in animal nutrition. In: Lyons TP, ed. Biotechnology in the feed industry. Nicholasville, Ky, USA: Alltech Technical Publications, 1991:133–45.
7. Sharpley AN, Charpa SC, Wedepohl R, Sims JY, Daniel TC, Reddy KR. Managing agricultural phosphorus for protection of surface waters: issues and options. J Environ Qual 1994;23:437–51.
8. Lott JNA, Ockenden I, Raboy V, Batten GD. Phytic acid and phosphorus in crop seeds and fruits: a global estimate. Seed Sci Res 2000;10:11–33.
9. Raboy V, Gerbasi P, Young KA, Stoneberg S, Pickett SG, Bauman AT, Murthy PPN, Sheridan WF, Ertl DS. Origin and seed phenotype of mai*ze low phytic acid* 1-1 a*nd low phytic acid* 2-1. Plant Physiol 2000;123 (in press).
10. Ertl DS, Young KA, Raboy V. Plant genetic approaches to phosphorus management in agricultural production. J Environ Qual 1998;27:299–304.
11. Mendoza C, Viteri FE, Lönnerdal B, Young KA, Raboy V, Brown KH. Effect of genetically modified, low-phytic acid maize on absorption of iron from tortillas. Am J Clin Nutr 1998;68:1123–8.
12. Adams C, Raboy V, Krebs N, Westcott J, Lei S, Hambidge M. The effect of low-phytic acid corn mutants on zinc absorption. FASEB J Abstr 2000;14:A359.11.
13. LarSON SR, Young KA, CooK A, Blake TK, RaBOY V. Linkage mapping two mutations that reduce phytic acid content of barley grain. Theor Appl Genet 1998;97:141–6.
14. Rasmussen SK, Hatzack F. Identification of two low-phytate barle*y (Hordeum vulga*re L.) grain mutants by TLC and genetic analysis. Hereditas 1998;129:107–12.
15. Larson SR, Rutger JN, Young KA, Raboy V. Isolation and genetic mapping of a non-lethal rice low phytic acid mutation. Crop Sci 2000;40 (in press).

Testing iron and zinc bioavailability in genetically enriched beans (*Phaseolus vulgaris* L.) and rice (*Oryza sativa* L.) in a rat model

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Abstract

A rat model was used to determine the bioavailability of iron and zinc in bean seeds and rice grain from enriched genotypes of these globally important staple foods. Seed and grain from the genotypes tested (intrinsically radiolabelled with either ^{59}*Fe or* ^{65}*Zn) were cooked, homogenized in water, and lyophilized to dryness. The dried, radiolabelled powder was fed to young male rats in single meals. Bioavailability was calculated from the amount of radiolabelled iron and zinc retained in the rats over a 10-day period as determined each day by whole-body gamma spectrometry assay. The data collected demonstrate that increasing the amount of iron or zinc in enriched rice grain and bean seed significantly increases the amount of iron or zinc bioavailable to rats.*

Although a rat model is not ideal for determining iron and zinc bioavailability to humans, because rats are much more efficient at absorbing iron and zinc from plant foods than humans, rats can be used to give relative estimates of bioavailable iron and zinc in plant foods. These estimates can be used to rank promising genotypes of staple foods for use in later feeding trials with humans, greatly reducing the numbers of genotypes that would have to be tested in humans without use of the rat model. Ultimately, because of the complexities of determining the bioavailability to humans of iron and zinc in plant foods, human feeding trials performed under free-living conditions should be conducted with the most promising genotypes before these genotypes are released for distribution to breeding programmes worldwide

Introduction

From its inception, the CGIAR (Consultative Group on International Agricultural Research) Micronutrients Project has stressed the importance of knowing the bioavailability (defined as the amount of a nutrient in a food that is absorbable and utilizable by the person eating the food in a typical meal) of the micronutrients in staple plant foods selected for improvement, which include rice, wheat, maize, beans, and cassava. Just increasing the concentration of a micronutrient in a plant food does not guarantee improved nutritional status of people with micronutrient deficiencies who consume that food. This is because not all of a micronutrient in a plant food is bioavailable to a person consuming the food in a traditional meal. Various interacting factors, both genetic and environmental (fig. 1), can reduce the bioavailable levels of micronutrients in staple plant foods in meals [1]. Therefore,

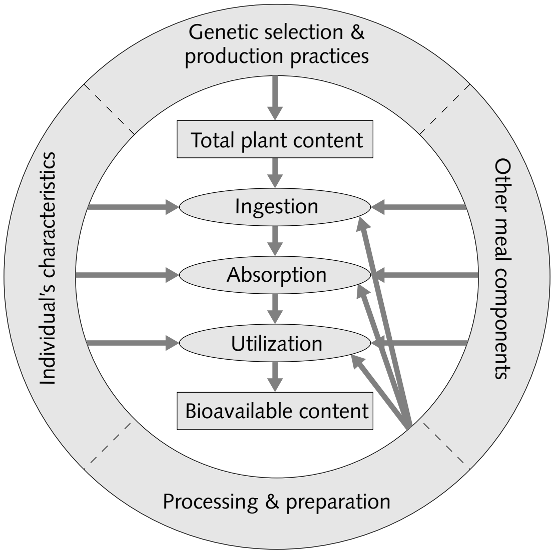

FIG. 1. A holistic model of the complexities of micronutrient bioavailability from plant food sources

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a method was needed to determine iron and zinc bioavailability in micronutrient-enriched genotypes identified by scientists at cooperating CGIAR centres to ensure that any improvement in iron or zinc concentrations in select lines would be effective in improving the micronutrient status of persons with micronutrient deficiencies.

There is no single bioavailability method that is ideal for all micronutrients and for all circumstances. The equipment required, the costs of labour and animals, and the funds available all play important roles in determining the method of choice. Selecting a method to use in determining micronutrient bioavailability in plant foods requires consideration of several issues that can affect the results obtained. Some of the more important issues are intrinsic versus extrinsic labelling of plant material, the bioavailability model to use (*in vitro*, animal species), the micronutrient status of the experimental subjects, and the level of antinutrients and promoter substances in test plant food and test meals.

Many iron and zinc bioavailability techniques use either radioisotopes or stable isotopes of iron and zinc incorporated into a meal to determine bioavailability [2]. Intrinsic labelling of plants with either stable isotopes or radioisotopes requires growing plants in nutrient media labelled with an isotope of the micronutrient under study. This is a time-consuming and costly exercise, but it ensures that the micronutrient being tested in a meal will be in a form that occurs naturally in the food. Extrinsic labelling techniques (i.e., adding isotope labels during preparation of test meals) are easy and relatively inexpensive; however, the use of extrinsic isotope tags does not ensure that the added isotope will be fully equilibrated with all forms of the micronutrient in the plant food [2, 3]. Thus, using intrinsic labels is the only way to obtain unequivocal results from bioavailability studies; this method was chosen in the studies reported here.

Various *in vitro* and *in vivo* methods and animal models are available for determining the bioavailability of iron and zinc in plant foods [2–4]. Most *in vitro* methods cannot reproduce the interactions (e.g., release of intrinsic factors) that occur between intestinal mucosal cells lining the gut and the food constituents in the gut. Therefore, *in vitro* methods were not chosen for this project, although recently developed human intestinal cell (Caco-2) culture techniques are being tested for their suitability for determining bioavailable iron and zinc from plant food sources in this project [5]. Some large animal models (e.g., pigs) closely mimic human subjects in the quantitative bioavailability results obtained. Unfortunately, using these large animal models is expensive and requires special housing and equipment not available to many scientists, including those associated with this project. We have chosen primarily to use a rat model for initial screening of promising genotypes for bioavailable iron and zinc content. Although a rat model is not ideal for determining iron and zinc bioavailability to humans (because rats are much more efficient at absorbing iron and zinc from plant foods than humans are), rats can be used to give relative estimates of bioavailable iron and zinc in plant foods. These estimates can be used to rank promising genotypes of staple foods for use in later feeding trials with humans, greatly reducing the numbers of genotypes that would have to be tested in humans without use of the rat model. Ultimately, because of the complexities of determining the bioavailability of iron and zinc in plant foods to humans, human feeding trials performed under free-living conditions should be conducted with the most promising genotypes before these genotypes are released for distribution to breeding programmes worldwide.

The bioavailability of iron and zinc is greatly affected by the iron and zinc status of the experimental subject, because homeostatic mechanisms controlling the absorption of these micronutrients from the gut are highly regulated. Persons with deficiencies or low body stores of these micronutrients up-regulate their intestinal absorption, whereas normal persons down-regulate their absorption [6]. Therefore, any bioavailability model should use subjects with depleted stores of these micronutrients to ensure that their full ability to absorb these nutrients is expressed.

Discussing the issues raised by antinutrients (e.g., phytate and tannins) and promoter substances (e.g., ascorbic acid and peptides high in sulphur-containing amino acids) in plant foods is beyond the scope of this report. For further information on this topic, refer to Welch and Graham [7].

In this paper we present the results collected on the bioavailability of iron and zinc in promising genotypes of beans and rice selected for their ability to accumulate significantly more iron and zinc in their seeds when produced under various environmental conditions and at different locations. A rat model was used to determine both iron and zinc bioavailability.

Materials and methods

Genotypes selected

Bean seeds from the Centro Internacional de Agricultura Tropical(CIAT) core bean collection (grown at the same location during the same season) were initially screened in Cali, Colombia, for seed iron and seed zinc concentrations; 24 contrasting accessions were selected for iron studies, and 18 were selected for zinc studies. These accessions represented a range in seed types differing not only in their iron and zinc concentrations, but also in their seed colours and other important characteristics.

White-seeded beans generally contain a low amount of tannins; therefore, two accessions with white-coloured seeds were included to ensure variability in seed tannin content among accessions. Total sulphur concentration is an indicator of sulphur-containing amino acids (i.e., methionine and cysteine-cystine) in seeds. Total phosphorus is an indicator of phytate concentrations in seeds. Variability was likewise sought in sulphur and phosphorus concentrations in bean seeds among accessions.

Rice genotypes used in the bioavailability studies were selected by screening more than 1,500 lines of rice for iron and zinc concentrations from the International Rice Research Institute (IRRI) collections and from sets collected in China and Bangladesh. Genotypes were selected on the basis of their ability to accumulate significantly more iron or zinc in their grain. Popular high-yielding but low-iron IRRI rice varieties were included in the bioavailability testing for comparison purposes.

Bioavailability testing

The dried homogenates of either intrinsically ^{59}Fe-labelled mature beans or intrinsically ^{65}Zn- labelled mature rice grain were used to prepare single meals. The meals were fed to young male rats that were maintained on either a marginally iron-deficient diet or a commercially prepared, marginally zinc-deficient, eggwhite-based diet for seven days. The containers holding the meals were assayed for ^{59}Fe or ^{65}Zn before and after the meal was fed to the rats. All rats had free access to radiolabelled meals for three hours. The rats were assayed for radioactivity immediately after being fed the meals, and then daily thereafter for the next 10 days [8]. All radioassays were conducted by using a whole-body gamma spectrometer. The rats were then fed the basal diet for the remainder of the experiment. The whole-body retention data were used to calculate the absorption of ^{59}Fe from the meal [9]. Bioavailability was defined as the percentage of ^{59}Fe absorbed from the bean meal.

Results and discussion

Studies on beans

There was a wide range in the concentrations of iron, zinc, total sulphur, total phosphorus, tannin, and *myo*-inositolpentaphosphoric acid plus *myo*-inositolhexaphosphoric acid (IP5 + IP6) in the 24 select genotypes intrinsically labelled with ^{59}Fe, as shown in table 1.

Figure 2 depicts the significant positive correlation found between iron and zinc concentrations in the 24 genotypes of beans tested. These data suggest that breeding for high iron density in beans may also lead to high zinc levels.

There was no significant relationship between IP5 + IP6 concentrations in the beans and the concentration of either iron or zinc. Nor was there any significant relationship between either iron or zinc concentration in the beans and total phosphorus, tannin, or total sulphur concentration in the bean genotypes tested.

The relationship between the amount of bioavailable iron in the 24 bean genotypes studied and the concentration of iron in the beans is shown in figure 3. These data demonstrate that genetically selecting bean genotypes for increased seed iron concentration results in increases in the amount of iron bioavailable to rats, supporting the contention that it would be beneficial to select for iron-dense beans in plant-breeding programmes directed at improving the iron status of humans with iron deficiency.

The results of the ^{65}Zn-labelled bean bioavailability study closely resemble those of the ^{59}Fe-labelled

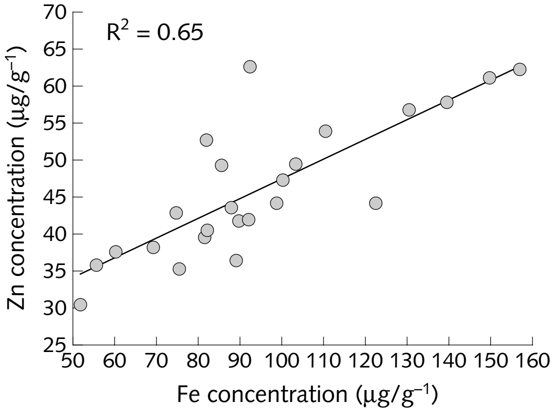

FIG 2. Relationship between the concentrations (dry weight basis) of iron and zinc in 24 lines of bean seeds grown in ^{59}Fe-labelled nutrient solutions

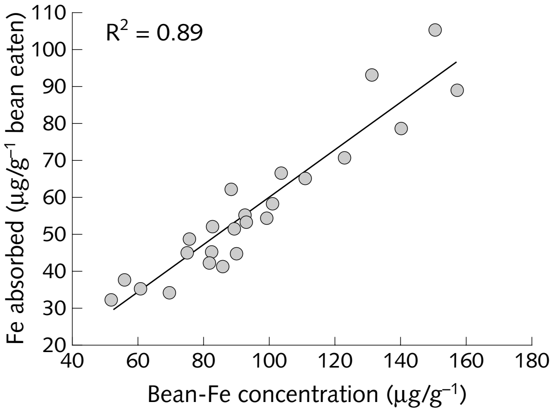

FIG. 3. Relationship between bean iron concentration and iron absorbed by iron-depleted rats fed intrinsically labelled bean meals

TABLE 1. Concentrations (dry weight basis) of iron, zinc, total phosphorus, total sulphur, phytate (IP5 + IP6),[a] and tannins in mature bean seeds from 24 genotypes grown in ^{59}Fe-radiolabelled nutrient solutions, and bioavailable iron absorbed by iron-depleted rats fed single meals prepared from beans

Bean genotype	Fe (µg/g)	Zn (µg/g)	Total P (mg/g)	Total S (mg/g)	Phytate (µmol/g)	Tannins[b] (mg/g)	Bioavailable Fe (µg per meal)
G12610	51.63	30.42	4.62	1.47	19.57	2.65	32.40
G8465	55.67	35.88	6.84	1.89	25.00	1.64	37.69
G21725	60.25	37.64	6.58	1.47	26.45	1.18	35.28
G21242	69.16	38.15	7.04	1.90	27.77	1.56	34.29
G21078	74.53	42.80	6.24	1.33	23.68	1.88	45.04
G2774	75.27	35.30	5.26	1.37	20.66	0.96	48.77
G19022	81.45	39.47	5.36	1.97	22.99	1.28	42.33
G15137	82.07	52.59	7.17	1.41	27.48	1.55	45.36
G4825	82.26	40.41	5.91	1.47	23.23	1.85	52.38
G14519	85.53	49.17	8.46	2.14	33.53	0.90	41.48
G18372	88.01	43.45	5.55	1.95	19.60	0.35	62.39
G23063	88.88	36.24	5.19	1.73	21.94	2.60	51.66
G1678	89.74	41.62	7.05	1.72	25.68	1.21	44.96
G11419	91.96	41.80	6.05	1.46	23.58	0.91	55.50
G1844	92.53	62.51	6.42	2.06	29.16	1.15	53.67
G11350	98.71	44.04	6.40	2.13	25.91	1.32	56.14
G5706	100.51	47.26	6.16	2.03	24.27	0.65	58.54
G2572	103.55	49.28	6.74	2.30	23.06	2.22	66.94
G16267	110.59	53.69	6.30	2.09	25.41	1.32	65.31
G13220	122.70	44.02	5.51	1.38	23.74	2.49	71.24
G18811	130.70	56.64	5.45	1.50	22.94	0.54	93.27
G3096	139.91	57.76	6.90	1.56	25.27	0.89	78.92
G87	149.86	60.87	6.45	2.04	26.15	1.97	105.50
G734	156.91	62.06	6.16	2.13	24.09	1.41	89.35
LSD[c]	±10.18	±1.93	±0.36	±0.45	±2.75	±0.04	±11.88

a. The phytate concentration is the concentration of *myo*-inositolpentaphosphoric acid plus *myo*-inositolhexaphosphoric acid (IP5 + IP6)

b. Determined as catechin equivalences in bean homogenates.

c. LSD is the least significant difference at $p = 05$ ($n = 72$ for iron, zinc, total phosphorus, and total sulphur; $n = 48$ for IP5 + IP6 and tannins; $n = 120$ for bioavailable iron).

study reported above. Selecting bean genotypes with increased zinc concentration in their seeds also tended to increase seed iron concentrations in the 18 bean genotypes studied. There was no significant relationship between seed zinc concentration and total phosphorus, total sulphur, tannin, or IP5 + IP6 concentration. Increasing zinc concentrations in the beans through genetic selection increased the amounts of bioavailable zinc in the seeds, as determined in the rat bioassay (fig. 4). These results also support the contention that selecting for traits in bean genotypes that enrich the zinc concentration in their seeds will provide more bioavailable zinc to target populations dependent on beans as a major source of zinc in their diet.

Interestingly, there was no significant relationship between IP5 + IP6 and tannin concentrations in the genotypes and bioavailable zinc. Apparently, some other factors (e.g., unknown plant-derived zinc complexes or promoters) besides phytate and tannins are affecting the bioavailability of zinc in bean seeds to rats. The identities of these factors remain to be elucidated through further research.

Studies on rice

To test iron bioavailability, ^{59}Fe-labelled grain representing six genotypes of rice was used to prepare meals fed to rats. There was a wide variation in the grain concentrations (dry weight basis) of iron (17.5 to 38.6 µg/g), inorganic phosphorus (9.9 to 22.7 µmol/g), and IP5 + IP6 (5.7 to 16.8 µmol/g). Zinc grain concentrations in the six genotypes tested varied from 31.9 to 61.8 µg/g dry weight. As shown for beans, the concentrations of iron and zinc in the rice grain were positively correlated. Unlike the case with beans, there was a tendency for genotypes that accumulated higher grain phytate to accumulate more iron ($R^2 = 0.41$).

Figure 5 shows the relationship between grain iron concentration and bioavailable iron absorbed by iron-depleted rats fed single meals prepared from six genotypes of rice grain intrinsically labelled with ^{59}Fe. As with bean seeds, increasing the concentration of iron in rice grain increased the amount of iron bioavailable to rats, supporting the contention that it would be worthwhile to genetically select for improved iron

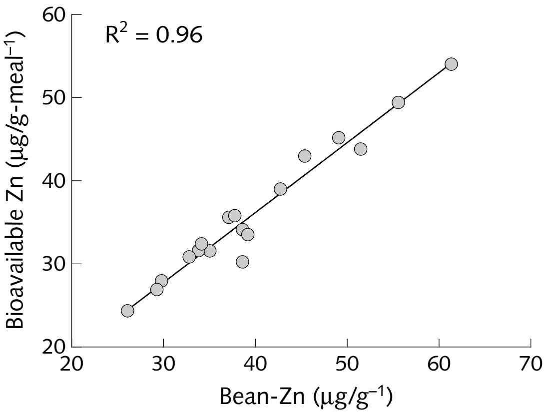

FIG. 4. Relationship between bean zinc concentration and zinc absorbed by zinc-depleted rats fed intrinsically labelled bean meals

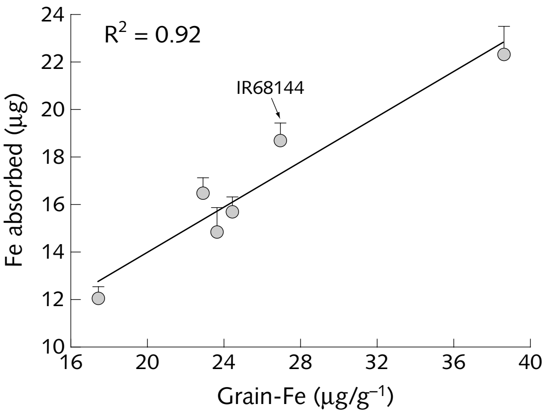

FIG. 5. Relationship between grain iron concentration and amount of iron bioavailable to rats fed single meals prepared from unpolished kernels from six rice genotypes

density in rice grain in order to increase the supply of iron to people dependent on rice as a staple food.

Selected rice genotypes were also intrinsically labelled with ^{65}Zn. There were two sets of intrinsically labelled rice fed to zinc-depleted rats. In the first set, grain zinc concentrations varied from 45.4 µg/g (Azucena) to 68.9 µg/g (Madhukar), whereas iron concentrations varied from 22.7 µg/g (Madhukar) to 31.6 µg/g (IR68144). Phytate (IP5 + IP6) and total kernel phosphate concentrations also varied greatly between genotypes, from 15.90 to 22.93 µmol/g for phytate and from 8.56 µmol/g (Azucena) to 17.16 µmol/g (IR68144) for phosphate. The percentage of bioavailable zinc in the six rice genotypes tested did not vary greatly between genotypes. Furthermore, there was no significant correlation between either grain phytate concentration (IP5 + IP6) or total sulphur concentration and percent bioavailable zinc to rats. Genotypes more enriched in zinc provided more bioavailable zinc to rats than genotypes containing relatively low levels of zinc.

Table 2 presents the data for the second set of 10 intrinsically ^{65}Zn-labelled rice genotypes tested for bioavailable zinc using the rat model. None of the factors determined were significantly related to the amount of zinc accumulated in rice grain (i.e., iron, total sulphur, phosphate, or phytate). As with the first set of rice genotypes tested (see discussion above), there was no relationship between grain phytate concentration and the amount of bioavailable zinc in the grain

TABLE 2. Concentrations (dry weight basis) of zinc, iron, total sulphur, phosphate, and phytate (IP5 + IP6),[a] in mature unpolished rice grain from 10 genotypes grown in ^{65}Zn-radiolabelled nutrient solutions, and percent zinc absorbed (bioavailable) by zinc-depleted rats fed single meals prepared from labelled kernels (1 g rice per meal)

Rice genotype	Zn (µg/g)	Fe (µg/g)	Total S (mg/g)	Phosphate (mol/g)	Phytate (µmol/g)	Bioavailable Zn (%)
IR101198-66-2	60.50	18.76	1.581	8.73	19.43	82.1
IR68144	53.13	22.38	1.439	13.83	17.48	75.1
Madhukar	51.09	17.75	1.346	5.08	13.35	77.6
Jalmagna	48.79	19.03	1.154	8.41	15.78	87.7
IR58	48.10	19.66	1.521	9.09	19.24	77.8
IR72	47.89	15.86	1.233	6.02	15.17	82.4
Heibao	46.69	21.35	1.535	10.46	17.31	76.1
IR36	46.60	16.11	1.292	7.98	17.33	79.8
IR74	44.07	16.93	1.120	7.13	19.72	81.2
IR26	35.09	13.26	1.196	5.79	15.18	83.2
LSD[b]	±16.43	±4.08	±0.201	±0.57	±1.55	±9.9

a. The phytate concentration is the concentration of *myo*-inositolpentaphosphoric acid plus *myo*-inositolhexaphosphoric acid (IP5 + IP6).

b. LSD is the least significant difference at $p = .05$ ($n = 12$ for iron, zinc, and total sulphur; $n = 18$ for phosphate and phytate; $n = 42$ for bioavailable iron).

of the different genotypes examined. There was a significant positive correlation between the amount of zinc absorbed by rats and the amount of zinc in the grain of each genotype tested ($R^2 = 0.88$). This result agrees with the data presented for the first set of rice genotypes tested and with the bean data presented, again supporting the contention that it would be worthwhile to select for high-zinc genotypes of rice, because they would provide more bioavailable zinc to people dependent on rice as a staple food.

Of special interest is the rice genotype IR68144. This line is a high-yielding and highly disease-resistant rice developed at IRRI by D. Senadhira. Grain produced from IR68144 consistently contains relatively high levels of both iron and zinc, and these elements were relatively highly bioavailable to rats fed grain from this genotype. Hence, it appears that this line should be given a high priority for further testing in human feeding trials. One such human study is currently being planned in the Philippines.

An *in vitro* human Caco-2 cell-culture model is being tested at our location to determine if this model would be more suitable than the rat model for use in screening iron- and zinc-enriched staples for bioavailable iron and zinc. If the Caco-2 cell model is proven reliable and accurate, the rat model will be abandoned in favour of the less costly and more rapid Caco-2 cell model in future studies.

The effects of food processing and cooking on bioavailable iron and zinc concentrations in the most promising iron- and zinc-dense genotypes of beans and rice must also be determined before a more complete understanding of the potential impact of breeding for micronutrient-dense staple foods is obtained. These types of studies have been initiated.

Conclusions

The results presented in this report using selected genotypes of beans and rice show that enriching these staples with iron and zinc provides significantly more bioavailable iron and zinc to rats. Although these findings support breeding for staple foods with improved micronutrient density, the actual benefits to humans must await future human feeding trials under real-world conditions. Therefore, it is strongly recommended that such human studies receive a high priority in the future. However, field studies using human subjects, which are necessary to demonstrate the feasibility of the breeding approach, are much more expensive than animal studies. We further recommend that the human trials be carried out for relatively prolonged periods, because single-meal studies in humans may not reflect the day-to-day changes in iron and zinc bioavailability that occur over the course of a year caused by variations in food availability, cuisine, dietary patterns, and health [6].

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References

1. Graham RD, Welch RM. Breeding for staple-food crops with high micronutrient density. Washington, DC: International Food Policy Research Institute, 1996: 1–72.
2. Van Campen DR, Glahn RP. Micronutrient bioavailability techniques: accuracy, problems and limitations. Field Crops Res 1999;60:93–113.
3. House WA. Trace element bioavailability as exemplified by iron and zinc. Field Crops Res 1999;60:115–41.
4. Rao BSN. Methods for the determination of bioavailability of trace metals: a critical evaluation. J Food Sci Tech 1994;31:353–61.
5. Glahn RP, Wien EM, Van Campen DR, Miller DD. Caco-2 cell iron uptake from meat and casein digests parallels in vivo studies: use of a novel in vitro method for rapid estimation of iron bioavailability. J Nutr 1996; 126:332–9.
6. Benito P, Miller D. Iron absorption and bioavailability: an updated review. Nutr Res 1998;18:581–603.
7. Welch RM, Graham RD. A new paradigm for world agriculture: meeting human needs. Productive, sustainable, nutritious. Food Crops Res 1999;60:1–10.
8. Welch RM, House WA, Van Campen DR. Availability of cadmium from lettuce leaves and cadmium sulfate to rats. Nutr Rep Int 1978;17:35–42.
9. Welch RM, House WA, Allaway WH. Availability of zinc from pea seeds to rats. J Nutr 1974;104:733–40.

Measuring iron and zinc bioavailability in humans

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Abstract

Iron and zinc deficiencies are common in populations dependent on cereal-based diets because of the poor bioavailability of these minerals in those foods. Selective breeding of high-mineral grains can improve the total intake of iron and zinc. However, the additional iron and zinc from those grains may not be available for absorption because of the high phytate content of cereals. Iron and zinc bioavailability needs to be measured before the high-mineral crops are promoted. Iron or zinc bioavailability can be measured from the response of a physiological variable, assessment of body retention, tissue or blood uptake, changes in pool size, or rates of absorption. Iron bioavailability is preferentially measured from erythrocyte uptake of oral radioactive or stable iron tracers; zinc bioavailability is measured from the rate of absorption of an oral isotopic tracer compared with an intravenous tracer. The oral label, which is required for studies of both iron and zinc, may be intrinsically added to the plant during growth or extrinsically added before feeding. Iron and zinc bioavailability from intrinsically and extrinsically labelled normal and high-mineral common bean varieties was tested in young women with low iron stores. The absorption of intrinsic and extrinsic labels of iron and zinc did not differ. The bioavailability of iron and zinc from both varieties was low, about 1.5% and 13%, respectively. Methods to improve the bioavailability of iron and zinc from plant foods need to be developed.

Introduction

Iron and zinc deficiencies are common not only in developing countries, where the diet is essentially composed of cereals and root crops, but also in some industrialized countries. It is estimated that about half of the world's population consumes insufficient iron and zinc. Iron-deficiency anaemia can impair mental and psychomotor development in children, increase morbidity and mortality of mothers and children at childbirth, decrease work performance, and decrease resistance to infection [1]. Zinc deficiency in humans impairs growth, sexual maturity, and the immune defense system [1]. Although body zinc homeostasis is maintained over a wide range of zinc intakes by increasing or decreasing both intestinal zinc absorption and endogenous intestinal excretion, low zinc intakes combined with poor bioavailability and increased needs during growth or reproduction ultimately result in zinc deficiency [2].

Iron absorption from different foods varies considerably. There are two types of iron in food: non-haem iron, which is present in both plant foods and animal tissues, and haem iron from haemoglobin and myoglobin in animal products. Haem iron represents 30% to 70% of the total iron in lean meat and is always well absorbed. Non-haem iron enters a common non-haem iron pool in the gastric juice, and the amount of iron absorbed depends to a large extent on the presence of enhancing and inhibitory substances in the meal and the iron status of the individual. Approximately 50% of the variation in non-haem iron absorption can be explained by intake of animal tissue, phytic acid, ascorbic acid, and iron status [3]. Haem iron is absorbed by a different mechanism from non-haem iron. The composition of the meal has little influence on haem iron absorption because it is taken up intact by pinocytosis. [4]. Although haem iron represents only 10% to 15% of dietary iron intake in populations with high meat intakes, it may contribute more than 40% of the total absorbed iron.

The absorption of non-haem iron varies widely

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from less than 1% to more than 50%, depending on the dietary components and the iron status of the individual. It is usually about 1% to 20%. The main inhibitory substances are phytic acid from cereals and legumes and polyphenol compounds from tea and coffee [5]. The main enhancers are ascorbic acid from fruits and vegetables and partially digested peptides from muscle tissues.

In the United States and other developed countries, meat, seafood, and dairy products are the primary sources of zinc, providing about 70% of the total intake. In developing countries, where the intake of animal products or tissues is low, cereals and legume seeds provide most of the dietary zinc [6]. Phytic acid is a strong inhibitor of zinc absorption. Animal proteins counteract the inhibiting effect of phytic acid on zinc absorption [7]. The total amount of zinc in the diet also influences zinc absorption. At low zinc levels with no inhibitory agents, zinc absorption can be as high as 50%; high intakes cause a lower fractional absorption. The reduction is not directly proportional to the increase in content, however, so a higher amount is always absorbed at a higher intake [7].

Measurement of iron and zinc bioavailability

Bioavailability is the fraction of the ingested nutrient that is utilized for normal physiological functions or storage [8]. One of the major determinants of bioavailability is the proportion that is absorbed from the gastrointestinal tract. However, tissue utilization (or lack thereof) of the absorbed nutrient also influences bioavailability. This is particularly true for some vitamins and minerals, such as selenium. Gastrointestinal absorption is the primary determinant of iron and zinc bioavailability.

When evaluating the bioavailability of iron and zinc from a food item in humans, it is important to remember that a number of factors unrelated to the characteristics of the food influence the proportion absorbed. Those factors include the previous intake of the nutrient, the body status of the nutrient, gut transit time, and gastrointestinal function.

Methods of measuring bioavailability

Five general approaches are available for assessing the bioavailability of iron and zinc in humans (table 1). The first is the response of a physiological variable or reversal of a deficiency symptom, such as low haemoglobin for iron deficiency. This method is limited, however, to studies in individuals with iron depletion, and the response, or change in haemoglobin concentration, is likely to be influenced by the degree of depletion.

Measurement of whole-body iron or zinc retention is a second approach. Mass balance can quantitate the whole-body retention of the minerals from a controlled diet containing the food or foods of interest. This method is flawed for some nutrients, such as zinc, where the amount absorbed is not tightly regulated and the excess absorbed is secreted back into the gastrointestinal tract. Thus, faecal zinc losses are a mixture of unabsorbed dietary zinc and absorbed endogenous zinc. This secretion into the gut leads to an underestimate of bioavailability. Administrating an oral zinc

TABLE 1. Techniques for measuring iron and zinc bioavailability in humans

Measurement	Technique
Response of a physiological variable	
Iron	Change in haemoglobin concentration in iron-deficient individuals
Zinc	Not used; no sensitive indicator of changes in zinc status available
Assessment of body retention	
Iron	Iron mass balance; retention of a single oral dose of an isotopic tracer; whole-body retention of radioiron
Zinc	Zinc mass balance; whole-body retention of radiozinc
Tissue or blood uptake	
Iron	Iron incorporation into erythrocytes
Zinc	Not used; no single tissue available for assessing zinc incorporation
Changes in body pool sizes	
Iron	Plasma iron response test
Zinc	Plasma zinc response test; changes in exchangeable zinc pool sizes
Rates of absorption	
Iron	Compartmental modeling of iron absorption; dual isotopic tracer studies
Zinc	Compartmental modeling of zinc absorption; dual isotopic tracer studies; deconvolution analysis

isotope and measuring faecal losses only partly corrects the problem, because the isotope absorption usually exceeds the need, and excesses are also secreted back into the gut [9]. Since iron absorption is regulated tightly, measuring the excretion of a single oral dose of iron in the stool is a valid estimate of iron bioavailability [10].

Whole-body isotope retention may also be estimated from the retention of a radioactive isotopic tracer of iron or zinc, i.e., ^{55}Fe, ^{59}Fe, or ^{65}Zn, which is given orally with the test food. The initial whole-body activity is measured after consumption of the test food, before any unabsorbed isotope has been excreted, and two weeks after tracer administration, when the unabsorbed tracer has cleared the gut [11–13]. The percentage absorbed is the portion of initial whole-body activity that remains after two weeks with correction for physical decay and for background activity.

The third approach involves measuring tissue or blood uptake or retention of an isotopic tracer. This approach, the incorporation of radioiron into erythrocytes, is the preferred method for measuring iron absorption [14]. The protocol entails feeding a single meal labelled with a radioactive iron tracer, withholding food (but not water) for several hours thereafter, analysing the radioactivity in the blood two weeks after the meal, and expressing the fraction absorbed as a ratio to absorption from a reference dose given with water to minimize potential confounding effects of intersubject variability caused by differences in iron status. The method requires an estimate of total blood volume and an assumption that 80% or more of the absorbed iron isotope is incorporated into erythrocytes within 14 days. This approach has not been used to measure zinc bioavailability because of the lack of a suitable tissue for measuring retention.

Assessment of changes in body pool sizes is a fourth approach used to measure the bioavailability of minerals. Evaluating the plasma concentration curve over several hours following an oral dosing of the mineral under study is an example of this approach. This technique has the drawbacks that a large amount of the nutrient must be given to produce a reproducible plasma response, and it is uncertain that the plasma concentration reflects the concentration at the tissue site of action [8]. Nevertheless, it has been used to screen the bioavailability of zinc or iron from different foods and to study mineral–mineral interactions [15–19]. Since the method only requires measurement of plasma zinc or iron concentration in several blood samples, it is relatively easy and inexpensive.

Radioactive and stable isotopic tracers may be used in whole-body kinetic models for measuring changes in zinc exchangeable pool sizes [20, 21]. Although it appears that the size of the exchangeable zinc pool measured over two days varies with dietary zinc intake, further studies are needed to determine if the size of the pool is sensitive to intakes of diets differing in zinc bioavailability.

The fifth approach, measuring the rate of iron or zinc gastrointestinal absorption, is the most direct measure of the bioavailability of the mineral. Isotopic tracers provide several methods for measuring the rate of iron or zinc absorption: compartmental analysis, deconvolution curves, or dual isotopic tracer studies. All of these methods require administering two isotopes, one orally with the test food and the second intravenously. In the deconvolution and dual isotopic tracer methods, zinc absorption is estimated from the ratio of the oral to the intravenous isotope concentrations in plasma and/or urine over the following three to five days. Lowe and co-workers recently compared the estimates of zinc absorption in a group of women when all of these methods were done simultaneously [9]. The deconvolution and the dual isotopic tracer methods compared favourably with the compartmental model estimate of zinc absorption. The dual isotopic tracer method requires only a single blood or urine sample, however, whereas the deconvolution method requires multiple blood and urine samples. Thus, the dual isotopic tracer method is the preferred method for measuring zinc absorption in humans (table 2). The intravenous infusion and the expense of administering and measuring several stable isotopes are drawbacks to this method.

Administration of oral isotopic tracer

The preferred methods for measuring both iron and zinc bioavailability require oral administration of isotopic tracers. Oral tracers may be administered in two ways: intrinsically or extrinsically. An intrinsic tracer is one that has been incorporated into the food during growth of the plant or animal; an extrinsic tracer is added to the food in small amounts as inorganic salts several hours before feeding. When an extrinsic tracer is used, it is assumed that the label equilibrates with all pools of iron or zinc in the food and is absorbed to the same extent and at the same rate as the intrinsic element in the food.

An extrinsic tracer is the preferred method for administering the oral tracer, because it is less expensive and easier to prepare than an intrinsic label. Numerous validity studies comparing extrinsic with intrinsic tracers of iron or zinc have been done [10, 22–26]. The studies suggest that the validity of extrinsic tracers for measuring iron or zinc bioavailability varies with the test food. Complete equilibration between extrinsic and intrinsic tags in the gastrointestinal tract is dependent on gut transit time and on the mineral-binding ligands present in the food. Thus, to be certain that an extrinsic tag is a valid tracer for bioavailability studies, the two types of tags should be compared before an extrinsic tag is used. In general, extrinsic labelling

TABLE 2. Preferred methods for measuring iron and zinc bioavailability in humans

Measurement	Procedure	Disadvantages
Iron: erythrocyte incorporation of radioiron	Label meal or food with radioiron (^{55}Fe or ^{59}Fe) Measure initial ingestion before any faecal loss by whole-body counting Measure retention 2 weeks later by whole-body counting Assume 80% of absorbed iron is incorporated into erythrocytes Estimate total body volume based on body weight	Exposure to radioiron
Zinc: dual isotopic tracer method	Label meal or food with one stable isotope of zinc (^{67}Zn) Infuse second isotope following ingestion of test meal/food (^{70}Zn) Measure ratio of oral to intravenous isotope 3–5 days later in plasma or urine	Requires intravenous infusion Expense of stable isotopes

for non-haem-iron bioavailability appears to be valid for most foods; milk may be an exception because of the more rapid transit of the liquid food [25]. Zinc extrinsic tags, however, do not appear to exchange fully with endogenous zinc in many foods [23].

Extrinsic versus intrinsic measures of iron and zinc bioavailability from common beans

Several years ago, an international collaborative project to increase the bioavailable concentrations of iron and zinc from staple plant foods was initiated [27]. Studies of the iron and zinc content of the common bean show that selective breeding strategies could increase the amount of iron by 60% to 80% and the amount of zinc by about 50% [28]. Before these high-iron, high-zinc varieties of the common bean are introduced into the agricultural systems of those regions of the world where intake of these minerals is inadequate, the bioavailability of iron and zinc from the legume needs to be determined. Therefore, we evaluated iron and zinc bioavailability from a test meal composed only of the common bean in a group of young women with low iron stores. The results of this study will determine whether the less expensive extrinsic tracers can be used in future field studies evaluating the impact of high-iron, high-zinc beans on mineral nutriture.

Subjects and methods

Twenty-three women, 20 to 26 years of age, participated in the study and were divided into two groups. Group I ($n = 12$) received a test meal of typical common beans; group II ($n = 11$) received the high-iron, high-zinc beans. Intrinsic and extrinsic iron absorption was compared in both groups; intrinsic and extrinsic zinc absorption was compared only in group II. All of the women were non-smokers, apparently healthy with no recent use of vitamin or mineral supplements, of acceptable weight-for-height, and users of oral contraceptive agents. At entry to the study, all women had haemoglobin concentrations greater than 110 g/L and plasma ferritin concentrations less than 20 g/L. The study was approved by the Radiation Safety Review Committee and the Committee for Protection of Human Subjects of the University of California, Berkeley.

The typical common beans provided 0.92 µmol of iron and 0.43 µmol of zinc per gram; the high-iron, high-zinc beans provided 1.5 µmol of iron and 0.85 µmol of zinc per gram. The test food, fed at 7:15 a.m., consisted of cooked beans, equivalent to 40 g dry weight, and deionized water. Immediately after consumption of the test food, a third stable isotope of zinc was infused into the antecubital vein. Iron absorption was estimated from the incorporation of radiolabelled iron into erythrocytes 14 days after oral administration of the tracer. Zinc absorption was estimated by the dual isotopic tracer method in spot urine samples collected in the mornings on days 3, 4, and 5 following the test meal [9].

The iron and zinc contents of the test meal, plasma, erythrocytes, and urine were determined by atomic absorption spectrophotometry (Thermo-Jarrell Ash 22, Massachusetts, USA). Aliquots of samples were digested with concentrated HNO_3 (Fisher Scientific, Pennsylvania, USA, TM grade) in a microwave digester (MDS 2000, CEM Corp., USA) and diluted with deionized water before measurement.

Iron absorption was calculated as the ratio of ^{59}Fe or ^{55}Fe in total erythrocytes and the ingested tracer dose, expressed as a percentage. The iron tracer content of blood was determined by liquid scintillation counting after acid digestion and ion-exchange chromatography. The amount of ^{59}Fe or ^{55}Fe in the blood was estimated from a calculation of total blood volume [29]. The estimated incorporation of radioiron into the erythrocyte cell mass was based on the initial blood haemoglobin and plasma ferritin concentrations [30].

The ratio of oral (^{70}Zn and ^{68}Zn) to intravenous (^{67}Zn) isotopic zinc tracers was measured in urine by a Sciex ELAN 500 Inductively Coupled Plasma Mass Spectrometer (Perkin-Elmer, Norwalk, Connecticut, USA). Before measurement, zinc was separated from the other elements in the urine by ion-exchange chromatography.

The data were tested for normality and log-transformed for plasma ferritin and iron absorption before further statistical analyses. Differences between intrinsic and extrinsic estimates of iron or zinc absorption were determined by a paired *t* test. The results were considered to be significantly different for $p < .05$.

Results

The composition of the typical beans and the high-iron, high-zinc beans is shown in table 3. The high-iron, high-zinc bean had 67% more iron and twice as much zinc as the typical bean. The amount of phytate (*myo*-inositolpentaphosphoric acid plus *myo*-inositolhexaphosphoric acid [IP6 + IP5]) and calcium was similar in both beans. The phytate/iron and phytate/zinc molar ratios were high in both varieties of beans.

There were no differences between intrinsic and extrinsic iron absorption from either the typical or the high-iron, high-zinc beans.The intrinsic and extrinsic geometric mean iron absorptions from the typical beans were 1.83% and 1.87%, respectively; the values were 1.03% and 1.01%, respectively, from the high-iron, high-zinc beans. The correlation between the intrinsic and extrinsic tracers was 0.989.

The absorption of intrinsically labelled zinc was slightly greater than that of extrinsically labelled zinc: 12.3% versus 13.2%. This difference did not reach statistical significance ($p = .17$). The correlation between the intrinsic and extrinsic estimates of zinc absorption was not as good as that for iron absorption (0.641).

TABLE 3. Composition of beans with normal and high iron and zinc contents

Component	Normal Fe and Zn	High Fe and Zn
Phytate (IP5 + IP6)[a]	31 μmol/g	33 μmol/g
Fe	0.9 μmol/g (50 ppm)	1.5 μmol/g (83 ppm)
Zn	0.4 μmol/g (28 ppm)	0.8 μmol/g (55 ppm)
Ca	34 μmol/g (1,380 ppm)	22 μmol/g (900 ppm)
Phytate/Fe molar ratio	34	22
Phytate/Zn molar ratio	152	65

a. Phytate is *myo*-inositolpentaphosphoric acid plus *myo*-inositolhexaphosphoric acid.

Discussion

There was no difference in the absorption of intrinsically and extrinsically labelled iron and zinc in common red beans by young women with low iron stores. The correlation between the intrinsic and extrinsic tags for iron was very high (0.989). The absorption of intrinsically labelled zinc tended to be higher than that of extrinsically labelled zinc, but the difference did not reach statistical significance. The precision of the zinc-absorption method is less than that of the iron-absorption method. That may explain why the comparison between the two labels differed more than that of iron. Alternatively, the extrinsic zinc tracer may have readily bound with the excessive amounts of phytate present in the beans, so that slightly less was available for absorption than for endogenous zinc. Since zinc absorption varies widely between and within individuals, the small difference between the intrinsic and extrinsic zinc tags is probably not relevant. Thus, it appears that future field studies of the bioavailability of iron and zinc from common beans can be done by using extrinsic tracers.

Implications

The test meal of beans only, given as the first meal of the day, was used to measure iron and zinc absorption in this study. This does not reflect the usual conditions for absorption of iron and zinc from a diet, however. There is no evidence that time of day influences absorption from a complete diet [5], but inhibitors such as phytate may have a greater effect on total absorption of iron and zinc when bioavailability is studied from the test food alone rather than from a complete diet. Before introducing high-iron, high-zinc beans in populations with iron and zinc deficiencies, the efficacy of high-iron, high-zinc beans for improving the status of these nutrients must be tested.

The bioavailabilities of iron and zinc from the beans were low, about 1.5% and 13%, respectively. Since the subjects had low iron stores and low plasma zinc concentrations initially, higher rates of absorption should have occurred if the elements were available. Possibly, the high phytate content of the beans reduced the solubility of the iron and zinc complexes in the gut and limited the amount that could be absorbed. It has been suggested that iron and zinc bioavailability can be improved by supplementing the diet with small amounts of animal tissue or by using food-preparation methods that reduce phytate content. Methods to augment the bioavailability of minerals from cereal crops need to be developed and tested in iron- and zinc-deficient subjects who normally consume these foods.

References

1. Frossard E, Bucher M, Machler F, Mozafar A, Hurrell R. Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. J Sci Food Agric 2000;80:861–79.
2. King JC, Shames DM, Woodhouse LR. Zinc homeostasis in humans. J Nutr 2000;130:1360S–6S.
3. Reddy MB, Hurrell RF, Cook JD. Estimation of nonheme-iron bioavailability from meal composition. Am J Clin Nutr 2000;71:937–43.
4. Fairbanks VF. Iron in medicine and nutrition. In: Shils ME, Olson JA, Shike M, eds. Modern nutrition in health and disease. Philadelphia, Pa, USA: Lea and Febiger, 1994:185–213.
5. Hurrell RF. Bioavailability of iron. Eur J Clin Nutr 1997;51:S4–S8.
6. King JC, Keen CL. Zinc. In: Shils ME, Olson JA, Shike M, eds. Modern nutrition in health and disease. 8th ed. Philadelphia, Pa, USA: Lea and Febiger, 1997:214–30.
7. Sandstrom B. Bioavailability of zinc. Eur J Clin Nutr 1997;51:S17–S19.
8. Jackson MJ. The assessment of bioavailability of micronutrients: introduction. Eur J Clin Nutr 1997;51:S1–S2.
9. Lowe NM, Woodhouse LR, Matel JS, King JC. Comparison of estimates of zinc absorption in humans by using 4 stable isotopic tracer methods and compartmental analysis. Am J Clin Nutr 2000;71:523–9.
10. Boza JJ, Fox TE, Eagles J, Wilson PDG, Fairweather-Tait S. The validity of extrinsic stable isotopic labeling for mineral absorption studies in rats. J Nutr 1995;125:1611–6.
11. Hunt JR, Gallagher SK, Johnson LK, Lykken GI. High- versus low-meat diets: effects on zinc absorption, iron status, and calcium, copper, iron, magnesium, manganese, nitrogen, phosphorus, and zinc balance in postmenopausal women. Am J Clin Nutr 1995;62:621–32.
12. Hunt JR, Mullen LM, Lykken GI, Gallagher SK, Nielsen FH. Ascorbic acid: effect on ongoing iron absorption and status in iron-depleted young women. Am J Clin Nutr 1990;51:649–55.
13. Hunt JR, Roughead ZK. Nonheme-iron absorption, fecal ferritin excretion, and blood indexes of iron status in women consuming controlled lactovegetarian diets for 8 wk. Am J Clin Nutr 1999;69:944–51.
14. Benito P, Miller D. Iron absorption and bioavailability: an updated review. Nutr Res 1998;18:581–603.
15. Fitzgerald SL, Gibson RS, de Serrano JQ, Portocarrero L, Vasquez A, de Zepeda E, Lopez-Palacios CY, Thompson LU, Stephen AM, Solomons NW. Trace element intakes and dietary phytate/Zn and Ca × phytate/Zn millimolar ratios of periurban Guatemalan women during the third trimester of pregnancy. Am J Clin Nutr 1993;57:195–201.
16. Solomons NW. Competitive interaction of iron and zinc in the diet: consequences for human nutrition. J Nutr 1986;116:927–35.
17. Solomons NW, Jacob RA. Studies on the bioavailability of zinc in humans: effects of heme and nonheme iron on the absorption of zinc. Am J Clin Nutr 1981;34:475–82.
18. Solomons NW, Jacob RA, Pineda O, Viteri F. Studies on the bioavailability of zinc in man. II. Absorption of zinc from organic and inorganic sources. J Lab Clin Med 1979;94:335–43.
19. Solomons NW, Pineda O, Viteri F, Sandstead HH. Studies on the bioavailability of zinc in humans: mechanism of the intestinal interaction of nonheme iron and zinc. J Nutr 1983;113:337–49.
20. Fairweather-Tait SJ, Jackson MJ, Fox TE, Wharf SG, Eagles J, Croghan PC. The measurement of exchangeable pools of zinc using the stable isotope ^{70}Zn. Br J Nutr 1993;70:221–34.
21. Miller LV, Hambidge KM, Naake VL, Hong Z, Westcott JL, Fennessey PV. Size of the zinc pools that exchange rapidly with plasma zinc in humans: alternative techniques for measuring and relation to dietary zinc intake. J Nutr 1994;124:268–76.
22. Egan CB, Smith FG, Houk RS, Serfass RE. Zinc absorption in women: comparison of intrinsic and extrinsic stable-isotope labels. Am J Clin Nutr 1991;53:547–53.
23. Fairweather-Tait SJ, Fox TE, Wharf SB, Eagles J, Crews HM, Massey R. Apparent zinc absorption by rats from foods labeled intrinsically and extrinsically with ^{67}Zn. Br J Nutr 1991;66:65–71.
24. Gallaher DD, Johnson PE, Hunt JR, Lykken GI, Marchello MJ. Bioavailability in humans of zinc from beef: intrinsic versus extrinsic labels. Am J Clin Nutr 1988;48:350–4.
25. Gislason J, Jones B, Lonnerdal B, Hambraeus L. Iron absorption differs in piglets fed extrinsically and intrinsically ^{59}Fe-labeled sow's milk. J Nutr 1992;122:1287–92.
26. Meyer NR, Stuart MA, Weaver CM. Bioavailability of zinc from defatted soy flour, soy hulls and whole eggs as determined by intrinsic and extrinsic labeling techniques. J Nutr 1982;113:1255–64.
27. Bouis H. Enrichment of food staples through plant breeding: a new strategy for fighting micronutrient malnutrition. Nutr Rev 1999;54:131–7.
28. Beebe S, Gonzalez AV, Rengifo J. Research on trace minerals in the common bean. Food Nutr Bull 2000;21:387–91.
29. Frenkel EP, McCall MS, Reisch JS, Minton PD. An analysis of methods for the prediction of normal erythrocyte mass. Am J Clin Nutr 1972;58:260–71.
30. Viteri FE, Kohaut BA. Improvement of the Eakins and Brown method for measuring ^{59}Fe and ^{55}Fe in blood and other iron-containing materials by liquid scintillation counting and sample preparation using microwave digestion and ion-exchange column purification of iron. Anal Biochem 1997;244:116–23.

A human feeding trial of iron-enhanced rice

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Abstract

A key unknown in the strategy of breeding for micronutrient-dense staple food crops is the bioavailability of the additional trace minerals in nutritionally improved lines. This paper describes a feeding trial to be undertaken in the Philippines during 2001 using human subjects that will examine the effect on iron status of long-term consumption of IR68-144, a high-yielding, aromatic, iron-dense rice that is currently undergoing agronomic testing at the International Rice Research Institute (IRRI). The subjects will be religious sisters-in-training who live year-round in convents in Greater Manila.

This population was selected because they represent a sex and age segment of the population at high risk for iron deficiency. The iron status of the sample of 27 sisters indicates that 74% were anaemic (haemoglobin <120 g/L) and 48% iron deficient (serum ferritin <12 μg/L). These subjects consume large quantities of rice (400 g/day), and all their meals are prepared in common kitchens where different varieties of rice can be easily introduced to the menu. A pilot study found that the introduction of IR68-144 rice was highly tolerated by the kitchen staff who prepared the rice and the sisters who consumed it. There were no perceived differences in taste, texture, colour, or other properties compared with the commercial variety normally consumed.

The high prevalence of iron deficiency, the considerable amount of rice consumed, the high level of cooperation of the subjects, and the structured routine of the convent make this an ideal research setting to investigate the effect of improving iron intakes through a staple food.

Introduction

As discussed by Gregorio et al. [1] in this issue, a promising high-iron, high-yielding aromatic rice, IR68-144, has been identified that may provide the basis for the first release of a nutrient-dense variety of rice, hopefully the first of many subsequent lines of ever-improving nutritional quality. The feasibility of breeding a high-yielding, high-profit, iron-dense rice from an agronomic viewpoint has now been established. The final key unknown is to examine the bioavailability of the iron in IR68-144, that is, to determine the degree to which the iron status of human subjects who consume this rice can be improved. This paper describes a feeding trial to be undertaken in the Philippines during 2001.

A positive finding of an impact on the iron status of iron-deficient subjects after consumption of IR68-144 for an extended period would be one of the first documented cases of a food-based, plant-breeding approach applied to correcting a major micronutrient deficiency problem; would speed up the dissemination of iron-dense germplasm to national agricultural research institutes throughout Asia for adaptation and eventual release; and would conclusively demonstrate the feasibility of using plant-breeding as a low-cost, sustainable tool in the fight against micronutrient malnutrition.

The specific objectives of the designed study are to:

- determine the effect of consuming iron-enhanced rice (IR68-144) over nine months on the iron status of young women at risk of iron deficiency;
- determine the effects of consuming iron-enhanced rice (IR68-144) on cognition and behaviour in young women;
- determine the time frame for response of iron status indicators to increased iron intakes in the study population;
- demonstrate the association between changes in iron status and changes in cognition and behaviour.

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Study setting

This study will be conducted in the Philippines on women between the ages of 20 and 35 years. The subjects will be religious sisters-in-training who live year-round in convents in and around Manila. This population was selected because they represent a sex and age segment of the population at high risk for iron deficiency. They consume large quantities of rice (400 g per day, cooked). All their meals are prepared in common kitchens where different varieties of rice can be easily introduced to the menu. The daily menus are fixed, with little variation and opportunity for individual choice of foods. The diet is typical of those in the Philippines, which are low in iron but with adequate variety to ensure consumption of foods that enhance iron absorption (fresh fruit and juice, and animal protein—mostly fish—in small quantities). Long-term observation, up to 9 to 12 months, is possible with strict compliance to a research diet protocol documented through a long-term pilot study in one convent. The women generally do not take vitamin and mineral supplements unless they are prescribed for medical reasons. Very few meals are consumed outside the convent, and between-meal snacks are easily recorded. Physical activity patterns are fairly homogeneous, in the light to moderate range of exertion.

One of the authors conducted a pilot and feasibility study during a seven-month period in 1999. The convent chosen for this study is typical of the non-contemplative religious congregations within Greater Manila. The convent trains approximately 70 women for various stages of the religious life for an average duration of four years. The sisters are classified as postulates, novices, or juniors. For the pilot study, first-year novices and juniors were specifically chosen as participants, since their training is conducted within the convent. Each class of novices and juniors take meals in separate dining halls with separate kitchens. The pilot study found that the introduction of IR68-144 rice was highly tolerated by the kitchen staff who prepared the rice and by the sisters who consumed it. There were no perceived differences in taste, texture, colour, or other properties compared with the commercial variety normally consumed.

Table 1 presents some of the characteristics of the convent diet. The average consumption of cooked rice among the 27 sisters over seven months of daily food weighing was 396 g. The daily iron intake of 9.2 mg represents about 35% of the Philippine recommended dietary allowance (RDA) of 26 mg for women between 20 and 39 years of age. Although the iron content of rice is low (5.4 ppm in traditional milled, dry rice), the women obtain about 9% of their dietary iron from rice because of the large amount of rice they consume. The two classes of sisters differ somewhat in the quantitative aspects of the diet, but the qualities of their diet are very similar. Of the 21 meals consumed per week, more than 90% contain some meat, usually fish and occasionally chicken or pork. Additional foods that enhance dietary iron absorption include fruit juice and fresh fruits and vegetables, which are consumed at every meal. Tea and coffee are not consumed on a regular basis with meals, and no other major inhibitors of iron absorption were observed to be present in the regular diet. Thus, the non-haem iron that is consumed is likely to be readily absorbed from the convent diet.

The iron status of the 27 sisters is summarized in table 2. At baseline, while they were consuming a popular variety of unenhanced rice with an iron content of 5.4 ppm dry weight, the mean haemoglobin was 111 g/L and the mean ferritin was 15.8 µg/L. Before they were introduced to the iron-enhanced variety of rice (IR68-144), there was a high prevalence of anaemia (74% with haemoglobin below 120 g/L) and iron deficiency (48% with serum ferritin below 12 µg/L). Thirteen of the 20 anaemic women had low ferritin values. Although anaemia was prevalent, it

TABLE 1. Summary of dietary data from the pilot study

Measurement	Novices (*n* = 13)	Juniors (*n* = 14)	Overall (*n* = 27)
Mean daily intake of cooked rice (g)	373	418	396
Mean daily intake of dietary iron (mg)	10.0	8.5	9.2
Mean contribution of rice to total dietary iron intake (%)	7.1	10.4	8.8
Mean adequacy of iron intake (% of Filipino RDA)	38.8	32.5	35.3

TABLE 2. Summary of iron status data from the pilot study

	Novices (*n* = 13)		Juniors (*n* = 14)		Total (*n* = 27)	
Measurement	Baseline	4 mo	Baseline	4 mo	Baseline	4 mo
Iron intake (mg/day)	9.4	10.3	10.0	8.2	9.7	9.3
Haemoglobin (g/L)	110	121	112	127	111	124
Haematocrit (%)	32.5	35.9	33.4	37.9	33.0	37.0
Serum ferritin (µg/L)	16.2	22.3	15.4	27.9	15.8	25.4

was not severe. Nine women had haemoglobin values between 110 and 119 g/L, and none had values less than 100 g/L. After four months of consumption of the iron-enhanced rice, the haemoglobin values increased by 13 g/L and ferritin increased by 60%. However, in the absence of a control group, it is impossible to determine how much of this improvement in iron status was due to the additional iron from the enhanced rice. Compliance to periodic venous blood collection was excellent. Two research assistants resided in the convents for the entire seven months of the pilot study. They were easily integrated into the routine of the convent and were readily accepted by the kitchen staff and sisters as welcome visitors. In summary, the high prevalence of iron deficiency, the considerable amount of rice consumed, the excellent cooperation by the subjects, and the structured routine of the convent make this an ideal research setting to investigate the effect of improving iron intakes through a staple food.

Study design and sampling

The proposed design of this study is that of a double-blind trial with iron intervention in 200 women from 10 different convents. Four treatments will be administered. Two of the treatments relate to the choice of rice consumed: either the iron-enhanced IR68-144 variety (Fe rice) or a popular commercial variety of rice that will serve as a control (control rice). A third treatment will be a daily oral iron supplement in the form of 20 mg of ferrous sulphate in a capsule administered to a subset of the control rice group. This group (Fe supplement) will be a positive control to determine the maximum effect that could be expected when iron intakes are at or above the level of recommended intakes. The fourth treatment will be given to a subset of the Fe rice group who will receive a placebo capsule (placebo).

The subjects will be identified from 10 convents in and around Manila. Within each convent, one of the two classes (novice or junior) will be randomly assigned to the Fe rice treatment and the other to the control rice group. Within 2 of these convents (selected at random from the 10 convents), all subjects in the control rice group will receive the Fe supplement, while subjects in the Fe rice group from the same convent will receive a placebo capsule. The study design, with the distribution of subjects by sample, is shown in table 3.

TABLE 3. Sample assignments

Treatment	Fe rice group	Control rice group	Total
Capsules			
Fe supplement	0	20	20
Placebo	20	0	20
None	80	80	160
Total	100	100	200

On the basis of previous analysis [1], we expect that the milled uncooked IR68-144 rice will contain between 8.4 and 12.2 ppm of iron, while the placebo rice will have about 5.4 ppm. Assuming a daily consumption of 400 g of cooked rice (160 g uncooked), those in the Fe rice group will obtain between 0.47 and 1.10 mg/day more iron from rice than those in the control rice group. This represents an increase of 55% to 126% in iron intake from rice for the Fe rice group. Since commercial, unenhanced rice contributes about 9% of the dietary iron in this population, the IR68-144 variety could contribute up to 20% of the dietary iron, assuming no change in the amount of rice consumed.

The convents will be selected on the basis of their willingness to participate. Although all the women residing in the convents will participate in the rice treatment, only those who consent will participate in the supplementation component. From the pilot study, we anticipate that about 60% of the women will be marginally anaemic (haemoglobin levels of 105 to 119 g/L). Any subject with a haemoglobin value less than 105 g/L will be treated with 30 mg of ferrous sulphate taken daily for two months and excluded from the study. Subjects whose haemoglobin values drop below 105 g/L during periodic (bimonthly) checks will also be treated with ferrous sulphate capsules. Since iron absorption from the diet is dependent on iron status, it is necessary that subjects be in a marginal state of deficiency in order to see an effect of the consumption of iron-enhanced rice with its relatively low iron content.

The study will require an intervention of approximately nine months to observe biologically meaningful improvements in iron status. The length of time required depends on the iron status of the subjects, the daily consumption of additional iron from Fe rice versus control rice, and the indicators of iron status to be monitored for response. We estimate that 262 days of intervention will be required to observe an increase in mean serum ferritin from 16 to 25 μg/L. This reflects a shift in body iron stores of 32 mg for a 45-kg woman and assumes that 20% of the additional 1.10 mg/day of iron from rice will be absorbed. Iron absorption could be higher than 20%, especially in the early stages of the intervention, when the subjects' iron stores are lowest. An increase in mean haemoglobin from 111 g/L observed in the pilot study to 125 g/L is also anticipated over this period.

Sample size

Based on an anticipated improvement in mean ferritin values from 16 to 25 μg/L and a standard deviation in post-treatment ferritin values of 6.0 (from four-month values in the pilot study, confirming Zhu and Haas [2]), we calculate that a sample of 36 subjects per rice treatment group will be required, on the assumption that $\alpha = 0.05$ and $1\text{-}\beta = 0.80$. A significant increase in haemoglobin of 1.5 SD from baseline would also require a sample of this size. Given that the subjects will be chosen from 10 different convents, with Fe rice treatments given to one of two classes per convent, the unit of treatment will be class per convent or 10 classes receiving the Fe rice and 10 receiving the control rice. This design effect results in an increase in sample size per treatment group of approximately 100%. Therefore, the final sample size required to test for the iron effect from rice is 144 subjects. The test for the maximum effect anticipated if supplemental iron was administered results in an additional 36 subjects. We expect to observe an improvement in serum ferritin equal to 1 SD of the final values in the supplemented group. This requires a sample of 18 subjects per group. The sample sizes have been increased by 10% in anticipation of dropouts due to medical or other personal reasons. Thus, the final sample size to be recruited is 200. We expect each convent to have approximately 20 sisters eligible to participate in the study. Therefore, a sample of 10 convents will be needed.

Calculations from pilot studies of university women in the United States by one of the authors (JLB) on the effects of iron on cognitive development suggest that a sample size of 48 per group is needed when the σ^2 is based primarily on attention (tachistoscopic threshold median threshold time). A smaller sample size is required ($n = 32$) if we use the means and standard deviations from the Sternberg task (a complex cognitive task) derived from our cognitive studies of women who are iron deficient and we assume the same α value and power previously chosen.

We expect to easily detect a cognitive response to iron therapy, assuming an improvement in haemoglobin of 90 to 150 g/L over nine months and a change in ferritin of 5–8 μg/L. These estimates are derived from the recent data collected from women and adolescents in the United States and on our experience with the response of anaemic subjects to ferrous sulphate therapy over a 12-week period [3]. Although there is considerable day-to-day variation in some of the indicators of iron status, this can be accounted for because the statistical variation is now known and has been partially established by our laboratory [3–5]. Our ongoing study with women using the full battery of tests with a sample size computed here has already demonstrated ample statistical power with a sample of 30 to 40 subjects. Most published intervention studies of iron deficiency and cognition in children have a sample size of 20 to 50 per cell and include a number of covariates similar to that which we want to consider.

Assessment of iron status

We will use multiple parameters for the assessment of iron. These include haemoglobin, plasma iron, transferrin saturation, plasma ferritin, plasma transferrin receptor, and complete blood count parameters. This assessment will occur three times during the study: at baseline, at the study midpoint or 135 days, and at the end of the study or nine months after initiation of the intervention. Haemoglobin will be assessed every eight weeks. The indicators chosen for determination of iron status allow a comprehensive examination of iron movement among various iron pools and functional iron status.

It is important to measure multiple indicators for a study of this type, in which the long-term effects of a small increase in dietary iron are expected to produce modest changes in iron status. It may be necessary to estimate changes in the entire body iron rather than rely on a single indicator. We have successfully used this approach, originally proposed by Cook et al. [6], to assess the effects of an iron supplementation trial in Costa Rica [7]. The estimation of total body iron requires measurements of several indicators (haemoglobin, ferritin, transferrin saturation, and mean corpuscular volume). Moreover, it is important to accurately assess the iron status of subjects at baseline, since the response to the iron intervention is likely to be affected by the severity of iron depletion.

Cognitive tests

Although iron deficiency was once presumed to exert most of its deleterious effects only when anaemia was present, it is now clear that many organs and systems show morphologic, physiologic, and biochemical changes before there is any drop in haemoglobin concentration [8, 9]. The previous research in the area of iron deficiency and cognition has focused on specific mechanisms involved in cognitive processing but has not studied how these specific functions contribute to functioning in daily life. To this end, we will assess specific cognitive functions that underlie cognitive processing (attention, memory, and learning). We will also extend our work on psychometric and experimental paradigms by studying cognitive tasks faced in everyday life to demonstrate the relevance of the findings.

Cognitive and emotionality measurements will also be conducted at the same three time points as the iron-status assessment. Both general and specific assessments of cognition will be conducted. The measures of general cognitive function (Wecksler Adult Intelligence Scale) will be used to assess how our sample compares with the general population. The specific measures (the Detterman tasks) will be used to identify both micro and macro variations in normative cognitive functioning due to changes or differences in iron status.

Food intake

The intake of all foods will be obtained from each subject on one randomly chosen day per week throughout the study. Since subjects within each of the 20 convent classes consume meals from the common menu prepared for each of the 20 kitchens, the calculation of nutrient compositions from menus will be facilitated. The total amount of rice prepared minus leftovers will be calculated daily for each kitchen. The subjects will weigh and record their rice intake at each meal throughout the study period. Experience from the pilot study indicates a high degree of compliance. Research assistants during the pilot study recorded the weights of each food portion of the total diet for 27 subjects daily for seven months with no difficulty.

The proposed project does not require this degree of precision in estimating individual dietary intakes. It is sufficient to estimate daily rice consumption and periodic total diet to determine the total macronutrient intake and sources of dietary iron intakes plus inhibitors and enhancers of iron absorption. Analysis of daily menus will provide the detail needed to determine how these complement iron consumed from rice. The dietary composition for specific nutrients will be computed from food-composition tables prepared specifically for the Philippine diet [10]. The subjects will be encouraged to maintain their usual consumption of food and asked to discontinue use of any vitamin or mineral supplements for the duration of the study (a very uncommon practice in this population).

Conclusion

At the time that this paper is being finalized for publication, five hectares of rice have been planted with IR68-144 for use in the feeding trials. This rice will be harvested in November, and feeding trials are planned to begin in February 2001. Pending the results of this study, infant-feeding trials are also planned.

References

1. Gregorio GB, Senadhira D, Htut H, Graham RD. Breeding for trace mineral density in rice. Food Nutr Bull 2000;21:382–6.
2. Zhu YI, Haas JD. Response of serum transferrin receptor to iron supplementation in iron-depleted, nonanemic women. Am J Clin Nutr 1998;67:271–5.
3. Borel MJ, Smith SM, Beard JL, Derr J. Day-to-day variation in iron status parameters in healthy men and women. Am J Clin Nutr 1991;54:729–35.
4. Ahluwalia N, Lammi-Keefe CJ, Haley NR, Beard JL. Day-to-day variation in iron status indexes in elderly women. Am J Clin Nutr 1993;57:414–9.
5. Cooper MJ, Zlotkin SH. Day-to-day variation of transferrin receptor and ferritin in healthy men and women. Am J Clin Nutr 1996;64:738–42.
6. Cook JD, Skikne BS, Lynch SR, Reusser ME. Estimates of iron sufficiency in the US population. Blood 1986; 68:726–31.
7. Cohen J, Haas J. Estimating the iron stores of a sample of Costa Rican infants and a sample of infants from NHANES III survey between the ages of 12 and 23 months. FASEB J 1999;13:A697.
8. Beard JL, Connor JR, Jones BC. Iron in the brain. Nutr Rev 1993;51:157–70.
9. Dallman PR. Manifestations of iron deficiency. Semin Hematol 1982;19:19–30.
10. Food and Nutrition Research Institute. The Philippine food composition table. Manila: Department of Science and Technology, 1997.

The quality protein maize story

S. K. Vasal

Abstract

*The paper describes the sequence of breeding stages that led to the development of acceptable quality protein maize (QPM) germplasm at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT). Initial emphasis was on the development of soft opaque-2 (*o2*) maize varieties, but these had undesirable consumer characteristics, among other problems. Research then shifted to the development of hard-textured QPM germplasm. Several breeding approaches were explored and tested in early 1970. The combined use of two genetic systems involving the *o2 *gene and the genetic modifiers of the o2 locus appeared to be the most promising approach. This strategy first involved the development of donor stocks from which a large volume of QPM germplasm was generated through a modified backcross programme and various recurrent selection procedures. Later merging and reorganization of QPM germplasm was undertaken, which resulted in a definite number of QPM populations and pools to meet germplasm needs for various agroclimatic conditions. This was a turning point in the breeding strategy that permitted work with homozygous *o2* genetic backgrounds. In the mid-1980s, a hybrid development initiative was started. Basic information on combining ability and heterotic pattern(s) of QPM germplasm was generated. Later emphasis was shifted to development efforts for inbred and hybrid QPM. Several superior QPM germplasm products are now spreading commercially in several developing countries of Asia, Central and South America, and Africa*

Introduction

Maize is one of the world's three primary cereal crops. It occupies an important position in world economy and trade as a food, feed, and industrial grain crop.* Several million people in the developing world consume maize as an important staple food and derive their protein and energy requirements from it. Maize is thus an important source of protein for humans and animals. The poor nutritional value of maize grain is well known, and the need to improve it has been recognized for a long time [1]. Most of the protein in a mature maize kernel is contained in the endosperm and the germ. The endosperm protein is low in quality, in contrast with the germ protein, which is superior in quality. However, because the endosperm constitutes the bulk of the grain, contributing as much as 80% of the total kernel protein, any major improvements for quality protein must target the endosperm.

In normal maize, the average proportions of endosperm fractions are 3% for albumins, 3% for globulins, 60% for zein, and 34% for glutelin. All fractions other than zein are balanced and quite rich in lysine and tryptophan. The zein fraction is completely devoid of two important essential amino acids, lysine and tryptophan. The high proportion of this particular fraction, then, is the primary cause of poor protein quality in maize. A reduction in the zein fraction thus results in a proportional elevation of other fractions rich in lysine and an elevation of these two amino acids in protein, but not on an absolute basis of per unit of endosperm in the grain.

Serious efforts to improve the nutritional quality of maize endosperm protein began in the mid-1960s. Prior to this, efforts were limited to screening elite maize germplasm and accessions to identify genotypes superior for this trait. In the absence of specific gene(s) associated with improved protein, recurrent selection

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The *Food and Nutrition Bulletin* congratulates Dr. Surinder Vasal and his colleague, Dr. Evangelina Villegas, on being named the Millennium World Food Prize Laureates for their research that led to the development of quality protein maize.

* Ito S. General overview on exploding maize demand in Asia. International Maize Conference in Tottori, Japan, 1–4 June 1998.

required step-by-step accumulation of favourable alleles over an extended period before a noticeable change in nutritional value could be observed. The lack of a simple genetic system also prevented the use of a straightforward backcross programme.

Development of quality protein mutants: The first step in the genetic manipulation of nutritionally improved maize

The discovery in the early 1960s by Purdue University researchers of the biochemical effects of two mutant alleles, opaque-2 (*o2*) and floury-2 (*fl2*), opened exciting opportunities for improving the quality of maize endosperm protein [2, 3]. These mutants alter the amino acid profile and composition of maize endosperm protein, which results in a twofold increase in the levels of lysine and tryptophan. The mutants derive their name from soft, floury opaque endosperm. In addition, other amino acids, such as histidine, arginine, aspartic acid, and glycine, are also increased. A decline is observed in other amino acids, such as glutamic acid, alanine, and leucine. A decrease in leucine is considered desirable because it makes the leucine/isoleucine ratio more balanced, which, in turn, helps to liberate more tryptophan for more niacin biosynthesis, thus helping to combat pellagra. A sulphur-containing amino acid, methionine, is elevated only in the *fl2* mutant.

Unfortunately, the mutations adversely affect agronomic performance, including yield, and consumer aspects, particularly kernel characteristics. The lower yield results from reduced accumulation of dry matter. The appearance of the kernel is altered to a soft, chalky phenotype that is unattractive to maize growers in the developing countries. Physiological drying is also affected. A higher vulnerability to ear rot is observed, resulting in high pest and infestation rates in stored grain.

Nevertheless, sufficient genotypic variation is present to combine such traits as pericarp thickness, larger germ size, reduced cob weight, seed colour intensity, and kernel weight and density with quality protein using conventional breeding techniques [4, 5].

A continuing search for new and better mutants has been under way during the past several decades. In addition to *o2* and *fl2*, other mutants have been discovered, such as opaque–7 (*o7*), opaque-6 (*o6*), floury-3 (*fl3*), mucronate, and defective endosperm. Unfortunately these mutants offer no additional advantages over the *o2* gene in practical maize-breeding programmes. Several mutants have been used in experiments at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), but the main focus in developing quality protein maize (QPM) germplasm has been an intensive use of the *o2* gene.

In the initial stages, both the *o2* and the *fl2* genes were used singly or in combination with each other. Later some undesirable effects of the *fl2* gene were discovered. Eventually its use was discontinued. For a decade, the major emphasis in most breeding programmes involved crossing mutant lines with standard improved genotypes. Many promising open-pollinated varieties and hybrids were tested in farmers' fields. However, by the mid-1970s discouragement set in because of the lack of competitiveness of these varieties due to undesirable consumer characteristics and somewhat lower yields than the most profitable releases available. Funding declined. Many institutions either abandoned or drastically reduced their research in this area. The institutions that continued vigorously and persistently to improve the protein quality were the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), the University of Natal, South Africa, and the Crow's Hybrid Seed Company in Milford, Illinois, USA. All three centres were eventually quite successful in developing products with good agronomic performance and market acceptability, as described below.

Redirection of breeding efforts

As problems plaguing the original soft *o2* materials became obvious and with no definite solution or particular strategy in sight at that time, many breeders and researchers found themselves in a state of dilemma and confusion. Pertinent options and breeding strategies needed to be identified to develop QPM germplasm that was competitive in agronomic performance and free of problems considered important for its acceptance. The options fell into two broad categories: abandoning the use of mutant genes altogether and continued experimentation with mutant genes. The former group included recurrent selection for improved protein quality, altering the germ/endosperm ratio, and increasing the aleurone layers of the maize grain. All three of these approaches have been tried and require long-term efforts to achieve lysine levels matching the specific mutants, which give a significant boost in lysine content.

In the latter group, one approach exploits double mutant combination(s). A second approach uses two genetic systems involving the *o2* gene and the genetic modifiers of the *o2* locus. The double mutant combination involving interaction of *o2* and sugary-2 (*su2*) has some advantages, such as vitreous kernels, acceptable kernel appearance, less ear rot, increased lysine levels, and better digestibility of protein. However, a significant disadvantage is the low yield, which is the sum total of independent negative effects of the two genes. A double mutant combination of *o2* and *fl2* also has been researched but not pursued further, because modified vitreous kernels are encountered in only a few genetic backgrounds. The most successful and rewarding option has involved the combined use of *o2* and the genetic modifiers of the *o2* locus.

The approach practised by CIMMYT researchers emphasized the development of market-competitive QPM genotypes with quality protein as a bonus. To achieve this goal, a conservative approach was used initially with respect to biochemical characteristics. Since the *o2* gene boosts lysine levels by twofold, efforts were devoted to maintenance rather than further enhancing the levels of lysine at protein levels of 9% to 10% in the whole grain. This greatly facilitated breeding agronomically superior QPM genotypes while focusing on critical and key consumer characteristic problems.

During the first decade of breeding, partially modified kernels had been observed by researchers at CIMMYT and elsewhere. Initially the significance of such kernels was not completely understood. In most instances, the breeders tended to discard them. The first published report highlighting the importance of such kernels appeared in 1969 [6]. Separation of such kernels when encountered began at CIMMYT as early as 1969 by Dr. John Lonnquist and Dr. V. L. Asnani. Modified kernels were classified in different categories and analysed for degree of modification of biochemical characteristics. Modified ears were sorted from every possible source as they appeared during the conversion programmes and during the process of seed increase of *o2* maize materials. As expected, the modification was exceedingly poor, ranging from slight to less than 25%. Such kernels were encountered in different frequencies from different genetic backgrounds. Caribbean, Cuban, and flint backgrounds in general tended to exhibit a higher frequency of modified kernels. As luck would have it, a few *o2* converted populations and population crosses were identified that had unusually high frequencies of modified kernels. Our hopes and enthusiasm from this point onwards rose. Increasing resources were allocated to developing QPM germplasm.

Development of QPM donor stocks

The next step in the breeding process was the development of QPM donor stocks with modified kernel phenotype and good protein quality. This also turned out to be a time-consuming and tedious process.

Two basic approaches were used in developing QPM donor stocks. The first approach was intrapopulation selection for genetic modifiers in *o2* backgrounds that exhibited a higher frequency of modified *o2* kernels. Four tropical populations and one highland population that met these criteria were chosen for this purpose. The breeding procedure used was controlled full-sib pollinations in the initial cycle, followed by a modified ear-to-row system suggested by Lonnquist [7]. Selection was practised for modified ears and modified kernels at all stages.

The second approach involved recombination of superior hard-endosperm *o2* families. The yellow and white families were recombined separately to develop both yellow and white composites. Genetic mixing coupled with selection of modified ears and modified kernels of good protein quality was practised for three to four cycles. By the mid-1970s, it was felt that these materials could be used as QPM donor stocks as well as QPM populations for further improvement.

The development of QPM donor stocks then led to large-scale QPM germplasm development in different genetic backgrounds, representing tropical, subtropical, and highland maize germplasm, involving different maturities as well as grain colour and texture. Because of the complexity and nature of the modified phenotype trait, it was realized from the beginning that a standard backcross programme would not work. An innovative breeding procedure, termed a "modified backcrossing-cum-recurrent selection," was designed to handle the conversion process [8, 9]. A number of advanced maize populations in the CIMMYT maize programme were converted to QPM using this procedure. During the conversion process, emphasis was placed on yield, kernel modification and appearance, reduced incidence of ear rot, and rapid drying.

Success was finally achieved in raising the yields of some QPM lines to those of non-QPM counterparts (table 1). The yield gap has been narrowed, as can be seen in figure 1. The average kernel modification scores have improved, with concomitant increase in the frequency of kernels with better modification scores.

The incidence of ear rot in QPM materials has been gradually reduced. Several materials are perhaps no different from the normal, but some still show slightly higher incidences. In several studies, normal and QPM counterparts did not differ in moisture content. In preliminary studies carried out in the CIMMYT entomology laboratory, the QPM and normals did not differ in the amount of damage by insect pests of stored grains. During all stages of improvement, protein

TABLE 1. Across-location performance of normal materials and corresponding tropical QPM germplasm, 1987

	Grain yield (kg/ha)		QPM (%
Material	Normal	QPM	of normal
Pool 23	5,405	5,330	98.6
Pool 24	5,706	5,457	95.6
Tropical high-oil	5,733	5,170	90.2
Population 62	5,347	5,484	102.6
Population 65	5,255	5,369	102.2
Population 63	5,705	6,236	109.3

Source: ref. 5.

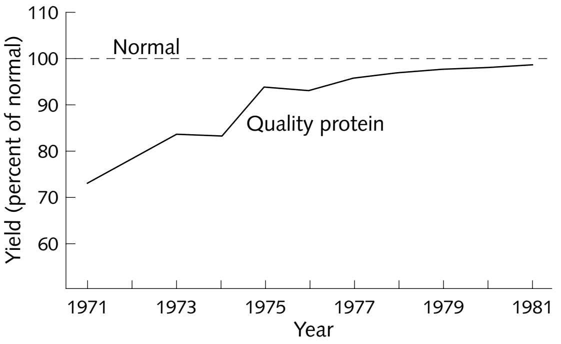

FIG 1. Grain yield performance of QPM corn expressed as a percentage of normal maize check in different years across all test locations

quality was monitored and maintained. In addition, considerable research effort was devoted to the formation and development of broad-based QPM gene pools.

A total of seven tropical and six subtropical QPM gene pools were developed and improved continuously by using a modified half-sib improvement selection system. The progress achieved in these pools is shown in figure 2. Since most of the QPM gene pools were handled by using non-inbred families, one may expect a low frequency of good lines surviving the inbreeding process. In a period extending over five to six years, a huge volume of QPM germplasm was developed that could meet the needs of several production environments in the tropical and subtropical areas. At this point it was realized that continuing the conversion programme would serve no useful purpose. Rather it was thought to be more advantageous to accelerate progress by switching over to working in homozygous *o2* genetic backgrounds. QPM germplasm consolidation and reorganization was considered appropriate at this stage.

New thrusts in QPM germplasm management strategy

Knowledge of the germplasm and considerations of colour and maturity were the principal guiding factors in the merging, consolidation, and reorganization of the QPM germplasm. From the available QPM germplasm, eight tropical and six subtropical QPM gene pools were formed. At the same time, 10 QPM advanced populations were identified. Six of the populations were tropical and four subtropical in adaptation. These populations were considered for international progeny testing trials for further improvement and as a mechanism of disseminating germplasm to the national agricultural research institutes. Handling of QPM materials in homozygous *o2* background was emphasized at this point to facilitate faster progress and rapid accumulation of favourable modifiers for kernel modification, weight, and density. Working in homozygous *o2* backgrounds had the additional advantage of reducing errors that generally occur due to misclassification and selection of kernels during the segregating generations. Selection in homozygous genetic backgrounds also permits completely modified or normal-looking kernels to be chosen with certainty. The handling of QPM germplasm, both pools and populations and involving different stages, has been discussed in several earlier publications from CIMMYT researchers [10, 11].

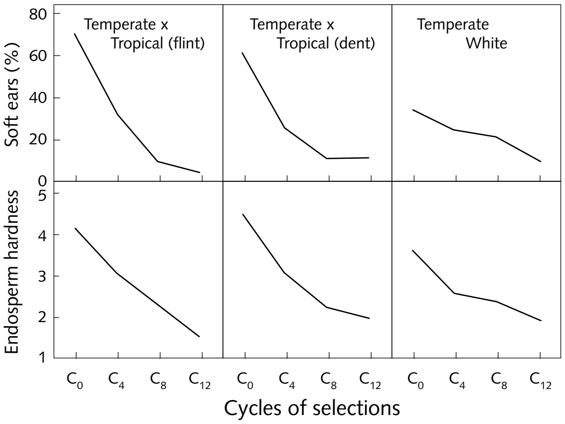

FIG. 2. Percentage of soft ears and endosperm hardness scores in different cycles of selection of three subtropical QPM gene pools

Emphasis on QPM hybrid development

The QPM hybrid initiative at CIMMYT was introduced in 1985. The use of hybrids offered several advantages, including seed purity, monitoring and maintaining protein quality, enhanced modification and added uniformity and stability, enhanced yield potential, circumventing breeding difficulties more efficiently and effectively, greater market acceptability, and spurring the development of the seed industry [12–14].* Several hybrid combinations have been tested internationally, and some of them have performed as well as or better than some of the local checks included in the trials (tables 2 and 3). Unfortunately, because of funding constraints, CIMMYT had to drop QPM activities completely beginning in 1993. However, the programme has now been reinstated. During the past three to four years, many more hybrid combinations have been tested again, and the outlook for QPM appears quite promising.

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* Vasal SK. Development of quality protein maize hybrids. A keynote paper presented at the first symposium on crop improvement in Ludhiana, India, 23–27 February 1987.

TABLE 2. Superior white QPM hybrids tested across 15 locations in El Salvador, Guatemala, and Mexico, 1998[a]

Pedigree	Yield (tons/ha)	Ear rot (%)	Tryptophan (%)	Ear modification (%)	Silking (days)	Plant height (cm)
CML142 × CML146	6.48	3.7	0.096	2.0	55	242
CML159 × CML144	6.39	4.3	0.100	1.6	56	230
(CL Q6203 × CML150) CML176	6.28	5.7	0.088	2.1	55	239
CML145 × CML144	5.81	5.8	0.840	2.0	54	241
CML158 × CML144	5.59	7.1	0.103	1.3	55	228
CML146 × CML150	5.48	8.7	0.084	3.6	56	222
POZA RICA 8763 TLWD	5.34	12.0	0.095	2.8	54	230
Normal hybrid check	5.58	9.5	0.070	2.0	56	228

a. Local checks: HB-83, CB-HS-5G, H-59, XM7712, GUAYOPE.

TABLE 3. Superior subtropical yellow QPM hybrids tested across five locations in Mexico and Zimbabwe, 1998[a]

Pedigree	Yield (tons/ha)	Ear rot (%)	Ear modification (%)	Silking (days)	Plant height (cm)
CML161 × CML165	9.82	0.1	1.5	98	219
CLQ3301 × CML193	8.09	6.0	2.0	91	207
CLQ6901 × CML193	8.08	2.1	1.5	94	216
CLQ3302 × CML193	7.78	3.3	1.5	92	198
CLQ3401 × CML193	7.78	1.5	2.0	93	199
CLQ3402 × CML193	7.69	2.0	2.5	94	197
Normal hybrid check	9.82	1.8	4.5	98	223

a. Local checks: H-358, A-7595, H-312.

Renewed emphasis on QPM in some national programmes

In recent years, several countries have shown unusually high interest in promoting and disseminating QPM cultivars to farmers. Mass utilization of the QPM variety, OBTANPA, in Ghana is exemplary. More than 50% of the maize area in the country is planted with this variety. The Brazilian programme has sustained QPM efforts all these years and has commercialized two QPM varieties, BR451 and BR473. A double-cross QPM hybrid was also released in 1997. The programme has greatly strengthened hybrid efforts and may soon be releasing more hybrids.

The potential of QPM hybrids in China is tremendous. QPM research is being undertaken in several academies, and the Chinese Government has shown a great commitment to promote QPM hybrids all over the country. In mid-1999 a QPM hybrid, Zhongdan 9407, was formally released in a special ceremony attended by several high-level dignitaries and scientists. In Guizhou Province in southern China, a QPM intervention is being used to alleviate poverty and improve the economic well-being of the farmers.

QPM interest in Mexico has grown with the support and commitment of the Mexican Government to cover a substantial area with QPM hybrids in the next two to three years. A few countries in Central America are ready to release QPM hybrids and to plant several thousand hectares with such materials. India released Shakti-1 last year and is deeply involved in testing hybrids from CIMMYT. Several countries of Asia, Africa, and Latin America are part of a network working on the improvement and promotion of QPMs, including Honduras, Bolivia, Colombia, Ethiopia, Mozambique, Tanzania, Uganda, Zimbabwe, and South Africa. Several of these countries will be testing QPM varieties and hybrids. The Republic of South Africa had earlier released hybrids HL-1 and HL-2, and has recently released HL-8, which has hard endosperm, good yield potential, and tolerance to diseases. The Sasakawa Global 2000 Project has helped to promote QPM in Ghana and is assisting some other countries in Africa in the promotion of QPM.

Conclusions and future outlook

Realizing improvements in the quality of protein in maize through conventional breeding efforts has proved difficult, complex, and frustrating and has required long-term investments, sustained research efforts, patience, and continuing administrative, financial, and scientific support. Success required constant adjustments in research strategy, which had to address complex and interrelated problems of poor agronomic performance and undesirable consumer characteristics in a single but multipronged strategy.

The strategy used by CIMMYT researchers in developing QPM has proved to be successful. Practically all QPM research programmes in several countries are now using this approach, based on the combined use of the *o2* gene and genetic modifiers. Hybrid development efforts in QPM have become increasingly important, as is evident from recent experience. It is hoped that many countries now involved in the QPM network will be able to select one or two of the most promising hybrids for release in their respective countries. Optimism is especially high in China for the promotion and dissemination of QPM. There may be increasing use of molecular genetic tools in QPM research in the future.

Programmes at the CIMMYT, at Texas A&M University, and in Brazil and South Africa are already using these new tools on a limited scale. The mechanism controlling kernel modification and the role of gamma zein (a storage protein) need to be further elucidated. Better characterization of zein proteins may facilitate and expedite conversion programmes. In the future, more sophisticated techniques may become available that can distinguish modified *o2* kernels from normal kernels.

Finally, and perhaps most importantly, there is a pressing need for a series of rigorous studies to determine the benefits of consumption of QPM to human nutrition.

References

1. Osborne TB, Mendel LB. Nutritive properties of maize kernel. J Biol Chem 1914;18:1–16.
2. Mertz ET, Bates LS, Nelson OE. Mutant gene that changes protein composition and increases lysine content of maize endosperm. Science 1964;145:279–80.
3. Nelson OE, Mertz ET, Bates LS. Second mutant gene affecting the amino acid pattern of maize endosperm proteins. Science 1965;150:1469–70.
4. Harpstead DD. High lysine maize in its proper perspective. In: Proceedings of the 24th Annual Corn and Sorghum Research Conference. Chicago, Ill, USA: American Seed Trade Association, 1969:74–80.
5. Bjarnason M, Vasal SK. Breeding of quality protein maize (QPM). In: Janick J, ed. Plant Breeding Review 1992;9:181–216.
6. Paez AV, Helm JL, Zuber MS. Lysine content of opaque-2 maize kernels having different phenotypes. Crop Sci 1969;9:251–2.
7. Lonnquist JH. Modification of the ear-to-row procedure for the improvement of maize populations. Crop Sci 1964;4:227–8.
8. Vasal SK, Villegas E, Bjarnason M, Gelaw B, Goertz P. Genetic modifiers and breeding strategies in developing hard endosperm opaque-2 materials. In: Pollmer WG, Phipps RH, eds. Improvement of quality traits of maize for grain and silage use. The Hague, Netherlands: Nighoff, 1980:37–71.
9. Vasal SK, Villegas E, Tang CY. Recent advances in the development of quality protein maize at the Centro Internacional de Mejoramiento de Maiz y Trigo. In: Cereal grain protein improvement. Vienna: International Atomic Energy Agency, 1984:169–89.
10. Vasal SK, Villegas E, Bauer R. Present status of breeding quality protein maize. In: Seed protein improvement in cereals and grain legumes. Vienna: International Atomic Energy Agency, 1979:127–50.
11. Vasal SK, Villegas E, Tang CY, Werder J, Read M. Combined use of two genetic systems in the development and improvement of quality protein maize. Kulturpflanze 1984;32:171–85.
12. Vasal SK, Srinivasan G, Pandey S, Gonzalez FC, Beck DL, Crossa J. Heterosis and combining ability of CIMMYT's QPM maize germplasm. I. Lowland tropical. Crop Sci 1993;33:46–51.
13. Vasal SK, Srinivasan G, Gonzalez FC, Beck DL, Crossa J. Heterosis and combining ability of CIMMYT's QPM maize germplasm. II. Subtropical. Crop Sci 1993;33:51–8.
14. Vasal SK. High quality protein corn. In: Hallauer AR, ed. Specialty corns. Boca Raton, Fla, USA: CRC Press, 1994:80–121.

Application of biotechnology to improving the nutritional quality of rice

Swapan Datta and Howarth E. Bouis

Abstract

This paper summarizes research to date on improving the nutritional characteristics of rice by using biotechnology, including efforts to produce β-carotene in the rice endosperm, to introduce a heat-stable phytase gene, and to increase iron concentration. The results obtained using biotechnology are compared with the results of breeding research by conventional techniques. Based on this comparison, the following lessons are drawn as to the potential usefulness of biotechnology in providing more nutritious food staples: (1) It must be established that plant-breeding is more cost-effective than alternative interventions. This is apparently the case, in large measure because of the multiplier effects of plant-breeding, over time and space, as compared with supplementation and fortification. (2) There must be aspects of breeding for which biotechnology is superior to conventional techniques. For rice, this is the case for adding β-carotene-related and heat-stable phytase genes. For increasing mineral concentration, conventional breeding techniques work as well and may be applied more quickly. (3) For those aspects of the plant-breeding strategy for which biotechnology is superior to conventional breeding, it must be established that there are no serious negative agronomic consequences; that consumers will accept any changes in the colour, taste, texture, and cooking qualities; and that the characteristic being added will result in a measurable improvement in the nutritional status of the malnourished target population. The conditions under lesson three, in particular, have yet to be firmly established. However, it is important not be overly cautious, in view of the potentially enormous benefits to the poor.

Introduction

This paper begins by reviewing recent research related to the application of biotechnology to improvements in the nutritional content of rice. The discussion here on advances using biotechnology to improve the micronutrient content of rice, and an earlier discussion in this issue by Gregorio et al. [1] on the use of conventional breeding techniques for rice, permits a discussion of ways in which biotechnology and conventional approaches are complementary, and what can be accomplished through biotechnology that cannot be accomplished using conventional breeding techniques. General lessons are drawn for assessing the potential of biotechnology in improving human nutrition, followed by conclusions for directions for future research.

Recent findings on improving the nutrient content of rice by biotechnology

Increasing iron content

Ferritin is an iron-storage protein found in animals, plants, and bacteria. The ferritin gene has been isolated and sequenced in plants, including soya bean, French bean, pea, and maize. Recent studies show the ferritin is used by both plants and animals as the storage form of iron and that, orally administered, it can provide a source of iron for treatment of rat anaemia [2].

However, human studies with extrinsically radiolabelled animal ferritin have indicated that iron contained within the ferritin molecule added to a meal is only about half as well absorbed as vegetable iron [3, 4] and as ferrous sulphate [5]. As yet, there have been no

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This paper draws heavily from "The role of biotechnology for food consumers in developing countries" by H. Bouis (In: Qaim M, Krattiger AF, von Braun J, eds. Agricultural biotechnology in developing countries: towards optimizing benefits for the poor. Boston, Mass, USA; Dordrecht, Netherlands; and London: Kluwer Academic Publishers, 2000:189–213), which contains a more detailed analysis of the issues discussed here.

human studies with plant ferritin, and animal studies are not considered a good model for humans [6].

Goto et al. [7] reported improvement of the iron content of rice by transferring the entire coding sequence of the soya bean ferritin gene into a Japonica rice. The introduced ferritin gene was expressed under the control of a rice seed-storage protein glutelin promoter to mediate the accumulation of iron specifically in the grain. The transgenic seeds stored up to three times more iron than the normal seeds.

Iron levels in the whole (unmilled) seeds of the transformants varied from 13 to 38 ppm.* In a heavily rice-eating population, an adult may consume 400 g (1,400 calories) of rice (dry weight) a day. If the differential in iron content in milled rice is 10 ppm between an iron-dense (say, 18 ppm) and a normal-iron rice (say 8 ppm), this adds 4 mg of iron to the diet per day, which may be a 50% increase over the average daily intake of a poor person who obtains 80% to 90% of his or her energy from rice. This underscores the importance of determining where in the endosperm the iron (and other trace minerals) are deposited and how mineral levels are affected by milling. Although that for the non-transformants varied from only 9 to 14 ppm, the pooled mean values were 23 ppm for transformants and 11 ppm for non-transformants. The average iron contents in the endosperm were 3.4 ppm for transformants and 1.6 ppm for non-transformants.

The authors speculated that the amount of iron accumulation is restricted by transport of iron to the ferritin molecule, rather than simply by the levels of ferritin protein. Thus, it may be possible to store larger amounts of iron in the ferritin molecule by co-integrating the ferritin gene and the iron reductase-like transporter gene. Robinson et al. [8] reported a newly discovered ferric-chelate reductase gene that allows plants to absorb iron from the soil, thus introducing the possibility of widening the scope of rice varieties with high iron uptake. Transgenic rice plants have already been produced with this gene, and further work is on progress [Datta K, personal communication, 19 July 2000].

Doubling of the iron content in a rice using a ferritin gene derived from *Phaseolus vulgaris*, Lucca et al. [9] reported that metallothionine was also expressed in the rice grain, increasing the cysteine content sevenfold. It is not known if the cysteine-containing peptides formed on digestion of metallothionine in the human gut have a similar enhancing effect on iron absorption as those formed on digestion of muscle tissue [Hurrell T, personal communication, 14 January 2000].

Introducing a heat-stable phytase gene that breaks down phytic acid

The phytase level in rice is normally low. Several studies have already demonstrated the usefulness of adding phytase to the rice diets of poultry [10–12]. The phytase that does exist in rice seeds will hydrolyse phytic acid if seeds are left to soak in water. However, boiling destroys the phytases that occur naturally in rice. Lucca et al. [9] also reported introducing a transgene for a heat-stable phytase from *Aspergillus fumigatus*, which increased the level of phytase by 130-fold. The fact that the phytase is potentially heat-stable, then, is critically important.

An amino acid was changed in the sequence to make the phytase heat stable [13]. It was also active at pH values found in the digestive tract and degraded all the phytic acid in a very short time during model *in vitro* digestion. Unfortunately, after being expressed in the grain, it was no longer stable to heat and lost its activity on boiling [Hurrell R, personal communication, 14 January 2000].

Increasing lysine

Lysine, an important essential but limiting amino acid in rice, which might promote the uptake of trace minerals, can be improved by genetic engineering. Introduction of two bacterial genes DHDPS (dihydrodipicolinic acid synthase) and AK (aspartokinase) enzymes encoded by the *Corynebacterium dapA* gene and a mutant *Escherichia coli lysC* gene has enhanced lysine about fivefold in canola, corn, and soya bean seeds [14, 15]. Introduction of these genes is a realistic approach to improve the lysine content of rice. DuPont has agreed to collaborate with IRRI to provide genes to develop lysine rice at the International Rice Research Institute (IRRI). Nutritional genomics will have a tremendous impact on the improvement of foods for human health [16]. The recent rice genome sequence developed by Monsanto will accelerate gene discovery and crop improvement [17].

Adding β-carotene

β-Carotene, a precursor of vitamin A (retinol), does not occur naturally in the endosperm of rice. Ye et al. [18] have reported transgenic rice that produces grain with yellow-coloured endosperm. Biochemical analy-

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* The authors stated, “The iron content in a meal-size portion of ‘ferritin rice’ (approximately 5.7 mg iron/150 g dryweight of rice) would be sufficient to provide 30–50% of the daily adult iron requirement.” Presumably, 5.7 mg of iron is obtained by multiplying 38 ppm by 150 g. Unfortunately, this calculation assumes that consumers eat unmilled rice. The iron added by the “ferritin rice” in the endosperm is 1.8 ppm (3.4 ppm minus 1.6 ppm), which when multiplied by 150 g gives only an extra 0.27 mg of iron per meal-sized portion. Nevertheless, this alternative calculation probably understates the iron added, since milling does away with much, but not all, of the brown outer covering (bran) of the seed, which is relatively dense in iron.

sis confirmed that the colour represents β-carotene (provitamin A).

According to Ye et al. [18], the genes *psy* (cloned from *Narcissus pseudonarcissus*) [19], *cryt1* (cloned from Erwinia uredovora) [20]; and *lyc* have been introduced into the rice, driven by the endosperm specific glutelin promoter (*Gt1*). The *crt1* was fused to the transit peptide (tp) sequence by the pea Rubisco small subunit [20] to lead the accumulation of lycopene in the endosperm plastids. This is a remarkable accomplishment, considering that most traits engineered to date have only required the addition of a single gene [21].

The reported level of β-carotene in 1 g of the transformed rice is 1.6 μg. Multiplying that by a daily intake of 400 g of milled rice and dividing by a conversion ratio of 6 μg of β-carotene for every retinol equivalent (RE) gives 107 RE, which Ye et al. [18] stated is the target level for improved nutrition. However, widely accepted required daily amounts (RDAs) for vitamin A range between 375 and 1,200 RE, depending on age, sex, and physiological status [22], and recent evidence suggests that the conversion factor from carotene to RE varies between 12 to 26 units of β-carotene to 1 unit of retinol [23].* Nevertheless, RDAs are set relatively high by adding two standard deviations to the observed mean requirements of a nutrient for most people.

The introduction of ferritin, heat-stable phytase, and β-carotene in rice by the teams led by Potrykus and Beyer has been accomplished individually in separate Japonica rices (i.e., not jointly in the same rice). These cultivars may be used in the IRRI breeding programme to transfer the genes of interest to Indica cultivars, from which IRRI releases are derived. Alternatively, these genes would be introduced directly into tropical Indica cultivars by genetic engineering.

Future strategy for combining conventional breeding techniques and biotechnology

In breeding for micronutrient-dense staple food crops, what is the appropriate mix of conventional breeding techniques and biotechnology? Where are they complementary? When is one approach feasible, but the other not? Table 1 summarizes some of the issues involved.

To return to two of the themes raised earlier in this issue by Bouis et al. [24], the fundamental advantages of breeding for increased trace minerals are that agricultural productivity is not compromised and, indeed, is enhanced on soils deficient in trace minerals, and that consumer characteristics should remain unchanged. Thus, for rice, although it is fortunate that IR68-144 was discovered without resort to breeding explicitly for high iron, such a discovery has a relatively high probability of occurring, because of the compatibility with high yields of the nutritional trait being sought. Such discoveries can greatly speed up the development and dissemination process and lower the cost of breeding.

After milling, IR68-144 confers an increase of perhaps 80% in iron density over modern varieties presently being released. This is about the same average advantage as that reported by Goto et al. [7] and Lucca et al [9].** It may be possible to elevate this 80% advantage further by crossing various iron-dense genotypes that may have complementary, additive mechanisms for loading more iron into the seed.

The two successes at adding a ferritin gene to rice reported here have not produced results superior to those obtained by conventional plant-breeding. Moreover, breeding is still required to move the “ferritin” trait from Japonica to high-yielding Indica rice varieties. It may be that eventually the most iron-dense genotypes can be developed by using biotechnology, especially after the basic physiology of the mechanisms controlling translocation of trace minerals in plants is better understood. However, a specific strategy for doing so has yet to be demonstrated.

There are three complementary or alternative approaches to increasing the bioavailability of trace minerals in the grains of food staples: reducing phytic acid, introducing phytase, and increasing promoting compounds. As described by Raboy [25], low-phytic-acid mutants of cereals have already been produced in which virtually all or a large portion of the phytic acid has been replaced by inorganic phosphorus. This is

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* Ye et al. [18] used a ration of 300 g of milled rice in their calculations but added that they were optimistic that they could reach a goal of 2 μg/g of β-carotene in homozygous lines. In a relatively heavy-rice-eating population such as that of Bangladesh, non-breastfeeding pre-schoolers in rural areas might consume 250 g of milled rice per day (an RDA of 500 RE), adult women 500 g of milled rice per day (an RDA of 800 RE for those not pregnant or breastfeeding), and adult men 650 g of milled rice per day (an RDA of 1,000 RE).

** Goto et al. [7] and Lucca et al. [9] measured their iron increases against benchmarks that are the non-transformed genotypes. But are these benchmarks relatively high- or low-density genotypes to start with? The only figures available are from Goto et al. [7]. Their maximum value of 38 ppm in brown rice is quite high compared with all rices analysed under the CGIAR Micronutrients Project. However, this was an analysis of only one single grain from a plant grown under laboratory conditions (iron content varies by weather and soil type). Analyses under the CGIAR Micronutrients Project are averages for randomly drawn samples of several seeds of a single genotype grown in a specific season on a specific soil. Thus, the average of 23 ppm obtained by Goto et al. [7] (only 11 grains in total) is probably the best comparison with IR68-144, which has an iron density of 23 ppm for some plantings [1].

TABLE 1. Effects on plant yield, consumer characteristics, and human nutrition of various plant-breeding strategies

Type of deficiency and effects	Strategy			
Iron deficiency	*Increasing iron content*	*Reducing phytic acid*	*Adding phytase*[a]	*Endosperm specific promoter*
Plant yield	Neutral to positive effects	Effects may be negative on poor soils	Unknown	No effect
Consumer characteristics	Probably no effects	In most cases, no effects	Unknown	Unknown
Human nutrition	Substantial benefits, pending testing of bioavailability	Substantial benefits, pending testing of bioavailability	Substantial benefits, pending testing of bioavailability Improved bioavailability of several nutrients; however, phytic acid may have positive health effects	Substantial benefits, pending testing of bioavailability Improved bioavailability of several nutrients; however, phytic acid may have positive health effects
Zinc deficiency	*Increasing zinc content*	*Reducing phytic acid*	*Adding phytase*[a]	*Adding gene(s)*
Plant yield	Neutral to highly positive effects	Effects may be negative on poor soils	Unknown	Unknown
Consumer characteristics	Probably no effects	In most cases, no effects	Unknown	Unknown
Human nutrition	Potentially substantial benefits, pending testing of bioavailability; public health benefits suspected but not firmly established	Potentially substantial benefits, pending testing of bioavailability; public health benefits suspected but not firmly established Improved bioavailability of several nutrients; however, phytic acid may have positive health effects	Potentially substantial benefits, pending testing of bioavailability; public health benefits suspected but not firmly established Improved bioavailability of several nutrients; however, phytic acid may have positive health effects	Potentially substantial benefits, pending testing of bioavailability; public health benefits suspected but not firmly established
Vitamin A deficiency	*Increasing β-carotene content*[a]			
Plant yield	Unknown			
Consumer characteristics	Nutrition education required			
Human nutrition	Substantial benefits, although the numbers of individuals deficient in iron (and zinc) are high			

a. These strategies require the use of biotechnology.

a promising approach in terms of improving human nutrition, although a drawback may be its agronomic performance on phosphorus-poor soils.

Evidence as to which compounds promote bioavailability, such as sulphur-containing amino acids, is sketchy. Until this approach has been more thoroughly researched and specific compounds have been firmly identified as promoting bioavailability, it is probably too early to begin breeding for such compounds using conventional plant-breeding or biotechnology.

A promising approach for the use of biotechnology with respect to trace minerals is adding a heat-stable phytase to rice.* This particular approach may not be an option for conventional plant-breeding and therefore could only be pursued by using biotechnology. No evidence is presently available as to how adding

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* According to Preben Holm (personal communication, 2 November 1999), plant phytases have been very difficult to isolate. For cereals there are only two maize phytase genes isolated, one expressed in the seedling and the other in the root. This implies that there are virtually no tools available for gene expression analyses as well as for immunodetection of proteins.

phytase to rice would affect agronomic performance or consumer characteristics.

Turning now to vitamins, the addition of β-carotene to rice is possible only through biotechnology. No rice has been identified with β-carotene in the endosperm. Thus, the apparent success of "vitamin A" rice in this regard is quite exciting. Nevertheless, apart from breeding these β-carotene-related genes into high-yielding varieties and assessing possible effects on plant productivity, it is already known that the β-carotene turns the seeds yellow. How willingly will poor consumers purchase and consume yellow rice?

Most people agree that without a complementary nutrition-education programme, yellow rice will not be readily accepted by consumers. Opinions differ as to the power of nutrition education to overcome culturally held preferences for white rice. It is easy to speculate either way, but no hard data are available. If a nutrition-education programme were successful, however, the yellow colour would distinguish more nutritious from less nutritious rice, and the disadvantage of the yellow colour would be turned to an advantage.

An additional exciting possibility is that higher intakes of β-carotene (converted to retinol after ingestion) may promote the absorption of iron and vice versa. That is, there is possible synergy between higher intakes of these two nutrients [26, 27]. There is already considerable evidence on the synergy between vitamin A and zinc intakes [28].

Lessons to be drawn

The following lessons may be drawn as to the potential usefulness of biotechnology in helping to provide more nutritious food staples in developing countries:

1. It must be established that plant-breeding is more cost-effective than alternative interventions already in place to reduce micronutrient malnutrition. This is apparently the case, in large measure because of the multiplier effects of plant-breeding: a relatively small, fixed, initial investment in research may benefit the health of millions of poor people in developing countries all over the world, and at the same time may improve agricultural productivity on lands that are presently among the least productive.
2. There must be aspects of the breeding strategy for which biotechnology is superior to conventional breeding techniques. For rice, this is the case for adding β-carotene-related and heat-stable phytase genes. In the long run, as more is understood about the factors driving translocation of minerals in plants, it may also be the case for increasing trace mineral density.
3. For those aspects of the plant-breeding strategy for which biotechnology is superior to conventional plant-breeding, it must be established that there are no serious negative agronomic consequences associated with the characteristic being added; that consumers will accept any noticeable changes in the colour, taste, texture, cooking qualities, and other features associated with the characteristic being added; and that the characteristic being added will result in a measurable improvement in the nutritional status of the malnourished target population.

The conditions under lesson three, in particular, have yet to be firmly established. However, it is important not be overly cautious. The potentially enormous benefits to the poor in developing countries in relation to costs are so high that research in this area should be vigorously pursued.

Conclusions

Biotechnology can improve consumer welfare in a number of ways not discussed in this paper. By helping to improve crop productivity and thereby increasing the growth rate of supply of a range of foods, biotechnology can help to reduce food prices for poor consumers. Value-added rice can have substantial incentive affecting the higher income and purchasing power of the farmers.

Consumer-preferred characteristics of food, such as appearance, taste, and colour, can also be improved through biotechnology, but such research probably benefits rich consumers more than poor consumers in developing countries. However, farmers will always benefit from growing them with guaranteed higher price.

By helping to produce a greater quantity of food at lower cost, biotechnology will perhaps make its most important contribution to reducing malnutrition. However, this will require several decades to be realized, informed governmental policies, and a relatively large investment in agricultural research and other public and on-farm infrastructure.

Some successes in increasing the mineral content of staples can be achieved in the short run through conventional breeding techniques, because of the inherent compatibility of high yields and trace mineral density in some selected cultivars. Because molecular plant-breeding is a new strategy for improving nutrition, it is essential to take the steps necessary to make these early, nutritionally improved varieties available to farmers for commercial production and to measure any resulting improvements in micronutrient status, in order to demonstrate the feasibility and practicality of plant-breeding as an approach for improving micronutrient nutrition.

The full potential of biotechnology can be applied to improving the nutritional content of food staples by perhaps increasing mineral levels even further than is possible with conventional breeding techniques and pursuing complementary strategies, such as adding β–carotene and heat-stable phytase genes, genes for improving lysine that are not possible using conventional breeding techniques.

References

1. Gregorio GB, Senadhira D, Htut H, Graham RD. Breeding for trace mineral density in rice. Food Nutr Bull 2000;21:382–6.
2. Beard JL, Burton JW, Theil EC. Purified ferritin and soybean meal can be sources of iron for treating iron deficiency in rats. J Nutr 1996;126:154–60.
3. Martinez-Torres C, Renzi M, Layrisse M. Iron absorption by humans from hemosiderin and ferritin, further studies. J Nutr 1976;106:128–35.
4. Taylor PG, Martinez-Torres C, Romano EL, Layrisse M. The effect of cysteine-containing peptides released during meat digestion on iron absorption in humans. Am J Clin Nutr 1986;43:68–71.
5. Skikne B, Fonzo D, Lynch SR, Cook JD. Bovine ferritin bioavailability in man. Eur J Clin Invest 1997; 27:228–33.
6. Hurrell RF. Bioavailability of iron. Eur J Clin Nutr 1997; 51(suppl 1):S4–8.
7. Goto F, Yoshihara T, Shigemoto N, Toki S, Takaiwa F. Iron fortification of rice seed by the soybean ferritin gene. Nature Biotech 1999;17:282–6.
8. Robinson NJ, Procter CM, Connolly EL, Guerinot ML. A ferric-chelate reductase for iron uptake from soils. Nature 1999;397:694–7.
9. Lucca PR, Hurrell RF, Potrykus I. Genetic engineering approaches to improve the bioavailability and the level of iron in rice grains. Theor Appl Genet (in press).
10. Adrizal PE, Palo E, Sell JL. Utilization of defatted rice bran by broiler chickens. Poultry Sci 1996;75:1012–7.
11. Farrell DJ, Martin EA. Strategies to improve the nutritive value of rice bran in poultry diets. III. The addition of inorganic phosphorus and a phytase to duck diets. Br Poultry Sci 1998;39:601–11.
12. Martin EA, Nolan JV, Nitsan Z, Farrell DJ. Strategies to improve the nutritive value of rice bran in poultry diets. IV. Effects of addition of fish meal and a microbial phytase to duckling diets on bird performance and amino acid digestibility. Br Poultry Sci 1998; 39:612–21.
13. Pasamontes L, Haiker M, Wyss M, Tessier M, van Loon APGM. Gene cloning, purification, and characterization of a heat-stable phytase from the fungus *Aspergillus fumigatus*. Appl Environ Microbiol 1997;63:1696–1700.
14. Falco SC, Guida T, Locke M, Mauvais J, Sanders C, Ward RT, Webber P. Transgenic canola and soybean seeds with increased lysine. Biotechnology 1995;13:577–82.
15. Mazur B, Krebbers E, Tingey S. Gene discovery and product development for grain quality traits. Science 1999; 285:372–5.
16. DellaPenna D. Nutritional genomics: manipulating plant micronutrients to improve human health. Science 1999;285:375–9.
17. Sasaki T, Burr B. Monsanto sequence and physical map contribution to the International Rice Genome Sequencing Project (IRGSP) (www.demeter.bio.gov/4 april.html), 2000.
18. Ye X, Al-Babili S, Klöti A, Zhang J, Lucca P, Beyer P, Potrykus I. Engineering the pro-vitamin A (β-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. Science 2000;287:303–5.
19. Schledz M, Al-Babili S, Lintig J, Haubruck H, Rabbani S, Kleinig H, Beyer P. Phytoene synthase from *Narcissus pseudonarcissus*: functional expression, galactolipid requirement, topological distribution in chromoplasts and induction during flowering. Plant J 1996;10:781–92.
20. Misawa N, Yamono S, Linden H, de Felipe MR, Lucas M, Ikenga H, Sandmann G. Functional expression of the *Erwinia uredovora* carotenoid biosynthesis gene *crt*l in transgenic plants showing an increase of β-carotene biosynthesis activity and resistance to the bleaching herbicide norflurazon. Plant J 1993;4:833–40.
21. Guerinot M. The Green Revolution strikes gold. Science 2000;287:241–3.
22. National Research Council. Recommended dietary allowances. Washington, DC: National Academy Press, 1989.
23. de Pee S, West CE, Permaesih D, Martuti S, Muhilal, Hautvast JGAJ. Orange fruit is more effective than are dark-green, leafy vegetables in increasing serum concentrations of retinol and β-carotene in schoolchildren in Indonesia. Am J Clin Nutr 1998;68:1058–67.
24. Bouis HE, Graham RD, Welch RM. The Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project: justification and objectives. Food Nutr Bull 2000;21:374–81.
25. Raboy V. Low-phytic-acid grains. Food Nutr Bull 2000; 21:423–7.
26. Garcia-Casal MN, Layrisse M, Solano L, Arguello F, Llovera D, Ramírez J, Leets I, Tropper E. Vitamin A and β-carotene can improve nonheme iron absorption from rice, wheat and corn by humans. J. Nutr 1998; 128:646–50.
27. Graham RD, Rosser JM. Carotenoids in staple foods: their potential to improve human nutrition. Food Nutr Bull 2000;21:404–9.
28. Smith JC. The vitamin A–zinc connection. Micronutrients and agriculture. Washington, DC: Federation of American Scientists 1996;1:16–17.

Biotechnology and agriculture in today's world

Ronald L. Phillips

Abstract

The application of biotechnology, in terms of using the full range of scientific biological information available, is in its infancy. Although there are concerns being raised by the public that need to be carefully addressed, farmers are adopting the new technologies at an unprecedented rate, and the pipeline is full of new products of more obvious benefit to the consumer. Biotechnology will unlock some of the genetic variation available in the extensive genetic resource collections. Conventional breeding technologies require the crossing of these exotic collections, thus introducing many unwanted genetic traits. Biotechnology will allow the transfer of less than the whole genome, thus allowing easier utilization of these rich genetic resources. The application of molecular genetic markers is efficient for the backcrossing of single-gene traits and will become increasingly important for more complex traits such as those of quality protein maize, where modifier genes play a prominent role. Genomics—the study of the whole genome—is providing unprecedented information useful for the genetic manipulation of crop species. Understanding the structure and function of every gene in a plant will lead to many innovative applications. DNA chip or microarray technologies will allow every gene to be monitored. Comparative mapping indicates great similarity among broadly related species and indicates that genomics knowledge for rice and other model species will be quite informative. With respect to the improvement of human nutrition, a database on nutritional genomics related to crop plants would allow even greater progress than can be made with conventional techniques.

Human knowledge is doubling every five years, according to remarks by US President Clinton [1] at the American Association for the Advancement of Science meetings. He also indicated that the scientific literature is increasing at the rate of about one million publications per year. Gilbert indicated that DNA information is going up by a factor of 10 every five years [2]. This suggests that we all have the daunting task of keeping abreast of recent developments in science, and especially in molecular breeding. This vast increase in knowledge also allows us to predict that the application of science in agriculture will rapidly increase in the future.

Consumer reaction to the first generation of transgenic crops is not enthusiastic, even though farmers have rapidly adopted the technology. The consumer sees no direct benefit in the cost or quality of food from the early transgenics, which mostly possess traits such as insect or herbicide resistance. However, second-generation transgenic products will include improvements in traits such as oil, protein, micronutrients, vitamins, and anticarcinogens. These products probably will be perceived by the consumer as more worthwhile. The research pipeline is full of new products that address various nutritional and environmental needs [3–6].

Tremendous diversity exists in the crops grown around the world. Biotechnology promises to allow more efficient detection and utilization of this variability. Presently, such diversity is difficult to utilize, especially in more mature breeding programmes. When a cross is made between a useful line carefully bred to possess many important traits and an unimproved germplasm source, the hybrid receives 50% of its genes from each parent. The statistical probability of recovering a useful line in the progeny of the cross is quite low. The use of biotechnology to transfer less than the whole genome from the unadapted line may prove quite helpful.

One of the internationally important success stories of breeding for improved nutritional quality is that for quality protein maize (QPM) developed at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT). Vasal [7] has shown that populations homozygous for the opaque-2 (*o2*) gene

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can be selected for improved seed and plant quality traits—including yield—while maintaining high lysine levels. This is a laborious but highly successful process; molecular marker tagging of the modifier genes of *o2* may be a way that biotechnology can increase the efficiency of the process. If the efficacy of marker-assisted selection continues to be enhanced, as expected, the plant breeder may be able to simultaneously manipulate more traits than by strictly conventional breeding methods. This aspect of biotechnology should increase the efficiency of introducing various nutritional traits into the breeding programme.

Concerns over the application of biotechnology in agriculture must be tempered by the recognition that its utilization is in its infancy. For example, even if one believes that maize pollen expressing the *Bacillus thuringiensis* (Bt) toxin will have an ecological effect on the monarch butterfly, scientific methods can be employed that will preclude expression of the toxin in new hybrids. Another example is the concern over the use of antibiotic resistance as a selectable marker, resulting in transgenic products carrying this gene. Transgenics in the future will not carry such genes, because other selectable markers are already available.

Genomics is the study of the structure and function of all genes in an organism. Today's biotechnology applications will be improved upon as more information is garnered on the genomics of crop plants. This represents a major paradigm shift away from the study of one gene at a time to the simultaneous study of every gene. Information on the structure of all genes in an organism is available today for at least 100 microorganisms. The rough blueprint for the entire human genome will be available in 2000. *Arabidopsis* has become a model species for plant science research. This is because it has the lowest amount of DNA of any plant species and produces a generation (seed to seed) within 60 days. Several methods are available to manipulate and study the species. Considerable information on nutritional genomics is being generated by using *Arabidopsis* [8]. The entire DNA sequence of the genome of *Arabidopsis* will be available by the end of 2000. The entire rice genome may be finished within three to five years. Rice has become the pivotal cereal species to which all others are compared, because it has the lowest amount of DNA among the cereals [9]. Although the entire genome of corn is not being sequenced at the present time, the partial sequence of 50,000 genes will be available in 2000.

The ultimate goal of genomics is to understand the structure and function of every gene in an organism. The US National Science Foundation recently adopted a goal of understanding the function of every plant gene by the year 2010 [10]. Several technologies will be employed in order to achieve this goal. One technology involves DNA chips or microarrays that allow thousands of genes to be studied at one time. For example, the genome of yeast has been completely sequenced, and we now know that there are 6,100 genes that encode proteins of at least 100 amino acids in length. DNA chips have been used to determine which genes are expressed under one growth condition (glucose supplementation) or another (no glucose), or both. With regard to agricultural applications, experiments will undoubtedly be designed to determine which genes are turned on or off under such conditions as drought versus non-drought. The DNA chips will allow scientists to identify which genes are in a pathway, the coordinant expression of genes [11], and many other features of gene behaviour. Our ability to understand and manipulate complex traits—those controlled by many genes—will be greatly enhanced by this technology. The genomics approach should be especially useful in agriculture, where most traits, such as yield, are complexly inherited. In addition, DNA similarities of broadly related species [9], in terms of gene content and gene order, allow the extrapolation of genetic information from one species to another. These evolutionary relationships, now recognized more than ever before, will increase the value of the genetic information, especially as it relates to complex traits.

Much of the germplasm, such as recombinant inbred lines (RILs) representing highly homozygous derivatives of F_2 plants, will be useful for deciphering the genetics of complex traits. For example, RILs sometimes still possess heterozygosity at certain loci associated with complex traits. These lines can be self-pollinated to derive near-isogenic lines (NILs) that differ only in their allelic constitution at a specific locus. Demonstrating a difference in the complex trait of interest between the NILs with different allelic forms of the gene provides verification of the marker–trait association. These NILs also will prove valuable in using DNA chips or microarrays for identifying the genes affecting a trait. Development of such powerful genetic materials for studying nutritional traits will be a direct benefit of the CGIAR Micronutrients Project [12].

One goal of today's agricultural genetics is to identify DNA segments that co-segregate with traits of interest. In our research with oats [13], we have found that a DNA segment encoding acetyl Co-A carboxylase associates with the oil level of oats. Approximately 50% of the variation in oil can be accounted for by this genetic region. This finding may allow the identification of high-oil oat lines by using seedling tissue. Another approach to identify co-segregating markers is to examine backcross lines. If a DNA difference associated with one of the two parents is seen in an advanced backcross line, one can assume that the marker will co-segregate with the trait. Another example relates to lines that possess high levels of the amino acid methionine [14]. These can be readily identified by virtue of their carrying the DNA polymorphism donated by the high-methionine parent.

A database with nutritional genomic and related germplasm information would be extremely useful. One of the powerful aspects of Internet information is that it can be assessed anywhere in the world. Electronic communication and data storage and analysis are essential for keeping up with the extensive flow of information. The Consultative Group for International Agricultural Research (CGIAR) Micronutrients Project, for example, would benefit from the creation of a web site posting current data from the various participants.

Biotechnology is one way of making better use of our biodiversity heritage, either by providing the means to more effectively identify and transfer genes from exotic materials or by gene transfer from other organisms. Interestingly, the high-iron, high-vitamin-A rice recently reported [15] involved the transfer to Japanese white rice of genes from five organisms. The enhancement of β-carotene resulting in yellow rice derived from the transfer of specific genes from bacteria and the daffodil, while the iron improvement came from genes of a fungal species, French bean, and basmati rice.

In the end, the fruits of biotechnology are encapsulated in the simplest technology of all—the seed.

References

1. Clinton W. Catalyzing scientific progress. Editorial adapted from presidential speech given at the AAAS Annual Meeting, 13 February 1998, in Philadelphia, Pa, USA. Science 1998;279:1111.
2. Cohen J. The genomics gamble. Science 1997;275: 767–772.
3. Munson RD. Impact of biotechnology on the fertilizer industry. Norcross, Ga, USA: Potash & Phosphate Institute/Potash and Phosphate Institute of Canada/ Foundation for Agronomic Research Technical Bulletin 1999 (1).
4. Grusak MA. Genomics-assisted plant improvement to benefit human nutrition and health. Trends Plant Sci 1999;4:164–6.
5. Grusak MA, DellaPenna D. Improving the nutrient composition of plants to enhance human nutrition and health. Annu Rev Plant Physiol Plant Mol Biol 1999;50:133–61.
6. Datta S, Bouis HE. Application of biotechnology to improving the nutritional quality of rice. Food Nutr Bull 2000;21:451–6.
7. Vasal SK. The quality protein maize story. Food Nutr Bull 2000;21:445–50.
8. DellaPenna D. Nutritional genomics: manipulating plant micronutrients to improve human health. Science 1999;285:375–9.
9. Moore G, Devos KM, Wang Z, Gale MD. Grasses line up and form a circle. Curr Biol 1995;5:737–9.
10. Malahoff D, Bagla P, Stone R, Mervis J, Kondro W. Science Scope: 2010 or Bust. Science 1999;284:25.
11. Somerville C, Somerville S. Plant functional genomics. Science 1999;285:380–3.
12. International Food Policy Research Institute. CGIAR Micronutrients Project. Update No. 1. Washington, DC: IFPRI, 1996,1–4.
13. Kianian SF, Egli MA, Phillips RL, Rines HW, Somers DA, Gengenbach BG, Webster FH, Livingston SM, Groh S, O'Donoughue LO, Sorrells ME, Wesenberg DD, Stuthman DD, Fulcher RG. Association of a major groat oil content QTL and an acetyl-CoA carboxylase gene in oat. Theor Appl Genet 1999;98:884–94.
14. Olsen M. Genetic analysis of whole-kernel methionine in maize. Doctoral thesis, University of Minnesota, St. Paul, Minn, USA, 1999.
15. Gura T. New genes boost rice nutrients. Science 1999; 285:994–5.

Household-level economic and nutritional impacts of market-oriented dairy production in the Ethiopian highlands

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Abstract

Previous farm-level studies have shown that adopting improved feeding and management strategies improves livestock productivity and, in particular, increases the milk production and income of resource-poor smallholder mixed-crop and livestock farmers. This paper analyses the impact of the introduction of crossbred cow and improved feeding and management technologies in the Ethiopian highlands in terms of direct changes in household income, patterns of food and non-food expenditure, and caloric intake.

Using a recursive econometric model that takes into account the seasonal variability of consumption patterns, the analysis indicates a positive relationship between household income and adoption of the improved dairy technologies. The incremental increase in household income translates directly into higher expenditure on food and non-food items. Caloric intake is also positively related to adoption of crossbred cows and improved feed technologies. This indicates the significant role that improved smallholder livestock technologies can play in improving food security and nutrition as well as alleviating poverty.

Introduction

Improving human nutrition, including micronutrient status, is a critical element in achieving food security. Interest is mounting in food-based approaches (dietary change) for combating macronutrient and micronutrient deficiencies; food-based approaches are often more sustainable than supplementation [1]. Increased consumption of livestock and dairy products can make a unique and critical contribution to human nutrition, because of low levels of animal and fish consumption among the poor and the relatively high bioavailability of minerals and vitamins contained in animal products. Consumption of animal products can also increase the bioavailability of minerals and vitamins in plant foods consumed at the same meal.

Market-oriented dairy technology research carried out by the International Livestock Research Institute (ILRI) and its partners aims to develop and diffuse crossbred cow technologies for increased milk and meat production that can be adopted by resource-poor smallholder peri-urban farm households. The successful introduction of crossbred dairy cows requires complementary technologies adopted on the farm, including improved cattle management, feed production, and feeding systems. The technologies developed in Ethiopia are expected to increase the productivity and sustainability of the production systems surrounding Addis Ababa, but they are suitable for resource-poor smallholder mixed farming systems in peri-urban areas of other developing countries.

The introduction of crossbred cows and complementary feed and management technologies for increased dairy production results in commercialization of smallholder farms. Milk in peri-urban areas is a cash crop, and integration into the market occurs. Such intensified, market-oriented dairying has the potential to make smallholder systems more viable and sustainable. The introduction of these technologies substantially raises milk production and incomes where development efforts are market-oriented and demand-driven.* When market-oriented dairying is introduced, the household may consume some of the milk. The increased income from milk sales may also be spent on more and better quality food and result in improved nutrition and health. Consumption of more dairy products usually has a positive effect on human nutrition and health [1].

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The objective of this paper is to quantify the links between the adoption of new dairy technologies, increased household income, expenditure on food and non-food, and improved human nutrition as measured by caloric intake in the Holetta area of Ethiopia.

The farming system

The study site is located in the Ethiopian highlands about 40 km west of Addis Ababa, in the vicinity of a small town called Holetta. The altitude of the research area is about 2,600 m above sea level. The average annual rainfall is 1,100 mm, with mean daily temperatures under 20°C. The main rainy period, known as the *meher* season, starts in mid-June and continues to September. The short rains (*belg*) from February to April break up the soil. The farmers in Holetta depend on the *meher* rains to plant crops. The farming system in the study area is classified as a mixed-crop and livestock system, with livestock playing an important role for provision of food (milk and meat), draft power, and dung, which is used for fertilizer and fuel.

The Holetta area is characterized by variable soils, with a predominance of red-brown soils with a low water-holding capacity on the slopes and poorly drained, heavy, dark clay soils (vertisols) in the valleys. Three types of soils can be identified on household plots: vertisols, light and mixed upland soils, and heavy upland soils with vertisol properties. The average household owns about 0.35 hectares of vertisol land, 0.95 hectares of the light mixed upland soil land, and 0.95 hectares of the heavy upland soil land. In Ethiopia land is distributed in such a way that farmers receive separate plots of each of the three major land types. In addition, the household has access to communal grazing resources and may own about a hectare of grazing land.

Farmers produce a wide range of cereal and legume crops on small parcels of land. The production is geared towards satisfying household food requirements as well as provision of feed in the form of straw and hay for livestock. The main crops are barley in the *belg* season and wheat, teff, oats, and horse beans in the *meher* season. Other minor crops include field peas, chickpeas, linseed, sorghum, and rapeseed. Farmers usually use manure, urea, and diammonium phosphate for soil fertility management. These inputs are used either individually or in combination, depending on availability, type of soil of the plot, and the crop grown.

Beside crops, the household keeps a herd of animals, mainly consisting of dairy cows, at least two oxen for plowing, heifers, bulls, goats, sheep, and chicken. Because of the dependency on animal traction for crop production, keeping at least a pair of oxen and a follower herd (heifers and bulls) for replacement is necessary, despite the feed shortage. To ease the feed shortage, dairy-draft crossbred cows and adoption of on-farm forage production are encouraged. This technology allows the farmer to reduce the herd size while maintaining the capacity for both animal traction and milk production. However, farmers are reluctant to use crossbred cows.

Holetta is one of the areas where crossbred cows were introduced to increase dairy production to meet the increasing demand of the neighbouring urban areas and to improve farmers' incomes and nutrition. However, the practice of growing fodder crops for animals is rare, and there is an acute shortage of the high-quality feeds necessary for maintaining crossbred cows. Some of the newly introduced feeds intended to alleviate this problem include fodder beet, oat-vetch intercrop, and leguminous trees.

The empirical econometric model

This study addresses the impact of crossbred cows and feed technologies, first through changes in household patterns of production and incomes. Higher incomes, in turn, allow higher food expenditures and thus greater caloric intakes, indicating better access to food and improved nutrition; and higher expenditures on non-food, indicating better access to private health care as well as a demand stimulus for labour in the non-farm and service sectors. These issues and outcomes are modeled as part of the farm household's utility function, following Bouis and Haddad [2], Behrman and Deolalikar [3], and Kumar [4].

Let X_i ($i = 1,2,\ldots, 5$) define subsets from the vector of relevant household, farm, and area characteristics that influence adoption, expenditure, and consumption decisions. Household socio-economic characteristics include education, share of farm income in total income, family size, and age and sex of the household head. Among farm characteristics are farm area, access to extension services, and proximity to market. The following system of recursive equations captures the direct and indirect impacts of crossbred cow technologies:

Income equation:

$$Y = f(A, X_1, d_t) \tag{1}$$

Food expenditure equation:

$$C_f = (Y, X_2, d_t) \tag{2}$$

Non-food expenditure equation:

$$C_{nf} = f(Y, X_2, d_t) \tag{3}$$

Caloric intake equation:

$$I = f(C_f, X_3, d_t) \tag{4}$$

where Y = the household cash income, which includes sale of farm products and off-farm income

A = the number of crossbred cows owned by the household
X_i = a vector of relevant exogenous variables affecting income, food expenditure, non-food expenditure, and caloric intake
C_f & C_{nf} = respectively, expenditure on purchased food and non-food (including farm inputs)
d_t = a seasonal dummy variable
I = the per capita caloric intake

Household income here does not include the value of all farm output that is consumed by the household and is not marketed. Similarly, expenditure on food does not include the value of food produced on the farm, but only that purchased. However, caloric intakes do include food from all sources, purchased and non-purchased.

In the above system of equations, X_i defines the relevant subset of exogenous variables such that the equations are fully identified. Because of the likelihood of the simultaneity of some of the right-hand variables and the dependent variable, variables on the right-hand side of each individual equation may be tested for simultaneity by using Hausman's test [5] at each stage in the system. If the test rejects the null hypothesis of no simultaneity, an instrumental variable technique is used.

Source of data

The data for this study were provided by a collaborative dairy technology project involving the Ethiopian Agricultural Research Organization (EARO), and the ILRI. One major objective of the project is to develop technologies to enable resource-poor smallholder mixed-crop and livestock farmers to participate in market-oriented dairying. Another major objective is to test the use of crossbred dairy cows for traction, as well as milk production.

Pairs of crossbred dairy cows were introduced on 14 farms in Holetta in 1993, half for milk production only, and half for traction as well as milk production. In 1995 and early 1996, 120 more crossbred cows were introduced into an additional 60 households that were all using the cows for traction in addition to milk production and breeding. Willingness and ability to pay the initial fixed cost and the costs of maintaining the crossbred cows were the major criteria used for selection of the participating households. Although the initial 14 farmers were relatively rich, the last 60 farmers were selected from a list of farmers in three wealth groups: poor, medium wealth, and rich (table 1). Sixty control households using traditional practices of local Zebu cows for milk production and oxen for traction were included in the household surveys beginning in mid-1995. The number of control farmers in each wealth group is roughly equal to the number of crossbred cow owners in the same wealth group. Within each wealth group, participating and control households were comparable, selected on the basis of the same criteria.

The sample used in the analysis reported here consists of 84 farm households. These households include both those that were using the new technologies and those following traditional practices. Data collection carried out in 1997 included land use, labour allocation and activity times, draught power use and source, input use, output use and price data on a biweekly basis.

Households were visited monthly to obtain a recall of food intake for the previous day. The quantities of the main ingredients used for various recipes were recorded at the household level, as well as the numbers of persons consuming this food. The per capita average caloric intake was then calculated by summing the calorie content of the ingredients, netting out leftovers, and dividing by the numbers of people eating. Caloric intake was averaged for three days (one per month) to calculate the quarterly average intake used here.

The market-oriented dairy technology provides mainly milk but also provides butter and cheese, which can have significant impacts on the nutritional and health status of children. Members of households with crossbred cows on average consumed 17% more

TABLE 1. Average household family size and holdings of land and livestock according to wealth group

Wealth group	No. in household	Farm area (ha)	Livestock (TLUs)[a]
Crossbred cow owners (adopters)			
Poor	6.00	1.77	5.94
Medium	4.71	2.79	8.27
Rich	7.06	3.50	11.93
Non-adopters			
Poor	5.85	1.75	4.39
Medium	6.95	2.00	7.97
Rich	8.71	2.88	10.37

Source: ILRI nutritional survey in Holetta, Ethiopia, 1997.
a. TLU, Tropical Livestock Unit.

calories, 24% more fat, and 13% more protein than members of households owning non-crossbred cows. The households with crossbred cows spent about 7% more on food purchases, and in addition, they allocated more land to growing high-protein pulses and consumed about 30% more pulses (tables 2 and 3).

Results and discussion

The results reported here are preliminary results, and more refinement is under way to include other explanatory variables in the equations. Although we do not anticipate major changes, the magnitude of some of the coefficients reported here and their levels of significance may change.

The relationship between per capita income and adoption of crossbred cows and improved feeds is presented in the first column of table 4. In this regression equation, per capita income is a function of the number of crossbred cows owned expressed in tropical livestock units (TLUs), household size, dependency ratio, farm area, and proportion of arable land owned by the household. These variables reflect the resource base of the household. In addition, travel time to the nearest market, use of fertilizer, use of crossbred cows for traction, and three dummy variables to capture

TABLE 2. Average monthly income and expenditures of households with and without (control group) crossbred cows

Variable	Crossbred cow owners	Control group
Total monthly income (Birr)[a]	225.0	131.0*
Per capita food expenditure	14.9	12.4*
Per capita non-food expenditure	129.6	67.8*
Farm inputs per household	41.4	28.1*

Source: ILRI nutrition survey, 1997.

* $p < .05$.

a. 8.10 Birr = US$1.

TABLE 3. Average daily intake of selected nutrients by households with and without (control group) crossbred cows

Intake	Crossbred cow owners	Control group
Calories (kcal)*	2,332.0	1,959.0
Fat (g)*	19.6	15.8
Protein (g)*	70.3	62.1
Carbohydrates (g)	458.6	438.8
Retinol (μg)*	38.8	27.1
Iron (μg)*	74.2	65.6

Source: ILRI nutrition survey, 1997.

* $p < .05$.

TABLE 4. Parameter estimates of relationships between income, food expenditure, non-food expenditure, and caloric intake

Dependent variable[a]				
Variable	Income	Food expenditure	Non-food expenditure	Caloric intake
1st quarter (Jan–Mar)	0.7987*	0.4843*	−0.0379	0.2511*
2nd quarter (Apr–Jun)	0.8409*	0.6961*	0.5170*	0.2941*
3rd quarter (Jul–Sep)	0.5573*	0.6439*	0.5334*	0.2049*
No. of crossbred cows (TLUs)[b]	0.0643*	—	—	0.0236*
Use of crossbred cows for traction (yes/no)	0.0329	—	—	—
Farm area[a]	0.6762*	—	—	—
Cereal area[a]	—	—	—	0.2991
Pulse area[a]	—	—	—	0.1405
Travel time to market[a]	−0.0009	−0.2196*	−0.2589**	—
Household size[a]	−0.1994*	−0.1052*	0.0066	−0.0426*
Dependency ratio[a]	−0.0304	−0.0875**	−0.5434	−0.2240
Proportion of good land	−0.0108	—	—	—
Fertilizer use	−0.0002	—	—	—
Predicted income[a]	—	0.1885*	1.0069*	—
Food expenditure[a]	—	—	—	0.8530
Farm income share[a]	—	−0.3614*	−0.3865*	—
Knowledge, attitude, and practices[a]	—	0.2932	0.1473	0.0146
Constant	3.1701*	3.6331*	0.2734*	7.4918*
R^2	0.334	0.356	0.324	0.305

a. Variables defined in natural logs.

b. TLU, Tropical Livestock Unit.

* Significantly different from zero ($p \le .001$).

** Significantly different from zero ($p \le .005$).

the seasonal variability of income are included. Variables such as age and education of the head of the household, usually used to explain adoption decisions of the households, were omitted here because of the statistically significant correlation between these variables and household size.

The regression results show that ownership of crossbred cows and farm area are the principal positive determinants of per capita income in the study area. This is not surprising, since ownership of crossbred cows translates directly into higher milk production and marketed surplus, and land area is an indicator of marketed surplus of farm products. There is also significant seasonal variation in per capita income. Income is usually higher following harvest in the first quarter of the year.

With proper management, milk production per crossbred cow can increase to five to seven times that of traditional cows. The total monthly income of adopting households is 72% higher than that of non-adopting households (table 2). However, not all of this difference can be attributed to adoption of the technology. Other differences between adopters and non-adopters, such as farm size and household size, are important determinants of the income of farming households.

Also shown in table 4 is the estimation of two second steps in the recursive model, the relationship between per capita expenditures on food and non-food as functions of predicted income, household size, dependency ratio, travel time to the nearest market, and share of farm products (crops) in total income and three seasonal dummy variables. In addition to usual household needs, such as clothes, health care, and social expenditure, non-food expenditure includes farm production expenditures, such as improved seeds, fertilizer, feeds, and tools. Because of the detected endogeneity, the predicted per capita income from the above income relationship rather than the observed income is used here as an explanatory variable

Predicted income is positively related to both types of expenditure (table 4). This indicates that the incremental increases in income, resulting from adoption of the dairy technology, translate directly into consumption of higher quantities of food, food of better quality, or both, as well as higher levels of expenditure on non-foods. The per capita expenditures on foods and non-foods by adopting households exceed those by households without crossbred cows by 20% and 91%, respectively, although, again, only part of the difference can be attributed to the adoption of crossbred cows.

Per capita caloric intake is predicted as a function of the number of crossbred cows owned by the household, area allocated to cereal and pulses, household size, dependency ratio, food expenditure, nutritional and health knowledge, and attitudes and practices of the mother, in additional to seasonal dummies. The area allocated to cereals and ownership of crossbred cows have positive effects on total caloric intake. Adopting households consume 19% more calories than non-adopting households (table 3). Besides calories, these households consume significantly more fat, protein, retinol, and iron. As above, only part of this difference can be attributed to the adoption of crossbred cows.

Generally, the coefficient of determination, R^2, for the above equations is relatively low, ranging from 0.31 to 0.36. This should not be surprising in cross-sectional data from a sample of farmers with substantial variability in management ability, risk aversion, and resources. Variables accounting for some of this diversity, such as managerial capacity and risk attitudes, are not observable and, hence, cannot be included here.

Conclusions

This study investigated the household-level consequences of market-oriented dairy production based on the introduction of crossbred cows and complementary feed and management technologies. These technologies are being tested on the farm in a collaborative dairy technology project involving the Ethiopian Agricultural Research Organization (EARO) and the International Livestock Research Institute (ILRI). The analysis supports our hypothesis that adoption of livestock technologies can improve the food security and welfare of poor households and contributes significantly to the alleviation of poverty through higher food production and income, which translates into higher expenditures on food and non-food and consumption of more energy.

This may improve the nutritional status of the household members. Important questions that future research needs to address are whether higher household income would necessarily mean better nutrition for all household members (e.g., distribution between adults and children and between males and females) and whether diets have gained in quality. The first question requires analysis of the intrahousehold allocation of benefits from the adoption of technology and measurement of micronutrient status (e.g., using blood serum). The second question requires disaggregation of calories into those obtained from livestock, cereals, and non-staple plant foods. Further refinement of the analysis would also include the value of food consumed out of own-production in estimates of household income, as well as total food expenditures.

References

1. Neumann C, Bwibo NO, Sigman M. Diet quantity and quality: functional effects on rural Kenyan families. Kenya Project Final Report, Phase II—1989–1992. Washington, DC: Human Nutrition Collaborative Program Support Program, Office of Nutrition, US Agency for International Development, 1993.
2. Bouis HE, Haddad L. Agricultural commercialization, nutrition, and the rural poor: a study of Philippine farm households. Washington, DC: International Food Policy Research Institute, 1990.
3. Behrman J, Deolalikar A. Health and nutrition. In: Chenery H, Srinivasan TN, eds. Handbook of development economics. Vol 1. Amsterdam and New York: Elsevier, 1988:PAGES.
4. Kumar S. Adoption of hybrid maize in Zambia: effects on gender roles, food consumption, and nutrition. Research Report 100. Washington, DC: International Food Policy Research Institute, 1994.
5. Hausman JA. Specification tests in econometrics. Econometrica 1978;46:1251–71.

Integration of aquaculture into smallholder farming systems for improved food security and household nutrition

Mark Prein and Mahfuz Ahmed

Abstract

Aquaculture production techniques based on the culture of low-value herbivorous and/or omnivorous freshwater finfish in inland rural communities, within semi-intensive or extensive farming systems that use moderate to low levels of production inputs, have supplied large quantities of affordable fish for domestic markets and home consumption. Only recently have studies been initiated to assess the contribution of these integrated agriculture-aquaculture (IAA) systems to improved nutrition and food security, both within IAA farm households and in non-IAA households in the community. The effect can be direct, through within-household consumption and dietary improvement, but also indirect, through sale of fish produce and purchase of other food items (often at lower unit value than the sold fish). In the absence of in-depth studies, this contribution presents key elements from recent experiences in Africa and Asia that indicate where benefits from the integration of aquaculture into farming systems for human nutrition and food security can be achieved, and it recommends future avenues for research to provide much-needed information on the contribution of aquaculture to household nutrition and food security.

Introduction

The nutritional value of fish for the provision of essential nutrients that supplement those supplied by staples is well known [1]. In comparison to bulky staples, fish and other living aquatic resources (LARs) are considered nutrient-dense foods. Aside from protein and fatty acids, fish and other LARs provide highly bioavailable minerals and vitamins. This applies in general to most LARs, but some species have exceptionally high contents of particular micronutrients and are traditionally known for this in developing countries. For example, in Bangladesh, the small species locally known as *mola* (*Amblypharyngodon mola*) has a vitamin A content 20 times higher and a calcium content 10 times higher than commonly cultured fish species [1]. The high bioavailability of nutrients in LARs is an additional advantage for human nutrition. Moreover, the consumption of LARs or meats together with plant foods increases the bioavailability of minerals and vitamins from the latter sources.

The role of fish in human nutrition in developing countries varies from negligible to essential, depending on prevailing biophysical conditions and cultural traditions. Where LARs contribute to a major extent to the nutrition and food security of poor people in subsistence and semi-subsistence households, these originate mainly from the capture of wild fish [2, 3] or from the collection of "wild" fish from ditches and residual ponds towards the end of flood seasons [4, 5]. Aside from small wild fish species, a wide variety of organisms collected and utilized for human consumption, including insects, shrimps, crabs, snails, mussels, frogs, turtles, snakes, and also aquatic plants, are included in the term "living aquatic resources." In several countries, fishing and foraging on aquatic animals are the measure of last resort, even if only on a part-time or seasonal basis, to ensure survival when crops have failed or land resources are inaccessible.

In human diets, the share of animal proteins derived from fish varies from 30% in Asia to 20% in Africa and 10% in Latin America and the Caribbean. These shares have remained fairly stable over the last decades [6]. Within continents, per capita annual consumption varies considerably across countries. Despite an overall increase in the supply and consumption of fish globally, present consumption rates have been declining in many low-income, food-deficit countries and are expected to decline even further with greater overexploitation of inland and marine fisheries and with perceived demographic trends.

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In 24 countries (5 in Asia, 8 in Africa, and 11 in Latin America and the Caribbean) the annual per capita supply of fish food decreased by over 25% in the decade from the late 1980s to the late 1990s [2]. Over a longer time span, the trend in per capita food supply from 1961 to 1990 declined steadily in Bangladesh, Jamaica, Laos, Lebanon, Mauritania, Surinam, and Zambia [2]. In Bangladesh the per capita supply of fish food protein has been more than halved over this period, and it has not been replaced by other sources of animal protein, resulting in a net absolute decline in the intake of animal protein.

Aquaculture, the farming of fish and other LARs, is generally understood to have the potential to provide high-quality protein and micronutrients for human nutrition in developing countries [2]. Considerable increases in aquaculture production and value over the last decade have resulted mainly from gains from a few high-value species such as shrimp and salmon grown in high-input systems, and from the intensified use of large ponds and reservoirs in China and India through stocking and feeding of carp polycultures supplying the domestic market.

In three decades of aquaculture research and extension efforts targeting smallholder producers in developing countries, the main objective has been to induce poor farmers to adopt fish farming as a single enterprise based on a single technology package. These efforts have had limited success in Asia and Latin America and have essentially failed in Africa.

In the past decade, a new farmer-focused systems approach has been adopted in which an aquaculture activity is incorporated into existing farming systems based on the household's resources, capacity, and needs [7, 8]. This diversification, in the form of integrated agriculture–aquaculture (IAA), is only successful when requirements for investments (e.g., pond construction, feeds, and fertilizer) are minimal and the use of existing on-farm and near-farm resources can be optimized, for example, through recycling of residues. The resulting location-specific solutions are highly varied and cannot be simply extended in the form of a standard technology package. A flexible participatory strategy has provided sustainable results when introducing IAA to new-entrant farm households [9, 10].

These small-scale IAA farming systems are perceived to have great potential for providing nutritional as well as economic benefits to the rural poor [11]. Usually targeted at subsistence and semi-subsistence households, the underlying assumption is that most of their production is consumed by the producing household themselves and only a small portion is shared or traded with neighbours, which has been shown for remote locations [12]. In areas of poor transport infrastructure, such as Malawi, most fish is marketed and consumed within the rural communities in the vicinity of the farms [13], a practice that is enforced by social pressure against marketing of fish outside the community.

Only very recently have studies been initiated to assess the actual contribution of aquaculture to household nutrition and food security, the most thorough of which are two studies conducted in Bangladesh [14, 15]. Therefore, this contribution presents elements and available data from recent experiences in Africa and Asia that indicate where benefits from the integration of aquaculture into farming systems for human nutrition and food security can be achieved. Additionally, given the dearth of adequate information, recommendations are made as to future research needs.

Integrated agriculture–aquaculture systems and nutritional benefits

Aquaculture has been successfully adopted by small farmers in situations in which the local demand for fish and other LARs is high because of a decline in supply from naturally fished stocks, a reduction in the per capita supply as a result of human population growth, rising incomes of the middle class, and urbanization. Additionally, where occupational traditions exist for part-time fisheries in various types of freshwaters, the propensity to embark on aquaculture, i.e., husbandry of LARs, is often higher.

In such cases, aquaculture can contribute to meeting the demand through culture of species accepted by consumers, either introduced or indigenous species. Technologies requiring low levels of investment, labour, and material inputs have been developed and adopted by farmers. Management of existing seasonal or perennial water bodies by individual households, but more often by communities, can be the easiest entry level into aquaculture. More contained operations are rice-and-fish systems, in which farmers already have the skill of water management. The management of ponds requires higher levels of experience. With increased levels of management and inputs for greater outputs, the systems also become more vulnerable to mistakes and perturbations (e.g., overfertilization or disease outbreaks at high stocking densities). Experience has shown that low entry-level technologies with modest production provide a low-risk start to a learning curve over several years that new entrants must go through.

With experience, further increases in productivity can be achieved through greater levels of inputs, such as feeds and fertilizers. Additionally, genetic improvements in growth performance and survival of fish can achieve gains within low-input systems, although profits will be higher in higher-input systems [16, 17].

In all of the above situations, it is generally assumed that increased production and accessibility of fish to the poor will also lead to greater consumption, with resultant benefits to nutrition and livelihoods. Direct measurements of the nutritional impact of aquaculture are almost never conducted.

In the following, recent examples of IAA introductions are outlined for Africa and Asia together with elements indicating nutritional and food-security benefits. In the highlighted cases, factors and issues considered to impinge on the nutritional impact of IAA in their respective sociocultural, political, economic, and agroecological environments are presented.

Africa

The modification of natural resource types to better cope with drought situations can lead to improved food security. In Malawi the introduction of ponds has been shown to make farms more resilient under drought conditions through diversification into aquaculture and vegetables, and the capability to produce a crop of marketable vegetables in dried-out ponds, which still contain residual moisture in their bottom soils [18]. Thereby these farm households with IAA systems were able to subsist from their own production and income over the entire drought, while non-IAA farms were dependent on food aid.

In many countries a “hungry season” is common in the annual farming calendar between the depletion of food stores and the main crop harvest. For such defined and recurrent seasons, which are periods of severe household stress, an aquaculture operation can be designed and scheduled to provide fish and vegetables to counter the usual undersupply of essential nutrients. Appleton [19] used a food-consumption calendar with semi-quantitative data as a participatory tool for rapid assessment of community nutrition in Zambia. The results were later used by a development project to design appropriate actions, but further quantifications of fish consumption resulting from interventions were not conducted.

In the southern region of Malawi, a country with severe poverty and malnutrition, there is a high demand for fish within local rural communities, so that fish produced in ponds on smallholder farms is sold exclusively on the farms (essentially to neighbours) by 44% of the farmers, sold on the farms and also in nearby markets (at a maximum distance of 5 km) by 42%, and sold exclusively in markets by only 14% [13]. Farmers face considerable social pressure to market fish within the same community [Brummett RE, personal communication, 1999].

In the central region of Malawi, a household nutritional study on fish-farming and non-fish-farming households over a four-week period found that there was no difference in nutritional status between them: the stunting rates of children (height-for-age < 2 SD of National Center for Health Statistics standards) was 25% in households with fish ponds and 29% in households without fish ponds [20]. Undernutrition of children occurred in 33% of households in both groups.* It was not reported what type of aquaculture system design was used, but fish consumption was very low; only 5% of surveyed households consumed pond-raised fish at least once per month. Fish cultured with the main intention to be marketed, particularly species of larger size, are usually harvested once at the end of the culture cycle. Inadequate knowledge of intermediate harvest methods, using alternative species intended for home consumption, and inappropriate system design are perceived as the reason for minimal own-consumption. These flaws were later addressed in research activities in subsequent projects in other areas, e.g., introduction of small species in polycultures and research into, and training in, intermittent harvest techniques [21].

In Ghana, a study estimated the potential household nutritional impact of the adoption of an IAA component by smallholder farmers in three different agroecological zones with a total of eight different farming systems [22]. It was concluded that considerable economic and nutritional benefits could be gained by the farmers in the inland regions away from the coast, which has an ample supply of marine fish, but with favourable water availability and soil quality to enable pond construction and operation. Required intakes could be met through the inclusion of the fish-vegetable enterprise.

Asia

In Bangladesh, a study found that there are fewer communal water bodies today than there were 16 years ago as a result of conversion of these areas into flood-controlled and irrigated rice-growing fields [4]. These areas are an important source of supply of small indigenous fish, of which there are several dozen species and which are an important part of the diet of the people in Bangladesh. About one dozen species are recognized by rural women to have specific nutritional and also medicinal characteristics. They are caught in floodplains by part-time fishing during the flooded season [1]. Today their availability from floodplains is considerably reduced, as evidenced by their increased unit price in the rural markets. The halved per capita total supply of fish in Bangladesh (a major portion of which consists of small indigenous species caught in the floodplains) is expected to have had subsequent negative effects on household nutrition through reduced dietary diversification and availability of

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* Anthropometry is a blunt instrument for measuring nutritional impacts of increased fish consumption. In any event, there may have been systematic differences between adopting and non-adopting households apart from aquaculture production that might explain observed differences in anthropometry.

micronutrients. Aquaculture experiments on these small species are under way, but their economics are not promising to date.

The culture of fish in rice fields is based on the natural occurrence of various LARs in rice fields, and these have historically played an important role in supplying protein and micronutrients to rice-farming households and particularly to landless labour households. In the Philippines, the LARs in rice fields are regarded as common property. By tradition anyone can catch them [23]. Nevertheless, households of rice-and-fish farmers have been found to consume more fresh fish than households without a rice-and-fish operation. Problems often arise from the tradition of common access to LARs in rice fields if fields are intentionally stocked with fish fry at a considerable cost to the farmer; it is socially very difficult to restrict access to the poor in the community on the grounds of this investment alone [23]. In Bangladesh, the benefits of rice-and-fish culture as identified by farmers are primarily as a source of additional income and as additional food for the family [24].

The fish output from existing excavation pits used as small ponds or from newly constructed fish ponds of small farmers in Bangladesh is perceived to be mainly for household consumption and secondarily for cash income [25]. In Quirino Province in the Philippines, a study introducing integrated aquaculture to farm households within the context of forest buffer zone management found that fish grown in ponds were used essentially for home consumption, with few fish given away, owing to the remoteness of the farms from markets and the lack of transport infrastructure [12]. Aside from pond fish, a variety of aquatic organisms, such as snails, bivalves, shrimps, crabs, frogs, and small fish, are caught from rice fields and streams and consumed regularly in the household or as part of meals prepared on site during fieldwork.

The benefits to women-headed households of such aquaculture operations have been found to be considerable, owing to appropriate technology designed in partnership with the women, and have led to substantial improvement of the livelihoods of the women and dependents [26]. On the other hand, the nutritional and economic benefits of the operation of ponds by women's groups may be less measurable [14]. Additionally, in cases where the ponds are not under the group's ownership, a lease may be revoked once the owner recognizes the possible gains, following the example of the successful women's group, as has been frequently the case in Bangladesh.

A study in Kapasia in Bangladesh, in which the impact of an earlier extension effort was assessed five years later, revealed that different improved technologies disseminated to farmers led to different disposal patterns (household consumption of pond grown fish after technology introduction as percentage of total production: carp polyculture 20%, tilapia monoculture 67%, silver barb monoculture 33%) compared with the situation before the new technology was introduced (before intervention, 33% was consumed at home, and the rest was mainly sold).* A one-year household food-consumption study of the impact of the earlier intervention in the same area revealed that households with small farms consumed fish on 80% of the days of the year, whereas those with medium and large farms consumed fish on 86% and 88% of the days of the year, respectively [15]. Households with small farms (0.2–1.0 hectare) consumed 15 kg fish/month or 83 g/person/day, compared with 11 kg (no per capita data given) by landless households (0–0.2 hectare), 15 kg/month or 85 g/person/day by households with medium-sized farms (1.0–3.0 hectares), and 18 kg/month or 96 g/person/day by households with large farms (over 3.0 hectares).** Owners of medium and large ponds tend to sell the majority of their cultured fish, in contrast to owners of small ponds, who consume most of their fish in the household.

Future research

In the past decades, the most significant aspect of the development of aquaculture around the world has been the steady increase in the production of fish species grown on agricultural farms in low-income, food-deficit countries. The polyculture technology has shown the potential to increase the growth rate of supply. Aquaculture production techniques based on culture of low-value herbivorous or omnivorous freshwater finfish in inland rural communities, within semi-intensive or extensive farming systems that use moderate to low levels of production inputs, have supplied large quantities of affordable fish for domestic markets and home consumption [27].

Fish prices and household incomes are important determinants of fish consumption. As a food group, fish tend to have high income elasticities, i.e., fish consumption rises rapidly with income. When fish prices rise, as has happened in Bangladesh, the poor probably cut back on fish consumption in percentage terms more than the rich. Such cutbacks by the poor,

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* Ahmed M, Lorica MH. Improving developing country food security through aquaculture development: socioeconomic and policy issues. Paper presented at World Aquaculture '99, the Annual International Conference and Exposition of the World Aquaculture Society, 26 April–2 May 1999, Sydney, Australia, 1999.

** Sultana P. Household fish consumption and socioeconomic impacts in Kapasia. Paper presented at the Workshop on Aquaculture Extension: Impacts and Sustainability, 11 May 2000, Dhaka. Penang, Malaysia: International Center for Living Aquatic Resources Management, and Dacca, Bangladesh: Department of Fisheries, 2000.

who are already nutritionally stressed, may be serious, although no empirical estimates of lowered nutritional status are available. Raising the incomes of the poor is very much a long-term strategy for increasing fish consumption and overall dietary quality. Lowering fish prices is a possible medium-term strategy if the rate of growth of supply can be increased faster than demand. By concentrating on low-value and/or small and indigenous fish species, which are usually less in demand by high-income consumers, it may be possible to keep the prices of these species down for poorer consumers.

There are several research questions that need be answered before one can see a clear link between the supply of certain types of fish and improvements in the nutritional status of the poor people in the developing countries. Future nutrition analyses should probably concentrate less on nutritional impacts of aquaculture adopters (inevitably a small proportion of the total population) and more on poor consumers (a group that includes poor producers). The most difficult research issue perhaps will be to obtain estimates of the effects of consumption of particular fish species on nutrition (e.g., micronutrient status as measured by blood analysis). At minimum this will require laboratory analysis of various fish species for their nutritional content. It will be important to understand factors driving demand patterns (e.g., price and income elasticities) for specific types of fish. The production potential of various species, of course, is a key issue on the supply side. Fish are part of an overall diet. Research on dietary diversification, trends in food habits, and changes in lifestyles, living conditions, and consumption patterns among the poor and working class in rapidly urbanizing societies will also be useful for recommending investments in fish species and farming systems development for aquaculture that take into account impacts on nutritional status.

References

1. Thilsted SH, Roos N. Policy issues on fisheries in relation to food and nutrition security. In: Ahmed M, Delgado C, Sverdrup-Jensen S, Santos RAV, eds. Fisheries policy research in developing countries: issues, priorities and needs. ICLARM Conference Proceedings 60. Penang, Malaysia: International Center for Living Aquatic Resources Management, 1999:61–9.
2. Kent G. Fisheries, food security, and the poor. Food Policy 1997;22:393–404.
3. Kent G. Fish, food, and hunger: the potential of fisheries for alleviating malnutrition. Boulder, Colo, USA: Westview Press, 1987.
4. Mazumder D, Lorenzen K. Developing aquaculture of small native species (SNS) in Bangladesh: village-level agroecological change and the level of SNS. Naga (the ICLARM Quarterly) 1999;22(3):20–3.
5. Guttman H. Importance of aquatic products to rural households. Poster-paper contributed to the Department for International Development (DFID) Email Conference on Aquatic Resources Management for Sustainable Livelihoods of Poor People, July 2000, DFID/NACA, Bangkok, Thailand. http://naca.fisheries.go.th/dfid. London: Department for International Development, and Bangkok: Network of Aquaculture Centers in Asia, 2000.
6. Food and Agriculture Organization. Agriculture: towards 2015/30. Technical Interim Report. Rome: Global Perspectives Studies Unit, FAO, 2000.
7. Edwards P. Aquaculture, poverty impacts and livelihoods. ODI Natural Resource Perspectives 56. London: Overseas Development Institute, 2000.
8. Lightfoot C, Bimbao MP, Dalsgaard JPT, Pullin RSV. Aquaculture sustainability through integrated resources management. Outlook on Agriculture 1993;22(3):143–50.
9. Prein M, Lightfoot C, Pullin RSV. ICLARM's approach to the integration of aquaculture into sustainable farming systems. In: Devendra C, Gardiner P, eds. Global agenda for livestock research. Nairobi, Kenya: International Livestock Research Institute, 1995:117–25.
10. Brummett RE, Haight B. Research-development linkages. In: Martinez-Espinosa M, compiler. Report of the expert consultation on small-scale rural aquaculture. FAO Fisheries Report No. 548. Rome: Food and Agriculture Organization, 1996:145–69.
11. Food and Agriculture Organization. Agriculture, food and nutrition for Africa: a resource book for teachers of agriculture. Rome: FAO, 1997.
12. Prein M, Bimbao MA, Lopez T, Oficial R. Upland integrated aquaculture–agriculture systems in forest buffer zone management. Final report to GTZ/DENR Community Forestry Project Quirino. Penang, Malaysia: International Center for Living Aquatic Resources Management, 1999.
13. Hesse WWJ. Perspectives of integrated small-scale aquaculture in the Southern Region of Malawi. M.Sc. thesis, Humboldt University, Berlin, Germany, Institute of Applied Animal Sciences, 1998.
14. Bouis H, de la Briere B, Gutierrez L, Hallman K, Hassan N, Hels O, Quabili W, Quisumbing A, Thilsted S, Zihad Z, Zohir S. Commercial vegetable and polyculture fish production in Bangladesh: their impacts on income, household resource allocation and nutrition. Vol. 1: Report. Vol. 2: Tables. Washington, DC: International Food Policy Research Institute, 1998.
15. Thompson P, Sultana P, Nuruzzaman M, Firoz Khan AKM. Fisheries extension evaluation project progress report March 1998 to mid 1999. Penang, Malaysia: International Center for Living Aquatic Resources Management, 1999.
16. Dey M. The impact of genetically improved farmed Nile tilapia in Asia. Aquaculture Economics and Management, Vol. 4, No. 1. Oxford, UK: Blackwell Science, 2000 (in press).
17. Cheftel J, Lorenzen K. An appraisal of the potential uptake of genetically male tilapia by small-scale farmers in Nueva Ecija, Central Luzon, the Philippines:

Final report. London: Imperial College Centre for Environmental Technology, for the Centre for Development Studies, Swansea, Wales, UK, 1999.

18. Noble R. Wetland management in Malawi: a focal point for ecologically sound agriculture. Information Center for Low External Input and Sustainable Agriculture Newsletter 1996;12(2):9–11.
19. Appleton J. Nutrition and RRA (rapid rural appraisal). RRA Notes 8:6-9. London: International Institute for Environment and Development, 1990.
20. Ayoade RB. The role of aquaculture in household food security, nutrition and health status in Central Malawi. In: Costa-Pierce BA, Lightfoot C, Ruddle K, Pullin RSV, eds. Aquaculture research and development in rural Africa. ICLARM Conference Proceedings 27. Penang, Malaysia: International Center for Living Aquatic Resources Management, 1991:52.
21. Brummett RE, Noble RP. Aquaculture for African smallholders. ICLARM Technical Report 46. Penang, Malaysia: International Center for Living Aquatic Resources Management, 1995.
22. Ruddle K, Prein M. Assessing the potential nutritional and household economic benefits of developing integrated farming systems. In: Mathias JA, Charles AT, Baotong H, eds. Integrated fish farming. Proceedings of a Workshop on Integrated Fish Farming held in Wuxi, Jiangsu Province, People's Republic of China, 11–15 October 1994. Boca Raton, Fla, USA: CRC Press, 1997:111–21.
23. Horstkotte-Wesseler G. Socioeconomics of rice-aquaculture and IPM in the Philippines: synergies, potential and problems. ICLARM Technical Report 57. Penang, Malaysia: International Center for Living Aquatic Resources Management, 1999.
24. Gupta MV, Sollows JD, Mazid MA, Rahman A, Hussain MG, Dey MM. Integrating aquaculture with rice farming in Bangladesh: feasibility and economic viability, its adoption and impact. ICLARM Technical Report 55. Penang, Malaysia: International Center for Living Aquatic Resources Management, 1998.
25. Gupta MV, Mazid MA, Islam MS, Rahman M, Hussain MG. Integration of aquaculture into the farming systems of the flood-prone ecosystems of Bangladesh: an evaluation of adoption and impact. ICLARM Technical Report 56. Penang: International Center for Living Aquatic Resources Management, 1999.
26. Bedford M, Mowbray D. Net worth: research with the rural women of Bangladesh. Washington, DC: Consultative Group on International Agricultural Research Gender Program, 1998.
27. Food and Agriculture Organization of the United Nations. State of food and agriculture 1996. Rome: FAO, 1996.

The integrated research approach of the Asian Vegetable Research and Development Center (AVRDC) to enhance micronutrient availability

Mubarik Ali and Samson Tsou

Abstract

This paper describes various activities of the Asian Vegetable Research and Development Center (AVRDC) in enhancing micronutrient availability through increased vegetable supply, improved micronutrient density in vegetables, enhanced micronutrient bioavailability, and recommendations for programmes and policies generated through economic research. Technological, nutritional, and socio-economic research are integrated at AVRDC. Nutrient considerations are incorporated at all levels of research planning, technology development, and dissemination of these technologies to clients. The approach ensures not only greater diversity and improved palatability of food, but also enhanced income and employment to poor farming and landless households and improved gender equity. All these factors are catalysts to improved health as well as faster economic growth for developing economies. To tackle widespread micronutrient deficiencies, future nutritional research should focus on making improved vegetable technologies economically viable under a wider range of economic and ecological environments, while enhancing or, at minimum, maintaining the nutrient density and bioavailability of new vegetable releases. To improve the efficiency of nutritional research, the dollar value of micronutrient enhancement research needs to be quantified and compared for different vegetables and other food items. A methodology for doing this is proposed and illustrated.

Introduction

The Asian Vegetable Research and Development Center (AVRDC) is one of the few International Agricultural Research Centres that integrates nutritional, technological, and socio-economic approaches to improve micronutrient supply through enhanced vegetable production. Micronutrient considerations are at all levels of research planning, technology development, and dissemination of these technologies to clients. This paper summarizes the Center's experiences and achievements.

Why vegetables?

Vegetables are rich in vitamins and minerals. They are the most economically efficient source of micronutrients, in terms of both land required and production cost per unit. For example, Chinese cabbages, onions, cabbages, tomatoes, and sweet peppers produce, respectively, 13, 3, 3, 3, and 2 times more iron than do cereals per unit land per production day. Similarly, Chinese cabbages, cabbages, sweet peppers, mung bean sprouts, and tomatoes are, respectively, 11.4, 3.8, 3.1, 4.8, and 2.8 times more cost-efficient than chicken in supplying iron (data from Taiwan) [1].

Studies have shown a direct relationship between health indicators and vegetable consumption. For example, Bouis [2] found a negative relationship between vegetable consumption and vegetable prices, and a positive relationship between vegetable prices and morbidity rates. Yusuf and Islam [3] found that increased consumption of micronutrient-rich foods from home gardens increased vitamin A availability in Bangladesh and resulted in a lower incidence of blindness in children. Many studies have quantified a negative relationship between cancer and vegetable consumption in relatively affluent societies [4–8]. Thus, vegetable consumption can help prevent human diseases and disorders. By improving the palatability of foods, vegetables also enhance the consumption of other major nutrients.

AVRDC's concept of nutrition: An integrated research approach

Some 17 minerals and 15 vitamins are critical for good health. Of these micronutrients, AVRDC focuses on

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those whose deficiencies affect the largest number of people in the most vulnerable groups, specifically women and children. These include vitamin A, vitamin C, and iron. Other micronutrients, such as folic acid, which comes primarily from vegetables, are also considered.

AVRDC believes that the dietary approach, rather than the medicinal approach, is the most economical and sustainable way to correct micronutrient deficiency. Among foods, vegetables not only are the most economical way to improve micronutrient deficiency, but they also provide diversity in food and make the diet more palatable. Nutritional, technological, and socio-economic research at AVRDC is well integrated to address the problem. The Center works to increase the consumption of micronutrient-dense vegetables, improve the micronutrient content of vegetables, enhance the bioavailability of micronutrients, and make recommendations for programmes and policies (including allocation of AVRDC research resources) based on the economic value of nutrients.

Of the four points listed above, AVRDC considers consumption enhancement to be the most effective way to alleviate micronutrient deficiency. Therefore, like other international centres, the Center's main emphasis is to develop the low-cost technologies that overcome environmental stresses to produce crops of ever-higher yield and ever-improved quality. This research is meant to make vegetables available and affordable to target populations year-round for improved health and increased income and employment.

Since there are more than 120 vegetables to work with, and research resources are limited, choices must be made. Nutrition is the principal factor in selecting vegetables to be researched, and provides a basic framework for technology-enhancement research. The commodities selected are not only rich in nutrients, but also have the potential for increases in production and consumption. Moreover, integration of nutrition research with technology research ensures that agronomic improvements are not achieved at the expense of a crop's nutritive value.

Improving nutrient content is an important research goal. AVRDC's nutrition laboratory works in concert with breeders to screen materials. Such screening has revealed vast variation in nutrient content within

TABLE 1. Nutrient values of vegetables grown in AVRDC home gardens in 1998

Name	Dry matter (%)	Fibre (%)	Sugar (%)	Vitamin C (mg/100 g)[a]	Calcium (g/100 g)[b]	Iron (mg/100 g)[b]	Carotene (mg/100 g)[a]
Amaranth	7–12	10–13	—	4–84	1.7–2.5	15–43	3.6–10.9
Basil	9	—	—	44	—	18	5.8
Carrot	10	—	—	—	—	10	7.1
Chinese kale	8–11	11–13	8–20	93–153	1.3–3.2	15–45	2.4–6.1
Chinese radish	6–8	8–12	14–19	73–133	1.4–2.7	18–42	3.2
Choy-sum	6–9	8–11	13–23	31–104	1.7–2.3	68–107	2.3–5.1
Chrysanthemum	7	—	—	26	—	20	3.5
Common cabbage	5–6	12–13	31–33	52–63	0.7–1.0	9–21	0–0.1
Coriander	13	—	—	137	—	12	6.6
Fennel	5	—	—	9	—	7	—
Indian mustard	6–11	10–13	14–26	62–112	2.0–2.9	6–53	1.5–5.9
Kale	7–8	10–13	—	47–132	1.7–2.4	12–38	2.9–5.8
Kangkong	5–11	13–14	9–26	62–112	1.2–2.9	34–57	2.4–5.9
Leaf-beet	6	—	—	150	—	16	2.9
Leafy sweet potatoes	11	—	—	52	—	18	3.0
Chien-pao-tsai	6	12	18	81	2.2	34	1.9
Mustard	6–7	11–12	—	72–111	1.1–2.0	13–36	3.2–4.8
Non-heading Chinese cabbage	5–7	10–13	12–28	23–112	1.4–3.4	24–69	1.3–3.3
Paitsai	5–7	10–12	—	31–83	1.6–2.7	18–40	1.3–4.2
Pak choi	5–8	8–12	16–26	52–120	1.9–3.4	21–97	2.3–5.0
Peppers	17	—	—	219	—	5	3.3
Rape	7–9	10–13	—	43–90	1.7–2.5	13–43	2.6–5.8
Spinach	7	—	—	40	—	26	4.3
Sweet peppers	5	—	—	62	—	9	0.4
Vegetable soya beans	28	—	—	—	—	12	—

Source: ref. 9.

a. Values based on fresh weight.

b. Values based on dry weight.

vegetable species, which suggests great potential for improvement through breeding (table 1). Moreover, wide variation across species suggest that promotion of nutrient-dense leafy vegetables in the home garden can enhance nutrient availability in the food produced in the home garden.

Although vegetables are rich in micronutrients, the bioavailability of minerals from vegetables is known to be low. The Center's nutrition laboratory is working to understand the reasons for this and at the same time is developing vegetable recipes and methods of food preparation and processing that enhance bioavailability.

Micronutrient research is also integrated with socio-economic research at AVRDC, with the overriding goal of improving the micronutrient supply from vegetables. The socio-economic unit studies consumption patterns, quantifies deficiencies in micronutrient intakes, estimates the nutritional values of different food items, and is working to quantify the nutritive efficiency of diets in terms of their economic value. In general terms, AVRDC works on chillies to enhance vitamin C, leafy vegetables to enhance vitamin A and iron, tomatoes to enhance vitamin A, and mung beans and soya beans to enhance iron and protein. These are major vegetables in many developing countries. Thus, improving their availability should have a high nutritional impact, even though other vegetables might have higher micronutrient contents.

Research to increase vegetable production and the nutrient content and bioavailability of vegetables (agronomic and nutrition research)

Nutrient content analysis

Food-composition tables are widely used in the investigation of the nutritional and socio-economic status of individuals and nations. Breeders and agronomists at AVRDC often use such tables as a reference for variety selection and quality improvement. Important nutrients and quality indicators for leafy vegetables are dry matter, crude fibre, sugar, vitamin A, vitamin C, calcium, and iron. Analytical results on nutrient content are greatly affected by such factors as environment, variety, and even sampling methods, but these factors are seldom considered in the development of composition tables. AVRDC's Nutrition and Analytical Laboratory works to understand how these factors affect the nutrient content of vegetables.

In order to assess sources of variation in vegetable nutrient levels due to season, variety, and field sampling, a study was conducted on 19 lettuce varieties grown at AVRDC during the summer and autumn. The contents of fibre, vitamin A, and vitamin C varied widely by variety but, with the exception of vitamin A content, varied little across seasons (table 2). Dry matter content, however, varied considerably across seasons, as well as across varieties. Other factors, such as harvesting time, cultural practices, and climate, were also found to cause large variability in fibre and vitamin C content.

Since 1984, AVRDC has accumulated data on the vitamin A, vitamin C, and iron contents of vegetables grown in the Center's home garden. The database now contains information on 181 varieties of 70 species.

Mass screening methods

AVRDC has accumulated a wealth of experience in mass screening of crops for nutrient content and eating quality. The methodologies routinely used at AVRDC are ready for transfer to national agricultural research systems. Analysis techniques for other micronutrients, such as iodine and folic acid, will be developed and incorporated into the AVRDC evaluation system.

Since 1984, AVRDC has used near-infrared spectroscopy to mass-screen samples. So far, about 50 calibration equations have been developed and are used routinely. Near-infrared spectroscopy is accurate and cost effective, and it can evaluate many quality traits.

AVRDC's breeding programmes and other units sent 4,109 vegetable samples to the Center's lab for analysis in 1998, on which 21,248 analyses were conducted using near-infrared spectroscopy and/or chemical methods of the Association of Official Analytical Chemists.

TABLE 2. Effect of season, variety, and replication on the nutrient contents of lettuce types

		% of total variance			
Source of variance	Df	Dry matter	Fibre	Vitamin A	Vitamin C
Season	1	37.2	0.1	25.1	3.7
Replication (season)	4	1.1	4.0	1.9	6.1
Variety	18	31.1	43.2	35.3	35.5
Season * variety	7	12.2	5.6	7.2	13.2
Error	53	10.2	46.9	23.3	39.7

Source: ref. 9.

Improving nutrient density

Tomatoes

AVRDC has bred high-β-carotene tomato varieties that are tropically adapted, indeterminate, disease and heat resistant, and suitable for home and school gardens. The screening for β-carotene density and for taste-related characteristics, such as pH, soluble solids, and acidity, as well as colour, was conducted at AVRDC headquarters.

About 180 samples of cherry tomatoes and 510 samples of fresh market tomatoes were evaluated for their provitamin A content and major qualities. The β-carotene contents ranged from 0.4 to 10.0 mg/100 g in the cherry types and from 0.3 to 10.0 mg/100 g in the fresh market types (table 3).

Animal models were used to compare the bioavailability of provitamin A in high-β-carotene tomatoes and regular tomatoes. The study showed that they have the same percent bioavailability, suggesting that the high-β-carotene tomato provides more total bioavailable provitamin A. Fibre and lycopene (present in higher quantities in the high-β-carotene tomato) did not have a negative effect on provitamin A bioavailability.

The average annual per capita consumption of tomatoes in South Asia is estimated to be about 5 kg or 14 g per day. However, a consumption survey in Bangladesh by AVRDC in February 2000 found vegetable growers consuming as high as 50 g per capita per day.

High-β-carotene tomatoes contain up to 10 times more provitamin A than normal tomatoes. A daily 35-g serving of fresh high-β-carotene tomatoes meets the minimum level of 300 μg of retinol equivalents per day recommended by the World Health Organization and the Food and Agriculture Organization [11]. High-β-carotene tomatoes, which are already gaining popularity in Bangladesh, thus represent a part of the solution to acute chronic vitamin A deficiency in that country. However, AVRDC believes that diversity in food consumption, rather than reliance on one or few food items, is the main solution to micronutrient deficiency.

Chillies and sweet peppers

Chillies and sweet peppers are important foods in many countries and are important sources of vitamin A in the form of provitamin A carotenoids. The average annual per capita consumption of fresh chilli in South Asia is estimated to be about 1 kg. To promote consumption, AVRDC has renewed research into developing high-vitamin-A and low-pungency chillies. Chilli germplasm was screened, and the provitamin A levels ranged from 0.5 to 10 mg per 100 g of fresh fruit.

Peppers contain large amounts of vitamin C compared with other vegetables. The estimated vitamin C contents in various pepper varieties ranged from 50 to 200 mg per 100 g of fresh fruit. Peppers are also strong antioxidants.

Estimation of and improvement in bioavailability

Bioavailability (broadly, the nutrients that the body can utilize) has been defined as the percentage of total digested nutrients absorbed and metabolized through normal pathways. Measuring the bioavailability of minerals and vitamins is a challenge, because the amount absorbed depends on the chemical form of the mineral in the food, and because absorption is affected by other ingredients in the food and the rest of the diet. Physiological factors further complicate measurement.

Several methods are used to assess nutrient bioavailability, including in vitro methods and animal and human models. Evaluation systems vary in cost, complexity, and precision and can produce varying results. To generate reliable results efficiently, research-

TABLE 3. Fruit quality characteristics of AVRDC high-carotene tomato lines[a]

Breeding line	Gene	Fruit size (g)	pH	Brix	Colour value	β-Carotene (mg/100 g)	Resistance
Cherry							
CLN2071B	β	21	4.15	4.7	0.45	2.79	TMV, BW
CLN2071J	β	21	4.11	5.2	9.25	4.11	TMV, BW
CLN2071F	β	21	4.20	6.2	0.28	3.81	TMV, BW
CH154 (normal check)	—	10	4.21	6.1	1.40	0.60	—
Fresh market							
CLN1314C	β	184	4.28	4.3	0.79	5.13	TMV, BW
CLN1314F	β	185	4.37	4.4	0.83	6.55	TMV, BW
CLN2112-86-2-10-14-2-0	β	55	4.05	4.3	0.82	4.82	TMV, BW
CLN1310RA	dg	113	4.34	4.1	1.67	1.34	TMV
CL5915-206D4 (check)		100	4.18	4.2	1.65	0.99	TMV, BW

Source: ref. 10.

a. β denotes the β allele for elevated β-carotene content, dg the dark-green allele, TMV resistance to tomato mosaic virus (Tm2a allele), and BW tolerance to bacterial wilt.

ers must choose their evaluation system carefully to suit the samples and experimental purpose. AVRDC uses mainly in vitro dialysis.

AVRDC is investigating how food processing and cooking affect the bioavailability of micronutrients. The Center's main emphasis is on enhancing iron bioavailability. Haem iron from animal sources has much higher bioavailability than non-haem iron from plant sources, although the latter can have higher iron density.

Nearly 50 vegetables were screened for their iron bioavailability by using an in vitro dialysis method. The bioavailability of iron in 37 of 48 vegetable samples was enhanced by cooking (fig. 1). A wide variation in iron bioavailability among fresh and cooked samples was observed, ranging from 0.19% to 33.75%. In both fresh and cooked forms, ginger, spinach, tomatoes, and chilli were found to be good sources of iron. Cooked amaranth, kale, cauliflower, and broccoli were also found to offer plenty of available iron compared with other vegetables tested. Cooked leek flower and pumpkin have somewhat less available iron than the vegetables listed above, but they can be useful in diversifying diets. Lima beans, soya beans, vegetable soya beans, mung beans, and Indian beans contain much more iron than do leafy vegetables, but the bioavailability is low. If the bioavailability of iron in pulses could be doubled, dietary iron status would be significantly improved, especially in areas where pulse consumption is high.

Food items can be divided into four groups with respect to the contents of enhancers and inhibitors of iron bioavailability: high-inhibitor, high-enhancer; low-enhancer, low-inhibitor; low-inhibitor, high-enhancer; and high-inhibitor, low-enhancer. The general principle is that when low-enhancer, low-inhibitor foods are cooked with low-inhibitor, high-enhancer foods, the iron bioavailability of the former group increases, and the total bioavailable iron of the combined cooked food will be higher than the sum of the bioavailable iron in the foods cooked separately. Further increasing the bioavailability of iron in high-inhibitor, high-enhancer foods is usually not considered or even may not be possible, whereas high-inhibitor, low-enhancer foods are avoided because they may inhibit the bioavailability of iron from other foods. AVRDC nutrition research is attempting to group vegetables according to these classifications, so that appropriate combinations can be worked out to enhance their iron bioavailability [10].

In addition to the above principle, the Center always keeps in mind traditional dietary patterns in its efforts to increase iron bioavailability through proper food preparations. Mung bean (low-enhancer, low-inhibitor) is a common food in South Asia, and therefore recipes were developed that combine mung bean with vegetables, such as tomatoes and sweet peppers (low-inhibitor, high-enhancer). Tomatoes can greatly increase the amount of available iron from mung bean. More iron is available when mung beans and tomatoes are cooked together (at a dry matter ratio of 1:1) than when tomatoes and mung beans are cooked separately. Tomatoes were also found to enhance iron bioavailability in soya beans and lima beans. Mung bean recipes with high bioavailability of iron are being tested in South India, where mung bean production is expected to increase as a result of improvements in crop production technologies.

Storing raw tomatoes, spinach, and cabbage overnight at 4°C did not affect iron availability, nor did storing cooked samples for three hours at 4°C. Cooked cabbage was also evaluated after one, two, and three days in storage at 4°C. Cold storage for more than one day was found to reduce the bioavailable iron content of cooked cabbage. This might be due to vitamin C oxidation and the slow reduction of bioavailable iron through interaction with the food matrix.

Evaluation of micronutrient contents has shed some light on the bioavailability mechanism in different vegetables. For example, leafy vegetables were found to generally have low bioavailability of carotenoids,

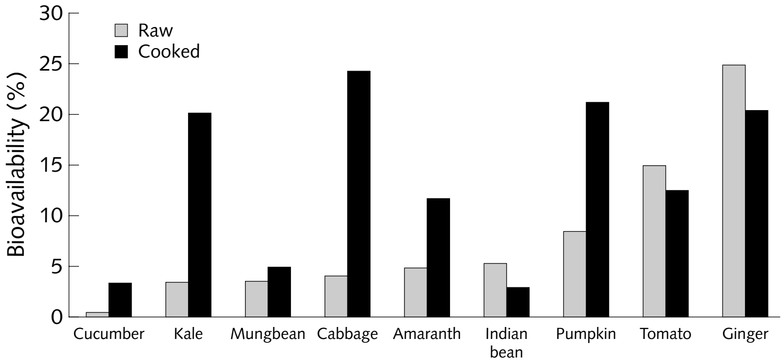

FIG. 1. Effect of cooking on iron bioavailability. Source: unpublished data from the Socioeconomic Unit, AVRDC

probably because of the low digestibility of provitamin A and the inhibitory effect of chlorophylls and non-provitamin A carotenoids. The bioavailability of provitamin A, enhanced by the addition of fat, can also be affected by dietary protein and fibre. Higher protein content improves the bioavailability of vitamin A. An opposite effect was observed with fibre content [12].

Improving production practices

Once a vegetable is selected for research attention, based on several criteria, including nutrition, AVRDC endeavours to enhance its supply through technical, management, and socio-economic research. For example, AVRDC has developed high-yielding, short-duration, disease-resistant, and uniformly maturing varieties of mung bean. The adoption of these varieties by farmers has doubled mung bean production in Pakistan and has substantially improved per capita consumption [13]. There are also indications of success in China, Thailand, Indonesia, and the Philippines. A project is under way to introduce the varieties to the intensive cereal-based production systems of South Asia. Similarly, as a result of collaborative efforts of AVRDC with its national partners, its vegetable soya bean (high in fat and protein) is gaining popularity in various countries, including Thailand and Sri Lanka.

The emphasis is not only on increasing quantity, but on reducing seasonality and annual fluctuations by overcoming biotic and abiotic stresses, especially during the hot, wet off-season. AVRDC develops varieties and management techniques that increase off-season production and reduce production risk. The ultimate goal is to increase year-round vegetable and micronutrient availability to consumers from profitable and sustainable vegetable production systems. AVRDC summer tomato lines, for example, have reduced the seasonality of prices in Taiwan [14].

In terms of crop management, raised beds and crop scheduling are common means used to reduce risk. Grafting is a specialized practice that imparts flood tolerance to tomatoes. Where water is deficient during the dry season, the scope exists to increase planted area and production by using drip-irrigation systems. Other practices, such as shading and mulching (with paper, plastic, composted waste, or fresh residues), are mature technologies in many areas and can be evaluated for suitability in peri-urban ecoregions. Many of these technologies have been described in recent AVRDC annual reports [14–18] and by Kleinhenz et al. [19, 20], Chen and Chen [21], Jaafar et al. [22], and Midmore et al. [23, 24]. These technologies are being tested on peri-urban sites in the Philippines and Vietnam.

Research to increase vegetable consumption and to set research priorities (socio-economic research)

Understanding factors driving demand for vegetables

Regional time-series vegetable production data have been collected by the socio-economics unit. The data cover the areas planted, production, yield, prices, and cost of production of different vegetable species; marketing margins, seasonal availability, and prices of major vegetables in major markets; and international trade and consumption patterns. The information has helped in evaluating deficiencies in vegetable availability, seasonality in availability and prices, annual fluctuation, and trade gaps in Asian countries. Except for East Asia, most Asian countries lack by 40% to 80% the quantity of vegetables required to meet minimum vitamin A and C requirements (fig. 2). Overall, Asia is a vegetable importer. However, South and South-East Asia are net exporters of vegetables, whereas rela-

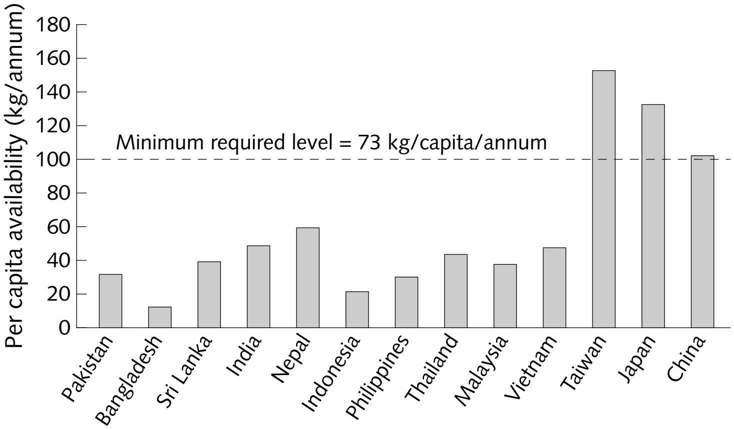

FIG. 2. Availability of vegetables in selected Asian countries during 1993. Source: unpublished data from the Socioeconomic Unit, AVRDC

tively wealthy East Asia imports vegetables [25]. The chance of increasing consumption and micronutrient availability through technological innovation varies across vegetables, depending on, among other things, consumers' preferences. One criterion in selecting vegetables for research is their potential for increased consumption. The socio-economics unit estimates demand elasticities from consumption survey data or reviews elasticities reported in the literature. Elasticities are estimates of percentage changes in quantities consumed for given percentage changes in household income (income elasticities) and in the prices of vegetables and other foods (own-price and cross-price elasticities).

The price and income elasticities of demand, seasonality, and annual fluctuation of AVRDC commodities in table 4 were determined from a survey of the literature. Tomato has high income and own-price elasticities, annual variation in yield, and seasonal fluctuation in prices. Therefore, increasing overall production, extending production in the off-season, and improving yield stability are the objectives of the tomato research programme. On the other hand, income elasticities and seasonality in chilli and eggplant prices are low (although eggplant has relatively high price elasticity), but these vegetables have strong annual fluctuations in yield. Therefore, chilli and eggplant research programmes focus mainly on stabilizing yield. Onion has moderately low price and income elasticities in South Asia, but high price and income elasticities in South-East Asia. Onion yields are relatively stable in South Asia but fluctuate in South-East Asia. More emphasis is placed on improving onion storability than on extending production in the off-season. Chinese cabbage has almost no potential for increased consumption in East Asia, but high-yielding and low-cost technologies could enhance consumption in South-East Asia, and moderate improvements in consumption could be achieved in South Asia. The own-price elasticity for leafy vegetables in urban India (South Asia) is high, whereas the same elasticity in rural India is quite low. The income elasticity is moderate, and there is moderate variation in annual yield and seasonality in prices. The Center has focused on increasing year-round leafy vegetable supply from peri-urban production systems. The high price elasticities of mung beans and soya beans also suggest potential for increased consumption through technological innovation.

TABLE 4. Demand and income elasticities, seasonality in prices, and fluctuation in yield of AVRDC vegetables in South Asia

Crop	Own-price elasticity	Income elasticity	Seasonality (%)	
			Price	Yield
Tomatoes	–0.60	0.40	200	15
Chillies	–0.09	0.10	34	11
Onions	–0.30	0.35	150	4
Eggplant	–0.50	0.20	41	12
Cabbage	–0.41	0.39	114	22
Mung beans	–0.69	0.24	10	5
Soya beans	–0.90	1.00	5	5
Leafy vegetables	–0.60	0.35	50	8
Overall vegetables	–0.60	0.40	143	15

Source: ref. 26.

Vegetables are known for high seasonal and annual fluctuations. These fluctuations are much higher than those of cereal crops [25]. This creates serious yearly and seasonal fluctuations in the supply of micronutrients. Because governments are more concerned with stabilizing the supply of major nutrients, such fluctuations in micronutrient supply receive less attention from policy makers. AVRDC's socio-economics unit also estimates seasonality and annual fluctuation in availability and prices at the regional and country level [25]. The information helps determine research resource allocation. Crops with the potential to reduce fluctuation get higher priority. Technological research is then directed at developing management practices and technological innovation to overcome seasonality.

Estimating the nutritive values of diets in terms of economic value

AVRDC has developed formulas to estimate the relative values of foods. These can be used to set dietary recommendations and research priorities based on the economic value of nutrients, rather than just on nutrient densities.

Relative nutritive values are estimated using the following formula:

$$\text{Relative nutrient value of commodity } i\,(N_i) = (1/m)\sum_{d}^{m} R_d \times B_d\,, \qquad (1)$$

where B_d is the content of nutrient $d\,(1,2,\ldots,m)$ in 100 g of food commodity i, R_d is the relative nutrient cost of nutrient component d, and m is the total number of all nutrients considered important in the analysis. The relative nutrient cost, R_d, is estimated using the following formula:

$$\text{Relative nutrient cost } (R_d) = \sum_{i=1}^{n-z} E_i \Big/ \sum_{i=1}^{n-z} C_{ki} \qquad (2)$$

where C_{di} is the amount of nutrient d provided from the consumption of food commodity i in the diet, E_i is the expenditure by a consumer on commodity i, n is the number of all commodities present in the diet, and z is the number of those commodities that do not contain the dth nutrient.

The relative nutrient value is the value of all nutrients a consumer gains by consuming 100 g of a commodity. A nutrient value–price ratio (n–p ratio or nutritive efficiency) greater than one suggests the nutritive value of the commodity is higher than its cost, and vice versa if the ratio is less than one.

The nutritive value of the whole diet can be worked out by taking the summation of the nutritive value of all individual commodities in the diet estimated at their current consumption level as follows:

$$\text{Nutritive value of diet (NV)} = \sum_{i}^{n} N_i \times X_i \qquad (3)$$

where X_i is the consumption level of the ith commodity in 100 g. The nutritive efficiency of the diet can be estimated as follows:

$$\text{Nutritive efficiency of the diet (NE)} = \text{NV/total expenditure on all food.} \qquad (4)$$

A nutritive efficiency (or *n–p* ratio) greater than one implies that consumers are spending more on more nutritious foods; the opposite is true for values less than one. The nutritive efficiency of the diet can be improved by reallocating the food budget from commodities with low nutritive value (especially those having *n–p* ratios less than one) to commodities with high nutritive values (especially those having *n–p* ratios greater than one). It is important to note that only relative values of these measures are important for policy purposes.

Consumption surveys in Taiwan and the Philippines

To understand food-consumption patterns, the role of vegetables in diets, and the extent of nutrient deficiencies, household consumption surveys have been completed in the northern Philippines and Taiwan, and similar surveys are in progress in central Luzon in the Philippines, northern and southern Vietnam, Laos, Cambodia, and Bangladesh. The 24-hour record method is used; all food items are listed (at the species level), as are prices and the source of the food item. To learn about seasonality in vegetable consumption and nutrient supply, the surveys are conducted four times a year. Micronutrient supply is estimated by using country-specific nutrient content tables.

Vegetable consumption pattern

Vegetable consumption in Taiwan is about three times the Philippine level, whereas rice consumption is about half that in the Philippines. Seasonality in vegetable consumption is more pronounced in the Philippines than in Taiwan.

Micronutrient consumption pattern

Estimates of nutrient availability suggest that the levels of consumption of food energy in the two countries are very similar (table 5). However, the Philippine diet is deficient in vitamin A (since availability is close to the lower range of recommended level), vitamin B_2, and calcium (availabilities are even less than the lower range of recommended levels), whereas the Taiwan diet is deficient only in calcium (availability is less than the lower range of the recommended level). It

TABLE 5. Nutrient consumption pattern per day in the Philippines and Taiwan

Nutrient	Unit	Recommended[a]	Mar–Apr	Jun–Jul	Sep–Oct	Dec–Jan	Overall
Philippines							
Energy	kcal	1,800–2,400	2,059	1,831	1,852	1,869	1,903
Protein	g	45–63	70	67	70	64	68
Calcium	mg	800–1,200	440	470	459	431	450
Iron	mg	10–15	11	10	11	10	11
Vitamin A	RE	400–1,000	473	471	621	518	521
Vitamin C	mg	50–70	73	90	106	75	86
Vitamin B_1	mg	1.0–1.5	1.20	1.23	1.28	1.09	1.20
Vitamin B_2	mg	1.2–1.8	0.99	1.07	1.07	0.90	1.01
Niacin	mg	13–20	23.72	21.70	23.23	21.13	25.04
Taiwan							
Energy	kcal	1,800–2,400	1,926	1,876	1,920	1,992	1,929
Protein	mg	45–63	81	79	80	85	81
Calcium	mg	800–1,200	575	596	584	621	594
Iron	mg	10–15	15	15	15	17	16
Vitamin A	RE	400–1,000	3,056	2,387	2,803	3,393	2,914
Vitamin C	mg	50–70	234	197	233	288	239
Vitamin B_1	mg	1.0–1.5	1.5	1.5	1.6	1.5	1.5
Vitamin B_2	mg	1.2–1.8	1.2	1.2	1.3	1.3	1.2
Niacin	mg	13–20	16.9	16.5	17.4	18.4	17.3

Source: Unpublished data of the consumption survey conducted by the Socioeconomic Unit, AVRDC, during 1998–99 in both Taiwan and the Philippines.

[a] The recommended levels of nutrients were taken from ref. 27. These levels are for males and females above the age of 10 years.

appears that iron availability in the Philippines is close to the recommended level, but actually, most of the iron in the food comes from rice, which has very low iron bioavailability. Moreover, seasonality in vitamin A consumption, especially in the Philippines, is prominent. Seasonality is also prominent in vitamin C availability, but because consumption is above the recommended level, it is not a serious problem.

Nutritive value of diet and vegetables

The nutritive efficiency of the diet was estimated by equation (4). It is higher in the Philippines than in Taiwan. In Taiwan the nutritive value of food is almost equal to the expenditure made on it, while it is much higher in the Philippines. This implies that food expenditure is distributed evenly between commodities of low and high nutritive value in Taiwan, whereas it is biased towards commodities of high nutritive value in the Philippines (table 6).

The *n-p* ratio (or nutritive efficiency) of vegetables was highest in the Philippines, and third after cereals and eggs or milk in Taiwan. This implies that the nutritive value of vegetables is much higher than the budget allocated to them in both countries. It also suggests that in countries with nutritive deficiencies, reallocation of the budget from other food items to vegetables would improve the nutritive efficiency of the whole diet without added cost. For this purpose, individual vegetables with high *n–p* ratio need to be identified for each region, and their production should be enhanced through technological innovations. For example, the dollar value of nutrition is highest in soya beans, English spinach, Chinese mustard, and lady's finger in Taiwan, whereas in the Philippines the value is highest in milk, jute leaves, horseradish, and carrots.

Summary and conclusions

Vegetables are rich and economical sources of micronutrients. AVRDC believes that the dietary approach, making use of vegetables, rather than the medicinal approach, is the most sustainable way to remedy the micronutrient deficiencies suffered by millions of people in developing countries.

To reduce micronutrient deficiencies, AVRDC works to enhance micronutrient density, increase micronutrient availability, and recommend high-nutrient-value vegetables. To achieve these goals, the Center integrates nutritional, socio-economic, and technological research. The key is to increase the economic accessibility of vegetables through technological innovation in vegetable production and marketing. For this purpose, technologies are developed (and tested in farmers' fields) that overcome environmental stresses and increase year-round vegetable supply. AVRDC is able to develop and adapt technologies to overcome environmental stresses. But these technologies are viable only in certain environments. Making these technologies viable in a wider range of economic and ecological environments will remain a challenge and a focus of AVRDC research. In the future, the emphasis of the nutrition laboratory will be on applied research of testing materials, technologies, and recipes for nutritional implications in different regions. The laboratory might also focus on selecting vegetables containing specific health-promoting substances.

Much more socio-economic research needs to be done. Factors affecting the supply and demand of vegetables, and deficiency in supply, need to be identified. Vegetable production generates employment and higher incomes. It engages the most vulnerable part of the labour force: women and children. Despite this, per capita micronutrient availability is insufficient. The production and consumption constraints specific to each crop in different regions need to be identified and prioritized. Moreover, to attract donors' investment in micronutrient research, the dollar value of micronutrient enhancement research needs to be quantified and compared for different vegetables and other food items.

TABLE 6. Nutritive efficiency of major food groups in the Philippines and Taiwan, 1998

	Taiwan			Philippines		
Food group	Market price (US$/100 g)	Nutritive value (US$/100 g)	Nutritive efficiency (ratio)	Market price (US$/100 g)	Nutritive value (US$/100 g)	Nutritive efficiency (ratio)
Cereals	0.1478	0.3263	2.21	0.047	0.078	1.66
Meat	0.4584	0.4382	0.96	0.224	0.163	0.73
Seafood	0.5459	0.3523	0.65	0.168	0.118	0.7
Vegetables and pulses	0.2021	0.2390	1.18	0.047	0.105	2.23
Fruit	0.1856	0.0997	0.54	0.048	0.032	0.67
Eggs and milk	0.1417	0.2670	1.88	0.167	0.185	1.11
Others	0.3931	0.3099	0.79	0.181	0.105	0.58
Whole diet (average)	0.2475	0.2538	1.03	0.080	0.096	1.20

References

1. Ali M, Tsou SCS. Combating micronutrient deficiencies through vegetables—a neglected food frontier in Asia. Food Policy 1997;22:17–38.
2. Bouis HE. The determinants of household-level demand for micronutrients: an analysis for Philippine farm households. Washington, DC: International Food Policy Research Institute, 1991.
3. Yusuf HKM, Islam NM. Improvement of night blindness situation through simple nutrition education intervention with the parents. Ecol Food Nutr 1994;31:247–56.
4. Bueno-de-Mesquita HB, Misonneuve P, Runia S, Moerman CJ. Intake of foods and nutrien ts and cancer of the exocrine pancreas: a population-based case-control study in the Netherlands. Int J Cancer 1991;48:540–9.
5. Shibata A, Paganini-Hill A, Ross RK, Yu MC, Henderson BE. Dietary beta-carotene, cigarette smoking, and lung cancer in men. Cancer Causes Control 1992;3:207–14.
6. Jedrychowshi BW, Boeing H, Popiela T, Wahrendrof J, Tobiasz-Adamczyk B, Kuling J. Dietary practices in households as risk factors for stomach cancer: a familial study in Poland. Eur J Cancer Prevent 1992;1:297–304.
7. Hirayama T. Green-yellow vegetables for human health with special reference to cancer prevention. J Jpn Soc Horticult Sci 1995;63(special issue):965–74.
8. Yu MW, Hseih HH, Pan WH, Yang CS, Chen CJ. Vegetable consumption, serum retinol level, and risk of hepatocellular carcinoma. Cancer Res 1995;55:1301–5.
9. Asian Vegetable Research and Development Center (AVRDC). Annual progress reports for 1998. Shanhua, Tainan, Taiwan: AVRDC, 1999.
10. Asian Vegetable Research and Development Center (AVRDC). Annual progress reports for 1999. Shanhua, Tainan, Taiwan: AVRDC, 2000.
11. Food and Agriculture Organization. Requirement of vitamin A, iron, folate, and vitamin B_{12}. Report of a Joint FAO/WHO expert consultation, FAO Food and Nutrition Series No. 23. Rome: FAO, 1988:25.
12. Asian Vegetable Research and Development Center (AVRDC). AVRDC Annual Report for 1987. Shanhua, Tainan, Taiwan: AVRDC, 1988.
13. Ali M, Malik IA, Sabir HM, Ahmad B. The mungbean green revolution in Pakistan. Technical Bulletin No. 24. Shanhua, Taiwan: AVRDC, 1997.
14. Asian Vegetable Research and Development Center (AVRDC). Annual Progress Reports for 1994. Shanhua, Tainan, Taiwan: AVRDC, 1995.
15. Asian Vegetable Research and Development Center (AVRDC). Annual Progress Reports for 1991. Shanhua, Tainan, Taiwan: AVRDC, 1992.
16. Asian Vegetable Research and Development Center (AVRDC). Annual Progress Reports for 1992. Shanhua, Tainan, Taiwan: AVRDC 1993.
17. Asian Vegetable Research and Development Center (AVRDC). Annual Progress Reports for 1993. Shanhua, Tainan, Taiwan: AVRDC, 1994.
18. Asian Vegetable Research and Development Center (AVRDC). Annual Progress Reports for 1995. Shanhua, Tainan, Taiwan: AVRDC, 1996.
19. Kleinhenz V, Schnitzler WH, Midmore DJ. Diversification and transformation of Asian paddy rice fields to upland vegetable production. Entwicklung und ländlicher Raum 1996;3:23–6.
20. Kleinhenz V, Schnitzler WH, Midmore DJ. High bed systems for off-season vegetable production in the tropics and subtropics. Entwicklung und ländlicher Raum 1995;2:26–8.
21. Chen YW, Chen HB. Year-round vegetable production under simple and movable construction. Research Bulletin of Tainan District Agricultural Improvement Station 1991;27:1–6.
22. Jaafar H, Yusoff E, Kamarudin R. Vegetable cultivation under simple rain shelters in Malaysia. Food and Fertilizer Technology Center of the Asian and Pacific Region Extension Bulletin No. 350: Taipei, Taiwan, 1992:16–26.
23. Midmore DJ, Wu DL, Roan YC. Response of grafted tomatoes to flooded conditions. Sci Agric 1994;42:57–64.
24. Midmore DJ, Roan YC, Wu MH. Management practices to improve lowland subtropical summer tomato production: yields, economic return, and risk. Exp Agric 1997;33:125–37.
25. Ali M, ed. Dynamics of vegetable production, distribution, and consumption in Asia. Publication No. 00-498. Shanhua, Tainan: Asian Vegetable Research and Development Center, 2000.
26. Asian Vegetable Research and Development Center (AVRDC). Annual Progress Reports for 1997. Shanhua, Tainan, Taiwan: AVRDC, 1998.
27. Food and Nutrition Board. Recommended dietary allowances. 10th ed. Washington, DC: National Academy Press.

Commercial vegetable and polyculture fish production in Bangladesh: Their impacts on household income and dietary quality

Howarth E. Bouis

Abstract

Given the low access that women in rural Bangladesh have to productive assets, their crucial role as caretakers, and their high vulnerability to micronutrient deficiencies, numerous non-governmental organizations target women for food-based income-generating activities. Three such programmes were examined, which promote adoption of polyculture fish production (two sites) and commercial vegetable production (one site). The programmes evaluated had income generation—and not better nutrition—as their primary objective. The fish and vegetable technologies were found to be more profitable than rice production, although rice production provided a higher share of total income. On the basis of the evidence collected, there is little reason to believe that adoption of the two technologies has improved the micronutrient status of members of adopting households through better dietary quality. There was no finding of disproportionately high own-consumption of fish and vegetables by adopting households. The impacts on overall household income, although positive, were not strong. The effects of adoption on women's status and time allocation do not change this conclusion.

It is consumers in general who benefit from research, extension, and credit programmes to increase the market supply of vegetables and fish. All other things being equal, increased market supply will lower prices for these foods. Although inflation-adjusted cereal prices in Bangladesh have fallen by 40% over the last 25 years (a remarkable achievement), real prices of lentils, vegetables, and animal products have increased by 25% to 50%. Real fish prices have perhaps doubled. Dietary quality for the poor may be declining over time due to these price effects.

Introduction

Poor dietary quality, that is, low intake of vegetables, fruits, pulses, and animal and fish products, is a primary cause of micronutrient malnutrition. Non-staple foods, particularly animal and fish products, are rich sources of bioavailable minerals and vitamins. Although many non-staple foods are high-status foods, the poor cannot afford these high-energy-cost foods in sufficient amounts in their diets. Their food expenditures are dominated by low-energy-cost, but mineral- and vitamin-poor, staple foods.

In the Bangladesh environment of water-rich flood plains, polyculture production of fish and vegetables, two foods rich in micronutrients, can be very profitable if managed properly, leading to higher incomes for farming households. Increases in income, in turn, may translate into higher expenditures for non-staple foods. In addition, households that take their consumption needs into account in their production and cropping patterns might consume a disproportionate share of their own production.

Numerous non-governmental organizations (NGOs) in Bangladesh are promoting adoption of vegetable and fish pond activities through credit and training programmes targeted at women. The present study examines three such programmes:

» commercial vegetable production (Saturia thana, Manikganj District, referred to below as "Saturia");
» polyculture fish production in household-owned ponds (Gaffargaon thana, Mymensingh District, and Pakundia and Kishoreganj Sadar thanas, Kishoreganj District, referred to below as "Mymensingh");
» polyculture fish production in group-managed ponds (Jessore Sadar thana, Jessore District, referred to below as "Jessore").

The primary objective of the study, stated in general terms, was to undertake a comparison of the differences in the patterns of linkages between agricultural production and nutrition outcomes in adopting and non-adopting households in the three study sites. To achieve this objective, and thus to derive useful

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conclusions for programme and policy implementation, required detailed information on (a) technology profitability and its effect on household income, (b) women's status and decision-making, (c) expenditures for health care and other non-food items, (d) food-consumption patterns and intrahousehold distribution of food, and (e) health and nutrition outcomes. In order to evaluate these programmes, the methodology involved selecting and surveying the following three groups of households in each site: 110 households that were members of NGOs and had adopted the technology (A households); 110 households that were NGO members residing in villages where the NGO had not yet introduced the new technology and that were deemed likely to adopt if and when the new technology was introduced (B households); and a random selection of 110 households from the remaining pool of households in A and B villages (C households). Four survey rounds were undertaken at four-month intervals during 1996–1997 to examine differential effects of technology adoption across seasons. This paper summarizes findings for (a) and (d) above; see Bouis et al. [1] for more information on (a) through (e).

It is important to note at the outset that the specific programmes being evaluated here had income generation—and not better nutrition—as their primary objective. Thus, these programmes may be distinguished from home vegetable garden interventions, in which nutrition education of adopting households is emphasized and specific vegetables that are high in provitamin A content are promoted. Some nutrition education was provided by the NGOs to the survey households studied here. However, nutrition was not emphasized.

How well are the poor targeted?

Across sites, households with more education, better access to land, primarily employed in farming, and with older spouses were more likely to adopt the new technology. In Jessore, 57% of adopting A households fall in the functionally landless category (less than 0.5 acres), as compared with 12% of A households in Mymensingh. Forty-one percent of A households in Mymensingh fall in the medium and large landowning categories (greater than or equal to 2.5 acres), as compared with 13% of A households in Jessore. The ownership distribution for A households in Saturia falls between these two extremes.

The group-managed polyculture fish pond programme in Jessore appears to be the best targeted of the three cases studied, in terms of reaching those households with the least access to land and the lowest value of consumer durables. However, even in this case, the ownership distribution of adopting households is similar to that found among rural households in Bangladesh on average, i.e., adoption does not appear to be skewed towards the poorest of the poor.

Profitability of vegetable and fish pond production as compared with rice

Rice accounts for about 50% of the total area harvested in Saturia, about 85% in Mymensingh, and about 75% in Jessore, so that rice is clearly the predominant crop. Vegetable production accounts for 9% of the area harvested in Saturia. Vegetable production accounts for only 1% to 2% of the total area harvested in Mymensingh and 3% to 4% in Jessore. The number of acres devoted to fish pond production in Mymensingh is about 25% less (however, there is no fallow period) than the number of acres devoted to vegetables in Saturia in absolute terms, but constitutes only 5% of the total area harvested because of larger farm sizes among sample households in Mymensingh. Fish pond areas among sample households are much smaller in Saturia and Jessore.

Feasibility of group-managed fish ponds

In Jessore, in four of nine group ponds surveyed, production was never planned and undertaken by the NGO-sponsored groups themselves. In two of these four cases of non-operation, excavation of ponds was not undertaken at all or was inadequate.* In the two other cases, the NGO groups leased out their ponds as a consequence of intragroup disagreements as to how to operate the pond and share in the output. Of the five ponds that were managed by groups themselves, only three were operated as intended with decision-making, work, and pond output shared among all group members.

In theory, programmes that make productive assets available to groups of women from asset-poor households can be an effective way to raise the incomes of the poor. However, as the above case study demonstrates, such programmes can be fraught with institutional constraints related both to ensuring actual control over the productive assets by the participants and to intragroup disagreements once access is secured. Such problems cannot be eliminated but can be minimized by the active participation in group activities of highly motivated extension officers who are employees of the NGO administering such programmes.

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* Pond owners agreed to long-term leases to the NGO in return for excavation of their ponds. Pond management was then given over to groups of women organized by the NGO.

Profitability of individually owned fish ponds and vegetable production

In Mymensingh, cash profits for A households from operation of family-owned fish ponds on a per acre per month basis were about twice as high as profits from rice production.* For B households, rice and fish pond production were about equally profitable. In Saturia, vegetable production for A and B households was two to three times as profitable on a cash basis as rice production, although this calculation does not take account of fallow time for either crop.**

Even though vegetable production is apparently considerably more profitable than rice production, as indicated above, households devote much more land to rice production than to vegetable production. There are a number of possible explanations. Rice can be grown virtually all year round (subject to availability of water), whereas vegetables do not grow well during periods of heavy rain and hot temperature. Vegetables cannot be grown on land that is subject to flooding (which may be ideal for rice production), or the risk of doing so is too high. Rice can be stored, whereas vegetables must be marketed immediately; thus, vegetable prices are more variable and vegetable production is more risky. Identifying the constraints to expanded vegetable production is an important question that merits further inquiry.

Effects of adoption on household income

Incomes are highly diversified, for example, as shown in table 1 for Mymensingh. Although apparently highly profitable as compared with rice, the two technologies

TABLE 1. Income (taka[a] per capita per month), by source as compared with total per capita expenditures, by household category for Mymensingh

	Household type			
Source of income	A[b]	B[c]	C1[d]	C2[d]
Profits on cash basis				
Rice production	192	198	133	57
Fish pond production	62	36	8	6
Vegetable production	4	3	3	0
Other crop production	35	28	15	6
Livestock	50	42	44	26
Rental of animals and equipment	21	41	24	2
Computed from 24-h recall information				
Value of collected food	18	27	19	27
Value of own-farm fruit	23	17	10	7
Net food transfers in	–10	–24	–1	10
Total own-farm income	395	368	255	141
Agricultural and non-agricultural wages	15	5	42	75
Trade and self-employment	102	184	145	198
Salaried employment	83	54	49	71
Remittances	29	55	41	5
Total off-farm income	229	298	277	349
Estimated total per capita incomee	624	666	532	490
Per capita total expenditures	650	691	659	474
Estimated income as percent of total expenditures	96%	96%	81%	103%

a. 40 taka = US$1.00.

b. 110 households that were members of NGOs and had adopted the new technology (fish or vegetable production).

c. 110 households that were NGO members residing in villages where the NGO had not yet introduced the new technology and that were deemed likely to adopt if and when the new technology was introduced.

d. A random selection of 110 households from the remaining pool of households in A and B villages. 55 C1 households were selected from A villages where the new technologies had been introduced and where the 110 households under b. resided. 55 C2 households were selected from B villages where the new technologies had not been introduced and where the 110 households under c. resided.

e. Not included are food collected and sold (e.g., fish caught in public water bodies) and own-farm production (other than fruit or livestock production) on land not included as plot production. The profitability per acre of non-rice, non-vegetable land is assumed to be the same as for rice.

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* This assumes that rice land is left fallow about one-third of the year. The ponds studied in Mymensingh are perennial.

** Similar findings for a much earlier period may be found elsewhere [2].

under study here contribute rather modestly to overall household incomes. In Mymensingh, fish pond production accounts for 9.9% and 5.4% of total household income in A and B households, respectively. The difference between the two figures, 4.5% of income, represents a rough estimate of the marginal effect of applying the polyculture management technology to existing fish ponds. Vegetable production in A and B households in Saturia contributes only 2.5% and 2.1%, respectively, of total household income, so that the marginal effect of adoption of improved seeds as compared with local seeds would constitute less than 1% of total household income.

Income effects of adoption, then, are rather modest for A households as compared with B households across all three sites. However, because of the high profitability of the polyculture fish and commercial vegetable production, the potential exists for much higher impacts on household income, if land devoted to production and other inputs were to be increased. A priority for research would be to understand what are the constraints to more intensive adoption by households.*

Food-consumption patterns

Given the small impact of adoption on overall household income, it is a foregone conclusion that dietary patterns and nutritional status will not be much affected through the adoption–income linkage. However, it may be that adopting households consume disproportionate amounts of fish and vegetables that are rich in micronutrients and so improve their nutritional status through the adoption–home consumption linkage. It may also be that, in general, increasing the market supply of fish and vegetables will hold down prices of these commodities and so increase the intakes of these micronutrient-rich foods. Thus, it is important to understand the underlying factors that drive patterns of food consumption, in particular household income and food prices.

Income and food-consumption relationships

Rice and wheat are the least expensive sources of calories. Rice is preferred to wheat. These two facts, in conjunction with low purchasing power, explain the high levels of rice consumption relative to intakes of other foods. Rice consumption does not vary significantly by income group, suggesting that consumers at all income levels give high priority to satiating hunger through rice consumption first, then purchase non-staple plant foods and animal and fish products for variety in their diets, to the extent that food budgets permit.** Likewise, consumption of vegetables varies little with income. In fact, consumption of green, leafy vegetables declines marginally with income.

In contrast, animal and fish consumption roughly doubles between low- and high-income terciles for the surveyed households. Non-staple plant food consumption rises by a slower rate with income; there is roughly a 50% increase in intake of non-staple plant foods between low- and high-income terciles, so that the lack of effect of income on vegetable consumption is atypical of non-staple foods in general. Although animal and fish consumption accounts on average for only 3% of total energy intake, because of their high cost it is striking that animal and fish consumption accounts for 20% to 25% of food budgets on average. Moreover, animal and fish consumption accounts for a high proportion of the marginal increase in food expenditures as income rises. This implies that there is much latent demand for animal and fish consumption as income rises, as well as for selected non-staple plant foods, such as fruits and sugar.

Consumer demand for both vegetable and fish products is sensitive to changes in their price, whereas consumption of rice is relatively insensitive to price changes.

Vitamin A and iron intakes

Most vitamin A intake (in the form of provitamin A carotenoids) comes from vegetables. There is a great deal of seasonality in vitamin A intake because of seasonality in vegetable prices and consumption. Animal and fish contribute small proportions of total iron intake (4% to 8%), although it is known that trace minerals from such food sources have higher bioavailability and contribute to higher bioavailability of iron from plant sources. Non-staple plant foods contribute about one-half of total iron intake across the three sites, and cereals about 45%.

Intra-household food distribution

Pre-schoolers appear to be favoured in the intra-household distribution of food, particularly pre-school boys, who receive a disproportionate share of animal and fish products, which are the most expensive sources of energy and account for a high percentage of foods purchased at the margin as income increases. It is adult women who tend to receive disproportionately lower shares of preferred foods. Although the energy intakes of adult women are, of course, substantially greater than those of pre-school children (a multiple of about

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* Preliminary results from a follow-up study in Saturia indicate that vegetable production has expanded considerably in the two years after these initial surveys were undertaken.

** A stronger relationship between rice consumption and income has been found in other studies in Bangladesh [3].

two), consumption of animal and fish products (in absolute amounts) is about equal in adult women and pre-school boys.

Effects of adoption of polyculture fish pond technology on own-consumption

The adoption of the polyculture fish pond technology leads to greater consumption of large fish, but not of total fish consumption; there is apparently a one-for-one substitution of small fish in non-adopting, fish pond-owning households. Although the magnitude of this substitution is small, nevertheless it should be noted that small fish in general are more nutritious gram-for-gram than large fish, so that the impact on dietary quality may be negative [4].

From one-half to two-thirds of the value of small fish consumed comes directly from market purchases. Much of this market supply, in turn, presumably originates from public water bodies, in that small-fish cultivation in privately owned ponds is not the subject of fisheries research nor encouraged by extension agents and programmes. If scientifically feasible, there would seem to be a large opportunity for profitable production of small fish in privately owned fish ponds if these small fish could be harvested from February through August, when small-fish prices are seasonally high.

Similar to the results for polyculture fish production, vegetable-producing households do not consume disproportionately high amounts of vegetables in total. A plausible explanation is that there is no latent, unsatisfied demand to be met. To encourage greater vegetable consumption through lower prices, production and marketing efforts need to concentrate primarily on extending growing seasons in order to dampen seasonal price fluctuations and, perhaps secondarily, on improving marketing channels so that vegetables may move cheaply and freely about the country in order to take advantage of differential regional growing seasons.

Effects of technology adoption on nutritional outcomes and implications for agricultural policy

Based on the evidence presented, there is little reason to believe that adoption of the two technologies under study has improved the micronutrient status of members of adopting households through better dietary quality. There was no finding of disproportionately high own-consumption of fish and vegetables by adopting households. The impacts on overall household income, although positive, are not strong (table 1).

Nutritionists know that inadequate consumption of animal and fish products in general, and of particular categories of fruits and vegetables, is a primary, underlying cause of micronutrient malnutrition. Thus, it is consumers in general (both non-adopting and adopting households) who benefit nutritionally from research, extension, and credit programmes to increase the market supply of vegetables and fish. Increased market supply will lower prices for these foods that increase consumption.

Although inflation-adjusted cereal prices in Bangladesh have fallen by 40% over the last 25 years (a remarkable achievement), real prices of lentils, vegetables, and animal products have increased by 25% to 50%. The price of fish has risen even more rapidly. Demand estimates demonstrate that consumers are price-responsive: consumption of these non-staple foods will increase if prices decline. Conversely, if policies are not undertaken to increase supply, prices of non-staple foods will almost certainly increase in the face of population growth, and nutritional status will be further compromised.

From a short-run perspective, the story that emerges is a discouraging one, in the sense that food-based production strategies based on commercial incentives cannot immediately result in a substantial reduction in the number of malnourished people. In the short run, such production strategies can only start to improve the nutritional situation at the margin—the initial step in a longer journey. It is very much a medium- to long-run objective for the agricultural sector in Bangladesh to produce sufficient quantities of non-staple foods for consumers to meet recommended daily allowances of minerals and vitamins. The task of developing and introducing these technologies is more complex than for rice, however, in the sense that potentially a large number of food commodities are involved. Nevertheless, the challenge of increasing the growth rate of non-staple food production must be met. Whether food prices are rising or falling sets the overall context for the extent to which complementary nutrition interventions (e.g., supplementation, fortification, and nutrition education) can be effective at the margin in lowering the prevalence of malnutrition.

Can food-based interventions work *in the short run* to improve micronutrient status? The cost of animal and fish products is simply too high with respect to consumer purchasing power. However, vegetable sources of provitamin A are well within the purchasing power of poor consumers. Thus, diet-based interventions may be possible for improving vitamin A status, in that the problem would appear to be one of consumer motivation, that is, informing and convincing consumers of the benefits of provitamin A consumption and providing the knowledge of which vegetables are rich sources. Education is key, because there does not appear to be a strong, latent demand for vegetables, as there is for animal and fish products, as income increases. Relatively weak demand is a serious constraint as well with respect to the role of vegetables as a sustainable source of production growth.

References

1. Bouis H, de la Briere B, Guitierrez L, Hallman K, Hassan N, Hels O, Quabili W, Quisumbing A, Thilsted S, Zihad Z, Zohir S. Commercial vegetable and polyculture fish production in Bangladesh: their impacts on income, household resource allocation, and nutrition. Washington, DC: International Food Policy Research Institute, 1998.
2. Rahman M, Khan M, Ahmed A, Church P. An economic analysis of rabi crop cultivation in Bangladesh (mimeographed). Dacca, Bangladesh: US Agency for International Development, 1979.
3. Ahmed A. Trends in consumption, nutrition, and poverty. In: Ahmed R, Haggblade S, Chowdhury T, eds. Out of the shadow of famine. Baltimore, Md, USA: Johns Hopkins University Press, 2000:9–10.
4. Hansen M, Thilsted SH, Sandström B, Kongsbak K, Larsen T, Jensen M, Sørensen SS. Calcium absorption from small soft-boned fish. J Trace Elem Med Biol 1998;12:148–54.

Mycotoxin contamination of foods in Africa: Antinutritional factors

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Abstract

Mycotoxins are regulated in foods and feeds because of carcinogenic (aflatoxin), immunotoxic (deoxynivalenol), or environmental estrogenic (zearalenone) properties. In addition to having tumorigenic properties, many mycotoxins are antinutritional factors that cause unthrifty growth and immune suppression in young animals. In the developed world, human exposure, and particularly exposure of children, to dietary mycotoxins is virtually nonexistent because of regulatory standards. In developing countries, monitoring and enforcement of standards is rare, and mycotoxin-susceptible foods are often the primary staples in rather undiversified diets. In sub-Saharan Africa, people are exposed to unsafe levels of various mycotoxins, often in mixtures, and the consequences in terms of public health burden have been ignored. This paper presents information on the health effects that have been attributed to mycotoxin exposure from the medical research literature and data on existing mycotoxin levels in maize in West and Central Africa. The International Institute of Tropical Agriculture (IITA), in its Maize Integrated Pest Management Project, has recognized mycotoxins as one of the most important constraints to the goal of improving human health and well-being through agriculture. An overview of various research and development activities at the Institute is given.

Mycotoxin effects on human and animal health

Mycotoxins are chemical contaminants in foods produced by fungal infestation that adversely affect human or animal health. Although there are hundreds of fungal metabolites that are toxic in experimental systems, there are only five that are of major agricultural importance: aflatoxin, produced by *Aspergillus flavus* and *A. parasiticus*; deoxynivalenol, produced by *Fusarium graminearum* and *F. culmorum*; fumonisin, produced by *Fusarium verticillioides* (ex-*moniliforme*); ochratoxin, produced by *Aspergillus ochraceus* and *Penicillium verrucosum*; and zearalenone, produced by various *Fusarium* species [1].

Generally, these toxins are stable throughout the typical processing and cooking of feeds and foods (aflatoxin [2], ochratoxin [3], fumonisin [4], deoxynivalenol [5]). Products from animals that have been fed mycotoxin-contaminated feeds can be dietary sources of some mycotoxins [6].

A recent report by the US National Academy of Sciences [7] noted that even with the high-quality food system in the United States, carcinogenic mycotoxins in American diets may increase cancer rates. Mycotoxins are certainly a major public health problem for humans in developing countries [8]. In numerous geographic studies, significant correlations between areas with high risk of dietary exposure to mycotoxins and cancers have been found. The effects of mycotoxin exposure range from acute intoxication to chronic, subacute responses. The following are summary statements taken from a very large body of scientific literature, concerning specific effects of the various mycotoxins on human and animal health.

Subacute chronic toxicity and growth faltering

Subacute mycotoxicoses (toxic effects by mycotoxins) are manifested in a syndrome of symptoms, which commonly include moderate to severe liver damage, reproductive problems, appetite loss, digestive tract discomfort, diarrhoea, growth faltering, immune suppression, increased morbidity, and premature mortality [9]. Aflatoxin is also implicated in the degenerative diseases childhood hepatic cirrhosis and Reye's syndrome [10]. Aflatoxins have been shown to pass transplacentally, thus having the potential to affect prenatal

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infant development [11]. In Kenya, the mean birthweight of the offspring of women exposed to aflatoxins prenatally was lower than that of those who had not been similarly exposed [12, 13]. An important research question is: How much morbidity and growth faltering are occurring in infants who are at high risk of aflatoxin exposure relative to those at low risk?

Immune suppression: Increased morbidity and mortality in animals and humans

Aflatoxin B_1 is hepatotoxic in humans and animals and is nephrotoxic and immunosuppressive in animals [14]. Experimental exposure of animals to a chemical family of *Fusarium* toxins called trichothecenes causes severe damage to actively dividing cells in bone marrow, lymph nodes, spleen, thymus, and intestinal mucosa. At lower doses, these compounds can be immune suppressive [15].

As a result of their studies on animals, researchers have concluded that mycotoxins are likely to be immunotoxic to humans as well [9]. Pestka and Bondy [15] dismissed the problem for the developed world by stating that "These [high doses of mycotoxins] might be most likely encountered in animal feed that is not inspected for interregional or international commerce. In contrast, human food is regulated at the low parts per billion ranges in Canada, the United States, and most developed countries because of potent hepatocarcinogenicity of aflatoxins. Thus, vigilant monitoring should minimize the potential for aflatoxin-induced immune suppression in humans." Monitoring is effectively done in the developed world. In the developing world, except in cases of exports of vulnerable commodities such as groundnuts or coffee to the developed nations, monitoring of internal food supplies is rarely implemented.

Interaction with nutrient assimilation

Protein–energy malnutrition, kwashiorkor, and aflatoxin exposure appear to be seasonally linked in tropical regions where aflatoxins are present [16]. Research has shown that there is no specific cause-and-effect relationship between aflatoxin and kwashiorkor, but children with kwashiorkor who had tested positive for aflatoxin in blood and urine had statistically significantly longer hospital stays and suffered from more infections [17, 18]. Thus, aflatoxin acted in conjunction with kwashiorkor, possibly by immune suppression, to worsen the prognosis [19]. Vitamins are thought to ameliorate genotoxicity, and aflatoxin B_1 has been reported to interact with assimilation of vitamins A and E [20, 21].

Carcinogenicity and genotoxicity

Naturally occurring aflatoxins are carcinogenic in humans [14]. Intracountry correlation between estimates of the incidence of primary liver cancer and the intake of aflatoxins in the same population groups has been demonstrated in Swaziland [22, 23] and was corroborated by data from Mozambique [24]. In China, where maize was the major source of aflatoxin exposure, mortality from liver cancer was 372/100,000 in areas at high risk of food contamination versus 33/100,000 in areas at low risk [25]. A strong relationship exists between hepatitis B virus infection, aflatoxin, and liver cancer [19], and in some studies a multiplicative or synergistic effect has been clearly noted [14]. Aflatoxin B_1 is defined as genotoxic because it causes DNA damage, gene mutation, and chromosomal anomalies [14].

Ochratoxin is suspected as the cause of urinary tract cancers and kidney damage in areas of chronic exposure in parts of Eastern Europe [14, 26]. Human exposure to ochratoxin primarily occurs from whole-grain breads, although coffee and wine are also implicated when fungi infect the berries and grapes.

Fumonisins are suspected as primary causal factors in esophageal cancers in the Transkei, South Africa [24, 27]. Marasas [28] suggested that levels of 100–200 ppb would be safe for humans consuming large amounts of contaminated maize.

Acute toxicosis

Acute aflatoxicosis (severe aflatoxin poisoning) occurs in poultry, swine, and cattle consuming feeds contaminated with aflatoxins. The same can appear in humans, and cases of lethal toxic hepatitis attributed to consumption of aflatoxin-contaminated maize have occurred [10, 27, 29, 30]. Large-scale acute human toxicoses due to consuming wheat and rice contaminated with deoxynivalenol have occurred in modern times in India [31], China, and Korea, among other countries [32].

Prevalence of mycotoxins in West and Central Africa

Although mycotoxins are strictly regulated in most parts of the world, outside of South Africa there is very little information about the amount of exposure to these dietary antinutritional factors in sub-Saharan Africa. From 1993 to 1996, the International Institute of Tropical Agriculture (IITA) conducted toxin analyses on corn samples collected from five agroecological zones of Benin, Nigeria, and Cameroon. Mycotoxin amounts vary between seasons and years, depending on environmental conditions and crop and produce management practices. The hypothesis was that there would be differences in the risk of mycotoxin contamination mediated by climatic conditions and crop management practices in the different agroecological zones [33, 34].

Risk of exposure to specific toxins from a maize-based diet

The Sahel, just south of the Sahara Desert, has high temperatures and the risk of drought stress, conditions that give *A. flavus* competitive advantage over other grain-infesting fungi. This zone also has a higher incidence of the much more toxic "S strain" of *A. flavus* than the other zones [35]. In the Sahel of both Benin and Nigeria, maize had a significantly higher risk of aflatoxin contamination after six months in storage than in the other zones (tables 1 and 2). In the dry savannah, ear-boring insects are known to increase aflatoxin contamination [37], and the dry savannah has a long monomodal rainy season during which farmers intercalate cotton, groundnuts, and maize in their fields. All of these crops are prone to *A. flavus* and aflatoxin buildup, and growing them together has the potential to increase contamination. In the dry savannah of both Benin and Nigeria, overall toxin levels were low, as a result of better crop husbandry and more advantageous climate [34, 38] (tables 1 and 2). The moist savannah has a bimodal rainy season, and farmers have difficulty in drying their first-season crop before storage, leading to insect infestation and rapid quality degradation. This zone had a significantly higher percentage of stores infected within the first three months of storage than the other zones in both countries. The high humidity and warm temperatures in coastal savannahs and humid forest regions increase the risk of fungal contamination of maize, but *A. flavus* and aflatoxin were relatively scarce, displaced by *Fusarium* and *Penicillium* species (tables 1 and 2). The cool climate found in the mid-altitude zones is more likely to promote the *Fusarium* species and the associated toxins such as fumonisin, deoxynivalenol, and zearalenone. These agroecological conditions exist across a large part of sub-Saharan Africa.

Risk of multiple toxin exposure

Mycotoxin mixtures are likely to occur naturally, and these may alter immunity in an additive or synergistic manner. In Benin and Nigeria, mixtures of mycotoxigenic fungi were found in all samples (fig. 1). In Benin in 1993–94, 80 samples were analysed for fumonisin at the beginning of storage. Fumonisins were found in all samples, ranging from 0.1 to 8.3 ppm [39]. It was shown that grain could be simultaneously contaminated with both aflatoxins in fumonisin. The presence of various mycotoxigenic fungi in grain in the moist savannah of Benin suggests that people are being exposed to multiple toxins. For humans and animals, the potency of the contaminated material is related to the mixtures present [1].

TABLE 1. Percentage of samples in aflatoxin classes per agroecological zone in Benin after six months of storage in 1993–95 ($n = 301$)

Zone	< 5 ppb	5–10 ppb	10–20 ppb	20–50 ppb	50–100 ppb	> 100 ppb
Sahel savannah	67.8	1.6	4.8	1.6	—	24.2
Dry savannah	71.3	5.0	11.3	—	5.0	8.8
Moist savannah	68.4	1.3	7.6	7.6	7.6	7.6
Coastal savannah	85.5	3.8	2.5	1.3	—	7.5

Source: ref. 33.

TABLE 2. Aflatoxin B detected in maize samples in five agroecological zones of Nigeria in 1994 and 1995 ($n = 25$ per zone)

	1994				1995			
Survey	Mean aflatoxin (μg/kg)[a]	Range (μg/kg)	% stores positive	Positive > 20 ppb[b]	Mean aflatoxin (μg/kg)[a]	Range (μg/kg)	% stores positive	Positive > 20 ppb[b]
Sahel savannah	104.3	0–1,380	12.0	868.9	51.0	0–408.3	25.0	204.2
Dry savannah	0.0	0–0	0.0	0.0	3.8	0–16.7	21.4	0.0
Moist savannah	32.9	0–600	24.0	423.3	40.6	0–650.0	18.7	216.6
Mid-altitude	55.2	0–1,380	4.0	1,380.0	0.0	0–0	0	0.0
Humid forest	125.0	0–1,050	16.0	781.3	21.1	0–202.9	27.7	77.4

Source: refs. 34, 36.
a. Zone mean including all samples.
b. Mean of positive stores.

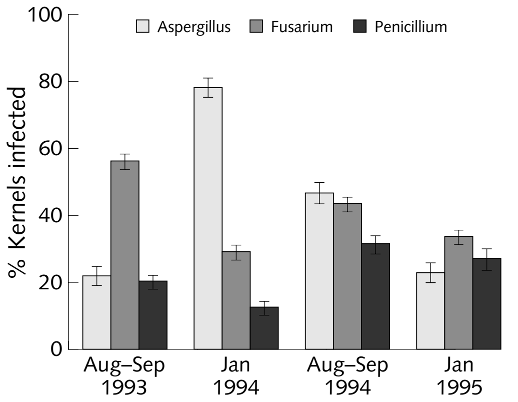

FIG. 1. Percent maize kernels from the southern Guinea Savannah of Benin that were infected with three genera of fungi during four sampling periods. Source: ref. 33

IITA strategy to ameliorate the problems of mycotoxin contamination in foods and feeds

Various projects are being coordinated by IITA, with multiple partners and donors, to try to reduce the amounts of mycotoxins that people are exposed to in West Africa. Inducing behavioural change—thus enabling families to improve their diets even without additional income—is often the most cost-effective way to improve nutritional status [40]. A three-year project, funded by Rotary International, is designed to conduct public information campaigns about the importance of consuming only good-quality grain. It is expected that an educated urban consumer will demand improved food quality from market sources. In partnership with governmental agencies and with market and consumer associations, a strategy for sustainable monitoring of markets will be put in place. A feasibility study will be conducted to look at methods for rendering poor-quality grain safe for animal feeds, in order to have an alternative market for the poorest-quality grain and so to help remove it from the human foods sector. Market demand should result in farmer demand for technologies to produce high-quality maize grain for human consumption.

To prepare a basket of technologies for on-farm reduction of contamination, research funded by the German BMZ/GTZ and the United States Department of Agriculture has three components. First, biological control of *Aspergillus flavus* is being developed to prevent aflatoxin contamination in all vulnerable crops. IITA is also working to introduce host plant resistance to *A. flavus* into tropically adapted maize. Second, farmer participatory research methods are being used to optimize field-to-store commodity management practices to improve grain quality and reduce aflatoxin contamination, and to assess the costs to the farmer of adopting improved management practices. Third, a medical epidemiology study is under way to detect the effect of exposure to aflatoxin in rural maize-based systems on the immune response to vaccination, and on the growth of children under the age of three. An assessment of the range of foods available in the households of the test children will be made to control for other nutritional deficiencies that can affect infant development.

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References

1. Miller JD. Fungi and mycotoxins in grain: implications for stored product research. J Stored Product Res 1995; 31:1–6.
2. Goldblatt LA, ed. Aflatoxin: scientific background, control, and implications. New York: Academic Press, 1969.
3. Kuiper-Goodman T, Scott PM. Risk assessment of the mycotoxin ochratoxin A. Biomed Environ Sci 1989; 2:179–248.
4. Castelo MM, Sumner SS, Bullerman LB. Occurrence of fumonisins in corn-based food products. J Food Protection 1998;61:704–7.
5. Young JC, Fulcher RG, Hayhoe JH, Scott PM, Dexter JE. Effect of milling and baking on deoxynivalenol (vomitoxin) content of eastern Canadian wheats. J Agric Food Chem 1984;32:659–64.
6. Prelusky DB. Residues in food products. In: Miller JD, ed. Mycotoxins in grain, compounds other than aflatoxin. St. Paul, Minn, USA: Eagan Press, 1994:405–19.
7. US National Academy of Sciences. Carcinogens and anticarcinogens in the human diet. Washington, DC: National Academy Press, 1996.
8. Miller JD. Global significance of mycotoxins. In: Miraglia M, van Egmond HP, Brera C, Gilbert J, eds. Mycotoxins and phycotoxins: developments in chemistry, toxicology and food safety. Fort Collins, Colo, USA: Alaken, 1998:3–16.
9. Miller JD, Trenholm ML, eds. Mycotoxins in grain: compounds other than aflatoxin. St. Paul, Minn, USA: Eagan Press, 1994.
10. Mehan VK, McDonald D, Haravu LJ, Jayanthi S. The groundnut aflatoxin problem, review and literature database. Patancheru, A.P. India: International Crops Research Institute for the Semi-Arid Tropics, 1991.
11. Wild CP, Jiang YZ, Allen SJ, Jansen LAM, Hall AJ, Montesano R. Aflatoxin-albumin adducts in human sera from different regions of the world. Carcinogenesis 1990;11:2271–4.

12. DeVries HR, Maxwell SM, Hendrickse RG. Aflatoxin excretion in children with kwashiorkor or marasmic kwashiorkor: a clinical investigation. Mycopathologia 1990;110:1–9.
13. Hendrickse RG. Of sick turkeys, kwashiorkor, malaria, perinatal mortality, heroin addicts and food poisoning: research on the influence of aflatoxins on child health in the tropics. Ann Trop Med Parasitol 1997;91:787–93.
14. International Agency for Research on Cancer. Monograph 56. IARC Monograph series on the evaluation of carcinogenic risks to humans. Lyons, France: IARC, 1993.
15. Pestka JJ, Bondy GS. Immunotoxic effects of mycotoxins. In: Miller JD, ed. Mycotoxins in grain: compounds other than aflatoxin. St. Paul, Minn, USA: Eagan Press, 1994:339–58.
16. Hendrickse RG. Clinical implications of food contamination by aflatoxins. Ann Acad Med 1991;20:84–90.
17. Adhikari M, Ramjee G, Berjak P. Aflatoxin, kwashiorkor, and morbidity. Natural Toxins 1994;2:1–3.
18. Ramjee G, Berjak P, Adhikari M, Dutton MF. Aflatoxins and kwashiorkor in Durban, South Africa. Ann Trop Paediatr 1992;12:241–7.
19. Wild CP, Hall AJ. Epidemiology of mycotoxin-related disease. In: Howard S, Miller JD, eds. The Mycota VI. Human and animal relationships. Berlin: Springer-Verlag, 1996:213–25.
20. Liu ZL, Zou YZ. The effect of aflatoxin B1 on vitamin A status and on microsomal mixed function oxidase in male mouse. Chung Hua Yu Fang I Hsueh Tsa Chih 1989;23:218–21.
21. Harvey RB, Kubena LF, Elissalde MH. Influence of vitamin E on aflatoxicosis in growing swine. Am J Vet Res 1994;55:572–7.
22. Linsell CA, Peers FG. Aflatoxin and liver cell cancer. Trans R Soc Trop Med Hyg 1977;71:471–3.
23. Peers F, Bosch X, Kaldor J, Linsell A, Pluijment M. Aflatoxin exposure, hepatitis B virus infection and liver cancer in Swaziland. Int J Cancer 1987;39:545–53.
24. van Rensburg SJ, Cook-Mozaffari P, van Schalkwyk DJ, van der Watt JJ, Vincent TJ, Purchase IF. Hepatocellular carcinoma and dietary aflatoxin in Mozambique and Transkei. Br J Cancer 1985;51:713–26.
25. Yeh F-S, Yu M-C, Mo C-C, Luo S, Tong MJ, Hendersons BE. Hepatitis B virus, aflatoxins, and hepatocellular carcinoma in southern Guangxi, China. Cancer Res 1989;49:2506–9.
26. Reports of the Scientific Committee for Food (SCF) of the European Unio*n (www.europa*.eu).
27. Marasas WFO. Medical relevance of mycotoxins in Southern Africa. Microbiologie—Aliments—Nutrition 1988;6:1–5.
28. Marasas WFO. Fumonisins: history, worldwide occurrence and impact. In: Jackson LS, DeVries JW, Bullerman LB, eds. Fumonisins in food. New York: Plenum Press, 1996:1–18.
29. Krishnamachari KAVR, Bhat RV, Nagarajan V, Tilak TBG. Hepatitis due to aflatoxicosis: an outbreak in Western India. Lancet 1975;1:1061–3.
30. Nagindu A, Johnson BK, Kenya PR, Ngigra JA, Ocheng DM, Nandwa H, Omondi TN, Jansen AJ, Ngare W, Kaviti JN, Gatei D, Siongok TA. Outbreak of acute hepatitis caused by aflatoxin poisoning in Kenya. Lancet 1982;1:1346–8.
31. Bhat RV, Beedu SR, Ramakrishna Y, Munshi KL. Outbreak of trichothecene mycotoxicosis associated with consumption of mould-damaged wheat in Kashmir Valley, India. Lancet 1989;1:35–7.
32. Beardall JM, Miller JD. Diseases in humans with mycotoxins as possible causes. In: Miller JD, Trenholm HL, eds. Mycotoxins in grain. St. Paul, Minn, USA: Eagan Press, 1994:487–540.
33. Hell K. Factors contributing to the distribution and incidence of aflatoxin producing fungi in stored maize in Benin. Doctoral dissertation, University of Hannover, German*y. www.gartenbau.uni-hannover.de/ipp/ipp-publications/diss-Ipp*.htm, 1997.
34. Udoh JM, Ikotun T, Cardwell KF. Storage structures and aflatoxin content of maize in five agro-ecological zones of Nigeria. J Stored Product Res 2000;36:187–201.
35. Cotty PJ, Cardwell KF. Divergence of West African and North American communities *of Aspergil*lus secti*on Fl*avi. Appl Environ Microbiol 1999;5:2264–6.
36. Udoh JM. Aflatoxin content of maize grains as affected by agricultural practices in five agro-ecological zones of Nigeria. Ph.D. dissertation, University of Ibadan, Nigeria, 1997.
37. Sétamou M, Cardwell KF, Schulthess F, Hell K. Effect of insect damage to maize ears, with special reference *to Mussidia nigrivene*lla (Lepidoptera; Pyralidae), *on Aspergillus fla*vus (Deuteromycetes; Monoliales) infection and aflatoxin production in maize before harvest in the Republic of Benin. J Econ Entomol 1998;91:433–8.
38. Hell K, Cardwell KF, Setamou M, Poehling H-M. Maize storage practices and their influence on aflatoxin contamination in stored grains in four agroecological zones in Benin, West Africa. J Stored Product Res (in press).
39. Hell K, Sétamou M, Visconte A, Cardwell KF, eds. Mycotoxins in foods in Africa. Proceedings of the Benin workshop. 6–10 November 1995. Cotonou, Benin: International Institute of Tropical Agriculture, 1996.
40. World Bank. World development report: investing in health. New York: Oxford University Press, 1993.

Improving the nutritional quality and yield potential of grasspea (*Lathyrus sativus* L.)

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Abstract

Lathyrus sativus *(grasspea or chickling pea) is a popular food and feed crop in certain Asian and African countries, such as Bangladesh, China, Ethiopia, India, Nepal, and Pakistan, because of its resistance to drought, flood, and moderate salinity and because of its low input requirements. When other crops fail under adverse climatic conditions,* L. sativus *can become the only available food source for the poor and sometimes is a survival food during famine. Although seeds of* L. sativus *are tasty and protein rich, overconsumption can cause an upper-neurone disease known as neurolathyrism, an irreversible paralysis of the lower limbs. The level of this compound in the dry seeds varies widely, depending on genetic factors and environmental conditions.*

The ability of L. sativus *to provide an economic yield under most adverse conditions has made it a popular crop in subsistence farming in many developing countries, and it offers a great potential for use in other parts of the world. In the West Asia and North Africa (WANA) region, under low-rainfall conditions there is a tendency for increasing monoculture of cereals, such as barley. The incorporation of grasspea in the rotation can make the production system more sustainable by improving soil fertility and breaking disease and pest cycles.*

*The objectives of the crop improvement programme of International Center for Agricultural Research in the Dry Areas (ICARDA) for this species are to improve its yield potential and nutritional quality through the reduction of its content of the neurotoxin 3-(*N*-oxalyl)-*L*-2,3-diaminopropionic acid (β-ODAP). Low-neurotoxin lines having 0.07% to 0.02% β-ODAP were developed by using conventional breeding methods and by developing somaclonal variants.*

Introduction

Lathyrus sativus L. or grasspea (*khesari* in India and Bangladesh, *guaya* in Ethiopia, *san li dow* in China, *pois carré* in France) has been cultivated in South Asia and Ethiopia for over 2,500 years [1] and is used as food and feed. It is a popular drought-tolerant crop as food and feedstuff in drought-prone areas of Africa and Asia [2, 3]. Its ability to provide an economic yield under adverse conditions has made it a popular crop in subsistence farming in many developing countries, and it offers great potential for use in marginal low-rainfall areas. Despite its tolerance to drought, grasspea is not affected by excessive rainfall and can be grown on land subject to flooding [4]. In Bangladesh, India, Nepal, and Pakistan, it is often broadcast into a standing rice crop, where it flourishes on the residual moisture left after the rice has been harvested. It is a very hardy crop with a penetrating root system and can be grown on a wide range of soil types, including very poor soils and heavy clays. This hardiness and its ability to fix atmospheric nitrogen make the crop one that seems designed to grow under adverse conditions.

More than 100 million people in drought-prone areas of Asia and Africa consider grasspea as a traditional popular crop, because of its easy cultivation, its relative resistance to drought, flood, moderate salinity and insect attack, and its good yield of tasty seeds, which has an edible portion of about 30% [3, 5]. When other crops fail due to adverse conditions, grasspea can be the only available food source for the poorest section of the population and sometimes is a survival food in times of drought-induced famine.

Since grasspea is often the cheapest food legume for low-income families, it is a common component of their traditional diet. Its seeds also contain a high amount of free *l*-homoarginin, which acts as a precursor of lysine in human nutrition [6]. These same seeds contain a neurotoxic non-protein amino acid that can cause irreversible spastic paraparesis (paralysis) of the legs when it is consumed as a major portion of the diet over a three- to four-month period [7, 8]. Recent

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outbreaks of famine in areas where grasspea could be a promising food crop for sustainable agriculture have been followed by outbreaks of this upper-motoneurone disease in epidemic proportions: Bangladesh in 1942–45 and 1972–74 [9], China in 1973 [10], and Ethiopia in 1976–77 [11] and 1997–98 [Lambien F, personal communication, 1999].

The causative agent of neurolathyrism was confirmed as 3-(*N*-oxalyl)-L-2,3-diaminopropionic acid (β-ODAP) or its synonym *β*-*N*-oxalyl-L-alanine (BOAA) [8, 12], and the biochemical pathway of the toxin has been elucidated [13, 14]. However, no biological role of β-ODAP in the plant has yet been proposed. The concentration of β-ODAP in ripe seeds is very variable and is influenced by genetic and environmental factors [15, 16]. Water stress can double the toxin level, whereas salinity in the soil may reduce the toxin level in the seeds [17].

Despite the obvious advantages of grasspea, until recently relatively little effort has been made towards the improvement of this very hardy pulse crop. Indeed, the history of grasspea has been one in which it has been banned by many countries due to its toxicity. In spite of this, grasspea is still produced in significant quantities in many parts of the world. Improvement of this crop is now being addressed at the International Center for Agricultural Research in the Dry Areas (ICARDA) through its germplasm enhancement programme.

The role of ICARDA in improving the nutritional quality of grasspea

The ICARDA, which has a mandate for improving the productivity of dry-land agriculture in the West Asia and North Africa (WANA) region, and more recently Central Asia and Caucasian Countries (CAC), is placing special emphasis on improving this crop. ICARDA has a breeding programme for the improvement of cool-season food and forage legumes, including grasspea. It also holds a rich collection of *Lathyrus* spp. germplasm (1,883 accessions, including 1,560 *L. sativus*) from different parts of the world. Using this precious resource, ICARDA is collaborating with national partners to develop new grasspea lines with the objectives of improving its yield potential, adaptability, and nutritional quality through reduction of its neurotoxin β-ODAP to a safe level for human consumption and animal feed.

Since 1989–90, the grasspea breeding programme at ICARDA has aimed to reduce the neurotoxin β-ODAP concentration by four approaches: germplasm evaluation; genetic detoxification (hybridization programme); exploitation of somaclonal variation induced in response to *in vitro* culturing of somatic cells (an application of plant biotechnology); and effect of the soil micronutrients Zn^{2+} and Fe^{2+} on the level of the neurotoxins in the grains.

Germplasm evaluation

An extensive screening programme was initiated in 1989–90 for five years to explore the possibility of identifying toxin-free lines from germplasm of different origins. The results indicated that no accession of any *Lathyrus* species was β-ODAP free, although in several lines the β-ODAP content was low. This appears to be species related, since samples of *L. cicera* ranged from 0.03% to 0.22%, with a mean of 0.16%. *L. sativus* showed the greatest range, from 0.02% to 2.4%, with a mean of 1.3%, whereas *L. ochrus* lines were highest in β-ODAP, ranging from 0.46% to 2.5%, with a mean of 1.4% in the ripe seeds [18]. Four lines of *L. sativus*—IFLLS 522 (Syria), IFLLS 588 (Cyprus), IFLLS 516 (Turkey), and IFLLS 563 (Turkey)—were found to have a low β-ODAP content in the seeds, ranging from 0.02% to 0.07%. The level presumed safe for human consumption is < 0.2% [19].

Analysis of a large number of germplasm accessions of *L.sativus* revealed that samples originating from Bangladesh, Ethiopia, India, Nepal, and Pakistan are high in β-ODAP content in the dry seeds, in a range from 0.7% to 2.4%, whereas samples from North Africa, Syria, Turkey, and Cyprus have significantly lower β-ODAP, ranging from 0.02% to 1.2%.

Genetic detoxification (hybridization programme)

Because the low-neurotoxin lines have undesirable traits, such as late flowering, susceptibility to insects and diseases, and low yields, a hybridization programme was initiated in 1991–92 with the objective of improving the yield potential and adaptability and of increasing the nutritional quality by transferring the low-neurotoxin character to locally adapted germplasm originating from grasspea-producing countries, such as Bangladesh, Ethiopia, and Pakistan.

The ICARDA breeding programme has made significant progress in selecting low-neurotoxin, high-yielding lines that can be locally adapted. This work is carried out by a multidisciplinary team involving the breeder, pathologist, entomologist, biotechnologist, and animal nutritionist. The major avenue of dissemination for the elite lines and segregated populations developed by the breeding programme for selection under target environments is through the ICARDA International Legume Nursery Program.

Research activities with the Ethiopian National Program commenced in the 1998–99 growing season. ICARDA supplied the Ethiopian National Program with 100 improved lines of *L. sativus.* These lines were planted at Holetta Research Station for quarantine in 1997–98. In 1998–99, these lines were tested at two locations, Inewari and Molale. Eight high-yielding lines were selected at Inewari, and 14 lines with high yield and cold tolerance were selected at Molale. Nine lines were also selected with a β-ODAP content 40% less than the checks (Adet local, Ginchi local, Inewari local, and Molale local). ICARDA also supplied the Ethiopian National Program with 120 samples of segregated populations of crosses between Ethiopian landraces and ICARDA's low β-ODAP lines for selection under Ethiopian conditions.

In 1999 the UK/Consultative Group on International Agricultural Research (CGIAR) Competitive Research Facility (CRF) of the Department for International Development (DFID) funded ICARDA to implement a project with the Ethiopian Agricultural Research Organization (EARO) on "Improving Yield Potential and Quality of Grasspea (*L. sativus*): a Dependable Source of Protein for Subsistence Farmers in Ethiopia." The project's goals are to alleviate malnutrition, reduce shortages of dietary protein, and increase food quality and quantity for rural subsistence farm households in Ethiopia. This project promotes grasspea as a safe source of dietary protein, thereby removing the stigma of neurolathyrism associated with this hardy and promising crop.

Through the DFID project, ICARDA supplies the Bangladesh Agricultural Research Institute with segregated populations for selection of lines with reduced concentrations of β-ODAP, combined with disease and insect resistance. ICARDA is collaborating with the National Agricultural Research Institute in Islamabad, Pakistan, in forage and fodder aspects of grasspea and in analytical aspects as well as development of high-yielding and reduced-β-ODAP adapted lines. For Nepal, target crosses between locally adapted lines and ICARDA's low-neurotoxin lines were performed, and segregated populations were supplied for selection of low neurotoxin and local adaptation.

Exploitation of somaclonal variation

Biotechnological methods are being applied to develop toxin-free lines of *L. sativus*. Recently, exploitation of somaclonal variation from landraces of Ethiopia and Pakistan has helped in isolating some somaclones differing in various characters with respect to flower colour, leaf size, seed colour, pod length, and number of seeds per pod. Somaclones with a low β-ODAP content (less than 1%) have been developed. These somaclones are being tested under different environments to study the stability of the neurotoxin content in the ripe seeds.

Soil micronutrients: Zn^{2+} and Fe^{2+}

The neurotoxin of *L. sativus* is hypothesized to function as a carrier molecule for zinc ions [20]. Soils that have been depleted in micronutrients from flooding by monsoon rains (Indian subcontinent) or that are otherwise poor in available zinc and with high iron content (Ethiopia vertisols) may be responsible for the high level of neurotoxin in ripe seeds and subsequently for the high incidence of human lathyrism. This may explain why landraces originating from Bangladesh, Ethiopia, India, Nepal, and Pakistan have a higher β-ODAP content than those from North Africa, Turkey, Syria, and Cyprus.

Zinc deficiency in the soil is an agronomic problem in Bangladesh, especially in the monsoon-washed soils where grasspea is grown during the dry winter. Zinc deficiency in patients is also a widespread phenomenon in Bangladesh and Ethiopia, leading to a number of symptoms such as loss of hair, nail deformation, diarrhoea, and mental retardation [21]. ICARDA, through the DFID project in collaboration with EARO, is placing more emphasis on the soil and other environmental conditions that can lead to a solution for neurolathyrism. More balanced fertilization of the soil may reduce toxin-increasing stress factors for the plants and at the same time increase productivity.

Conclusions

The Grasspea Improvement Program at ICARDA will continue to develop high yielding, adapted lines containing very little or none of the neurotoxin β-ODAP. The feasibility of introgression of the low-neurotoxin character from other closely related species such as underground chickling (*Lathyrus ciliolatus* L.) will also be addressed. Our attempts to apply plant biotechnological methods to develop toxin-free lines of grasspea will continue. Analysis of somaclonal variation in landraces from Bangladesh, Ethiopia, and Pakistan will be continued in order to identify new genotypes with zero or near-zero levels of neurotoxin. Development of low- or zero-neurotoxin lines will lead to grasspea consumption at a safe level and remove the stigma of neurolathyrism from this hardy crop.

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References

1. Bell EA. Lathyrus neurotoxin: history and overview. In: Spencer PS, ed. The grasspea: threat and promise. Proceedings of the International Network for the Improvement of *Lathyrus sativus* and Eradication of Lathyrism. New York: Third World Medical Research Foundation, 1989:86–97.
2. Khan JK, Kebede N, Kuo YH, Lambien F, De Bruyn A. Analysis of the neurotoxin β-ODAP and its α-isomer by pre-column derivatization with phenylisothiocyanate. Anal Biochem 1993;208:237–40.
3. Abdelmoneim AM, Saxena MC, El-Saleh A, Nakkoul H. The status of breeding grasspea (*Lathyrus sativus* L.) for improved yield and quality at ICARDA. In: Tekle Haimanat R, Lambien F, eds. Lathyrus and lathyrism, a decade of progress. Ghent, Belgium: University of Ghent, 1997:81–3.
4. Sinha SK. Food legumes: distribution, adaptability and biology of yield. Rome: Food and Agriculture Organization, 1980.
5. Rutter J, Percy P. The pulse that maims. New Scientist 1984;103:22–3.
6. Quereshi MY, Pilbea DJ, Evans CV, Bell EA. The neurolathyrogen—amino-β-oxalylaminopropionic acid in legume seeds. Phytochemistry 1977;16:477–9.
7. Spencer PS, Schaumburg HH. Lathyrism: a neurotoxic disease. Neurobehav Toxicol Teratol 1983;5:625–9.
8. Spencer PS, Ludolph A, Dawivedi MP, Roy DN, Hugon J, Shaumburg HH. Lathyrism: evidence for role of the neuroexcitatory amino acid BOAA. Lancet 1986;2:1066–7.
9. Haque A, Hossain M, Wouters G. Epidemiological and clinical study of lathyrism in Bangladesh: a preliminary report. Bangladesh J Neurosci 1991;7:60–71.
10. Liu X, He F. *Lathyrus sativus* and lathyrism in China. Lathyrism Newsletter 1990;2:2.
11. Haimanat RT, Kidane Y, Wuhib E, Kalissa A, Alemu T, Zein ZA, Spencer SP. Lathyrism in rural North Western Ethiopia: a highly prevalent neurotoxic disorder. Int J Epidemiol 1990;19:664–72.
12. Roy DN, Spencer SP. Lathyrogens. In: Cheeke PR, ed. Toxicants of plant origin. Vol III. Boca Raton, Fla, USA: CRC Press, 1989:169–201.
13. Lambien F, Ogena G, Kuo HY. β-Isoxazolinone-alanin is involved in the biosynthesis of the neurotoxin β-*N*-oxalyl-L-α-β-diaminopropionic acid. Phytochemistry 1990;20:3797–9.
14. Kuo YH, Lambien F. Biosynthesis of the neurotoxin β-*N*-oxalyl-L-α-β-diaminopropionic acid in callus tissue of *Lathyrus sativus*. Phytochemistry 1991;30:3241–4.
15. Lambien F, Khan JK, Kuo HY, Campell CC, Briggs IC. Toxins in seedlings of some varieties of grasspea (*Lathyrus sativus*). Nat Toxins 1993;1:246–9.
16. Abdelmoneim AM, Cocks PS. Adaptation and yield stability of selected lines of *Lathyrus* spp. under rainfed conditions in West Asia. Euphytica 1993;66:89–97.
17. Haque R, Hussaina M, Lambien F. Effect of salinity on the neurotoxin β-ODAP and other free amino acids in *Lathyrus sativus*. In: Kaul AK, Combes D, eds. Abstracts, Second International Lathyrus/Lathyrism Conference in Ethiopia. New York: Third World Medical Research Foundation, 1992:21.
18. International Center for Agricultural Research in the Dry Areas (ICARDA). Germplasm Program (Legumes) Annual Report for 1995. Aleppo, Syrian Arab Republic: ICARDA, 1995:167–9.
19. Dahiya BS. Seed morphology as an indicator for low neurotoxin in *Lathyrus sativus*. Qual Plant Plant Food Hum Nutr 1976;25:391–4.
20. Lambien F, Haque R, Khan JK, Kebede N, Kuo YH. From soil to brain: zinc deficiency increases the neurotoxicity of *Lathyrus sativus* and may affect the susceptibility for the motorneurone disease neurolathyrism. Toxicon 1994;32:461–6.
21. Mannan A, Rahim A. Zinc in nutrition. Dhaka: Bangladesh Agricultural Research Council, 1988:1–412.

Diversity for food security: Improving human nutrition through better evaluation, management, and use of plant genetic resources

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Abstract

The use of plant genetic diversity is essential for ensuring an adequate and stable supply of diverse food crops as well as for enhancing their nutritional quality. The role of effective conservation, management, and use of plant genetic resources in ensuring the availability of a diverse range of nutritious food crops is recognized throughout the work of the International Plant Genetic Resources Institute (IPGRI). Several research activities in the Institute's programme highlight how the diversity between and within food crop species is inextricably linked to the diversity of human cultural needs, preferences, and knowledge systems with respect to the management and use of plant genetic resources. The nutritional quality of food crops is among the major considerations that are important in both the improvement and conservation of genetic resources. Specific examples from IPGRI's work are used to illustrate these linkages.

Introduction

This paper aims to highlight how promoting food crop diversity at both the genetic and the species levels is key to improving nutrition, taking examples from the work of the International Plant Genetic Resources Institute (IPGRI) and related efforts. Promoting access to a wide diversity of food plants ensures the availability of a broad range of nutrients that combine to constitute a more balanced diet. Included in this broad concept of improved nutrition is the recognition that food is an integral aspect of human culture. Habits and cultural preferences—including palatability, cooking quality, and food preparation and storage methods—are therefore considerations that underpin the local acceptance, adoption, and continued use of a particular food plant.

The role of effective conservation management and use of plant genetic resources in ensuring the availability of a diverse range of nutritious food crops is recognized throughout the Institute's work. Relevant areas of IPGRI's work include the development of improved tools and methods for assessing and evaluating useful diversity in *ex situ* collections of germplasm to improve their accessibility for use in breeding programmes; conservation and use of "minor" or neglected and underutilized species; conservation and use of *Musa* through the International Network for the Improvement of Banana and Plantain (INIBAP) Programme; conservation and use of coconut through support to the activities of COGENT (Coconut Genetic Resources Network); and ongoing activities on *in situ* conservation of crop diversity both in traditional farming systems and in home gardens.

Intraspecific diversity: The need for improved evaluation and accessibility of genetic diversity for improving the nutritional quality of specific crops

Variation within major staple crops is relatively well represented in *ex situ* collections worldwide [1]. However, a very small proportion of this useful diversity is incorporated in improved varieties of these crops. Years of focused breeding efforts aimed at increasing yield and other important agronomic traits, such as disease and pest resistance, have resulted in a narrow genetic base in almost all major crop cultivars.

Improved methods for determining the extent and distribution of diversity in existing germplasm collections are therefore needed. More thorough germplasm evaluation work that includes screening for desirable

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nutrition-related traits can provide considerable support to the efforts of plant-breeding programmes. For example, genetic variation has been identified in wild relatives of wheat, which can be exploited to enhance protein content, seed weight, and yield in durum and common wheat [2, 3]. Extensive variation also exists for different characteristics of storage proteins with possible nutritional significance: an IPGRI-supported study uncovered very high variation in the glutenin content of wild wheat [4].

Traditional knowledge of the nutritional properties of different species and varieties can provide valuable leads in identifying useful variation that can be incorporated into breeding programmes to address various nutritional needs. The information held by farmers regarding their crop varieties is often seen in their diverse uses in local food cultures and is reflected in local taxonomies. One widely cited example is the highly valued landrace of Ethiopian sorghum. The local name of this plant, *wetet begunche* (”mouthful of milk”), reveals local knowledge regarding its high lysine content [5]. Germplasm collectors must work with farmers and use appropriate ethnobotanical methods to document such knowledge in the field as a means of flagging promising material. IPGRI has been revising the forms it recommends that collectors use to document germplasm by strengthening their ethnobotanical content, paying due attention to the possibility of gender differences in local people’s knowledge about genetic resources. Participatory plant-breeding approaches can be used to further tap into and add value to this reservoir of traditional knowledge [6].

Species diversity: Promoting the use of minor and neglected species and IPGRI’s work on specific crops

Many species neglected by agricultural research are essential to local communities as sources of both nutritious foods and income. Many of these species are adapted to marginal conditions, such as hilly areas, arid regions, and saline soils. Indeed, in some cases, these are the only crops that can be grown in marginal areas. Although genetic diversity is needed to supply useful traits for improving the nutritional value of specific crops, diversity of species can also provide a broader range of alternative crops that offer options for a more diverse and balanced diet.

Maintaining and ensuring the continued availability and use of a diversity of species provides an important basis for meeting both food security and nutritional goals. In recognition of this, IPGRI assigns priority to those species that make substantial contributions to people’s diets and livelihood strategies in developing countries. Ongoing genetic resources work on the following three categories of species are presented here as examples: neglected and underutilized species, *Musa* spp. (banana and plantain), and coconut.

Neglected and underutilized species

IPGRI has been involved in the compilation and publication of a series of monographs on underutilized and neglected crops in Africa, Asia, and the Americas. The selection of species for this project was partly based on their actual or potential contribution to local food security. Compiling information in this way represents an essential first step in identifying constraints and possible solutions to the use of these plants, and thus possible interventions, including identification of untapped genetic diversity useful for crop improvement programmes. Minor crops with local importance in different regions of the world include carbohydrate-energy-rich traditional cereal crops, such as fonio (*Digitaria exilis*) roots, and tubers, such as taro, as well as pulses and oil seed species, such as the highly nutritious *bambara* groundnut (*Vigna subterranea* L.Verdc.). There is also a diversity of traditional tropical vegetable and fruit species that serve as important sources of dietary vitamins and minerals for local communities throughout the developing world. Two examples are highlighted below.

Jackfruit

IPGRI has been actively involved in plant genetic resource-related activities on tropical fruit species. An expert consultation on “Tropical Fruit Species in Asia” was organized by IPGRI in Malaysia in 1994, in which three major species (mango, citrus, and rambutan) and three minor species (durian, jackfruit, and litchi) were identified as priority species for further work. Jackfruit (*Artocarpus heterophyllus*) is a tropical fruit species that often assumes the role of a secondary staple, particularly in tropical areas prone to seasonal food shortages. It is mainly grown in South and South-East Asia. Jackfruit is used in a variety of ways: fresh, canned, and made into jam, candy, or chutney. The raw fruits are used as vegetable, pickles, and with *papad* (crispy wafer snack of pulse flour). The seeds are eaten roasted, canned, or as flour. The ripe fruit has high nutritive value, with 1.3% to 2.0% protein, 0.1% to 0.4% fat, and 18.9% to 25.4% carbohydrates, and is rich in vitamin C (5.8–10 mg/100 g), vitamin A (540 IU/100 g), calcium (22–27 mg/100 g), and iron (0.4–1.1 mg/100 g).

As a result of IPGRI’s efforts, jackfruit country status reports for Bangladesh, Sri Lanka, and India have been developed and distributed. Although there are sizeable collections, information is scanty. Various constraints to conservation and the use of genetic resources have been identified, leading to the definition of the following research priorities: evaluating genetic variation, developing propagation techniques, designing effective and comprehensive conservation strategies, and identifying methods of adding value. Jackfruit descriptors are being developed in collaboration with the Underutilized Tropical Fruits Asia Network (UTFANET).

African leafy vegetables

African leafy vegetables are wild or semi-cultivated species or crops requiring little management and few inputs. Grown mostly by women in home gardens or gathered in the wild, they represent an affordable and easily accessible source of nutrition, supplying most of the daily requirements for vitamins A, B complex, and C. Many different leafy vegetables are used throughout Africa, some of the most popular being cleomes (*Cleome gynandra*), roselle (*Hibiscus sabdariffa*), bitter leaf (*Vernonia amygdalina*), and black nightshade (*Solanum nigrum*).

The diversity and nutrient value to be found even within this smaller subset of traditional vegetables is immense. However, this resource is under threat, partly because of neglect by the scientific and development communities [7]. The neglect has been attributed to several factors, including the sheer numbers of species involved and the difficulty involved in working with semi-wild material in a formal research station setting. Moreover, many of these species are viewed as “low-status” foods. As a result, many African leafy vegetables, and indeed many traditional food plants used throughout the continent, have been and are being displaced from traditional production systems.

The decline in the production and use of African leafy vegetables can have a significant impact on the nutrition and income of communities, particularly in rural households, where women farmers are very often the primary managers, producers, and sellers of these plants. In response to this concern, IPGRI convened workshops in 1992 in which national plant genetic resources programmes gathered to identify priority species and strategies to address these threats. These consultations led to a research study that IPGRI undertook in collaboration with local communities, scientists, development organizations, and technologists in five African countries: Botswana, Cameroon, Kenya, Senegal, and Zimbabwe. The aim was to increase knowledge about the plant genetic resources of priority species and to link the conservation and sustainable use of these resources to improved nutrition, economic development, and poverty alleviation. By combining indigenous knowledge and conventional documentation of genetic diversity, including nutritional analyses, the study tried to establish the link between plant diversity and nutritional well-being of the rural poor.

A major outcome of the study has been to disprove the conventional perception of African leafy vegetables as “famine foods”—marginal components of traditional farming systems, which are only used occasionally in times of food shortage [7]. In contrast, the study revealed that many of these species are the subject of close management, including selection. For example, several distinct genotypes of bitter leaf (*Vernonia amygdalina),* varying in bitterness, were identified that are grown to meet the dietary preferences in the food cultures of different ethnic groups. Similarly, although the highly prized species of the *Solanum nigrum* complex often grow spontaneously in forest zones, the seeds of preferred types are produced outside these areas, generating a lucrative seed trade.

Cowpea and cucurbits are better known and studied as grain legumes and fruits. Their central role in local diets as green leafy vegetables was clearly demonstrated by the study, which documented that varieties of cowpea and cucurbits used as green leafy vegetables were primarily selected and grown for that purpose. Often, leaf palatability is the primary characteristic used by farmers in selecting particular varieties. By paying closer attention to their uses as leafy vegetables, genetic resources conservationists and plant breeders can promote the contribution of such species as well as that of other better-studied crops (e.g., cassava and sweet potatoes) to local diets. Formal sector horticultural research and development programs can also support the continued use of leafy vegetable species by supporting local systems for the production and exchange of quality seed and planting material of preferred varieties.

Conservation and sustainable use of banana and plantain

The largest component of IPGRI’s work on specific crops is focused on *Musa* species and is carried out within the framework of the International Network for the Improvement of Banana and Plantain (INIBAP). Grown almost exclusively in tropical developing countries, bananas and plantains provide an important staple food for more than 400 million people. With increasing urbanization, bananas and plantains now play an important role in peri-urban agricultural systems. Bananas and plantains grow in a range of environments and produce fruit year-round, thus providing a reliable source of energy during the “hunger period” between harvests. Bananas and plantains are rich in carbohydrates, mainly starch and sugars; their fat content is very low. In addition they are good sources of vitamins A, C, and B_6 and are high in important minerals, such as calcium, phosphorus, and potassium.

Banana and plantain production worldwide is under increasing threat due to growing pest and disease pressure. In some areas, the spread of devastating diseases, such as black Sigatoka, is resulting in the abandonment of bananas. INIBAP's efforts to improve productivity at the smallholder level are therefore likely to have a direct effect on household nutrition levels. The work is focused on developing new disease-resistant varieties and increasing the availability of diversity to banana farmers.

There is a large and very diverse range of varieties of bananas and plantains. It is essential that improved varieties maintain the unique qualities of the cultivars originally selected and grown by farmers. Many such qualities relate to nutritional value and palatability and include traits such as juice production (beer bananas) and softness of flesh (infant food). In order to identify the particular traits that are of importance to the producer and consumer, INIBAP is increasing its efforts to work directly with farmers. Evaluation of new varieties is carried out in participatory trials, and results are fed back to breeding programmes. A recent project on the *in situ* conservation of bananas in East Africa is investigating farmer decision-making in maintaining diversity on the farm. The results will provide information on the role of nutritional value in this process.

Conservation and sustainable use of coconut (*Cocos nucifera* L.)

Coconut provides a good example of a multipurpose plant, the diverse uses and adaptations of which foster the generation and maintenance of genetic diversity, which in turn contributes to food security of local communities. Farmers who grow coconut are strongly attached to the various products and services derived from the plant. Over time, coconut growers throughout the world have contributed to the adaptation of the species to a range of different environments, including high elevations, high latitudes, drought-prone areas, and those subject to heavy winds, as well as a range of soil types.

From a nutritional standpoint, coconut is widely valued for a number of products. Copra (the dried white flesh of the nut) is especially rich in fatty acids and serves as a nutritious, high-energy food. Coconut milk contains appreciable levels of protein (especially glutamic acid) and vitamins and is highly appreciated for its special flavour in many food cultures. Although it is not of much nutritive value, the liquid inside the green coconut is valued as an easily accessible, hygienic, and refreshing drink. The health implications of this in areas where safe drinking water is a limited resource may be considerable. Coconut syrup and sugar, which contain high levels of sucrose, can also be produced by relatively simple traditional processing practices and are used in many local snacks and desserts [8].

Coconut-breeding objectives have been largely focused on improving the oil and copra yields. However, there have also been some nutrition-related coconut improvement efforts aimed at enhancing protein content and the quality of fatty acids in coconut oil. Utilizing a broader range of genetic diversity could strengthen such efforts. Breeders have had access to a very small fraction of the genetic variability that exists within the species, much of which remains in the hands of small-scale farmers growing coconuts in diverse traditional production systems for various local uses.

IPGRI maintains a strong involvement in the conservation and use of coconut genetic resources through the activities of the International Coconut Genetic Resources Network (COGENT) initiated by IPGRI in 1992. COGENT is a global network with a membership of 35 coconut-producing countries. It aims to improve the production and use of coconut and the conservation of its diversity. Genetic improvement of coconut through conventional plant-breeding is a long-term process. In recognition of this, the COGENT programme includes a strong biotechnology component aiming to expedite genetic crop improvement by using a range of novel tools and techniques, including zygotic embryo culture and molecular markers [9].

Diversity of the agricultural landscape: the role of traditional agroecosystems in household nutrition and food security

To ensure the continued availability of useful species and varieties, we need to be concerned not only with genes and genotypes, but also with the farming systems and agroecosystems within which genetic diversity is produced and maintained. Given their close proximity to the home, home gardens—microenvironments within agroecosystems containing high levels of species and genetic diversity—play a particularly significant role in human nutrition at the household level. The diversity of home gardens is intimately linked to the multiple and varied uses of plants [10]. Home gardens often contain species, varieties, and agricultural practices that have fallen into disuse in other settings. They are also foci for experimentation and introduction of new species and genetic diversity. Home gardens contribute to household nutrition and food security by providing direct access to diverse plant foods that can be readily harvested and processed for household consumption, often by using simple, low-input, traditional methods. While field crops often provide the main source of energy, the vitamin-rich vegetables and fruits grown in home gardens serve as important supplements.

Recognizing the importance of home gardens as a source of income and food for the rural poor, IPGRI initiated a project to explore the contribution that home gardens can make to the *in situ* conservation of crop genetic resources. This project includes multidisciplinary activities in five countries: Cuba, Ghana, Guatemala, Venezuela, and Vietnam. In combining biological and socio-economic research, the study will lead to the development of strategies for "conservation through use" that would maximize the benefits from home gardens while maintaining the unique diversity they may contain.

The study of home gardens also brings to the fore the crucial role of women in improving nutrition of their families. Because women's responsibilities in rural crop production systems usually extend from propagation, protection, harvesting, processing, and storage through to the final preparation of food, they often have the most complete understanding of the characteristics and uses of particular plants. Support to home gardens as loci for *in situ* conservation must include gender-sensitive approaches that recognize the specialized and comprehensive knowledge of women.

In situ conservation offers a number of advantages. It can allow the processes of evolution and adaptation of crops to their environment to continue, promote diversity at all levels (intraspecific, specific, and ecosystem), and improve the livelihood of resource-poor farmers.

For *in situ* conservation of crop genetic resources to be effective, more knowledge is needed of the decision-making processes of farmers in selecting and maintaining various varieties on the farm. In recognition of this, IPGRI, in collaboration with national partners in Burkina Faso, Ethiopia, Mexico, Morocco, Nepal, Peru, Turkey, and Vietnam, has initiated a global project to strengthen the scientific knowledge base of *in situ* conservation of agricultural biodiversity on the farm. The project presents opportunities for improving understanding of socio-economic and cultural factors that influence farmer decision-making criteria that have a bearing on genetic diversity as it relates to the nutritional characteristics of different varieties.

Both natural selection and human selection and management affect crop diversity in agroecosystems. Farmers generate and maintain genetic diversity by selecting plants with preferred characteristics, often including traits related to nutrition. Considerations such as taste, palatability, and colour, as well as other culturally valued food-processing, cooking-quality, and storage properties, are given high priority by farmers. This vast genetic diversity is threatened by socio-economic and environmental changes. *In situ* conservation offers a number of advantages for responding to this threat, allowing the processes of evolution and adaptation to continue while improving the livelihood of resource-poor farmers. However, for *in situ* conservation of crop genetic resources to be effective, knowledge is needed of the decision-making processes of farmers in selecting and maintaining different varieties on the farm.

IPGRI, in collaboration with national partners in Burkina Faso, Ethiopia, Mexico, Morocco, Nepal, Peru, Turkey and Vietnam, has initiated a global project to strengthen the scientific base of *in situ* conservation of agricultural biodiversity on the farm. The project is improving our understanding of the socio-economic and cultural factors that influence farmers' decision-making criteria that have a bearing on genetic diversity in useful agromorphological, agronomic, and nutritional traits.

Conclusions and prospects

In conclusion, we would highlight three areas of management and use of plant genetic resources where strategic efforts in the future can be expected to contribute significantly to improved nutrition.

First, it is necessary to recognize the value of the local knowledge held by farming communities with respect to the management, properties, and use of plant diversity at the intraspecific, specific, and agroecosystem levels. The generation and continued maintenance of diversity is supported by traditional knowledge and practices. To have a greater impact on local nutrition, whether through the identification and development of useful genetic variation or through support for on-farm maintenance and use of crop diversity, agricultural researchers and plant breeders will need to forge innovative partnerships with farming communities. The link between the sources of genetic diversity, the systems for maintaining that diversity, and the users of diversity is at the core of both the challenge and the opportunity that decentralized participatory breeding strategies offer for conserving and using crop genetic diversity to support the livelihoods of farming communities and meet their nutritional needs [6].

Second, nutrition can be further improved through attention to traditional storage and food-preparation and cooking practices, with a view to improving their effectiveness in maintaining levels of nutrients derived from different plants. In the case of important multipurpose crops such as coconut, such efforts can go a long way not only in enhancing their food value, but also in improving their competitiveness in the market, thereby supporting the livelihoods of the rural poor. There is considerable scope for improving preparation practices for many neglected and underutilized species, commonly cited as constraints to use. Although knowledge of how the plants are grown and of their genetic diversity is most pressing for such lesser-known species, strengthening local knowledge and capacity in processing and preparing them for food should also be an integral part of strategies to promote their continued use as vital components of local diets.

Finally, increased use of rapidly evolving molecular tools for assessing, maintaining, and using genetic diversity holds great promise for strengthening efforts not only to increase yields but also to enhance the nutritional quality of food crops. The greatest impacts are likely to be in the areas of *in vitro* conservation and use of plant genetic resources, including micropropagation techniques and the production of disease-free material for safe exchange of germplasm, better understanding of both the extent and the distribution of genetic diversity, within both *ex situ* collections and *in situ* populations, and marker-assisted identification and transfer of desirable traits (including those related to nutritional properties) to develop improved varieties [9]. Molecular techniques provide researchers with powerful new tools for exploiting the reservoir of valuable genetic diversity found in wild relatives and farmers' varieties, which account for the bulk of genetic diversity within most crop gene pools.

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References

1. Food and Agriculture Organization. State of the world's plant genetic resources for food and agriculture. Prepared for the International Technical Conference on Plant Genetic Resources, Leipzig, Germany, 17–23 June 1996. Rome: FAO, 1998.
2. Feldman M, Millet E. Utilization of wild tetraploid wheat, *Triticum turgidum* var. *dicoccoides* for the increase in yield and protein in cultivated tetraploid and hexaploid wheats. Rehovot, Israel: Plant Genetics, Weizmann Institute of Science, 1991.
3. Castagna R, Borghi B, Heun M, Salamini F. Integrated approach to einkorn breeding. In: Padulosi S, Hammer K, Heller J, eds. Hulled wheats. Promoting the conservation and use of underutilized and neglected crops. 4. Proceedings of the First International Workshop on Hulled Wheats, 21–22 July 1995, Castelvecchio Pascoli, Tuscany, Italy. Rome: Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, 1996:183–92.
4. Bahraei S. Study of genetic diversity in the wild species of *Triticum* (*T. boeoticum* and *T. urartu*) using seed storage proteins electrophoresis. Seed and Plant 1996;12(2):1–9.
5. International Crop Research Institute for the Semi-Arid Tropics. ICRISAT research highlights 1984. Andhra Pradesh, India: ICRISAT, 1985.
6. Eyzaguirre PB, Iwanaga M. Farmers' contribution to maintaining genetic diversity in crops and its role within the total genetic resources system. In: Participatory plant breeding. Proceedings of a workshop on participatory plant breeding, 26–29 July 1995. Wageningen, Netherlands. Rome: International Plant Genetic Resources Institute, 1996:9–18.
7. Chweya JA, Eyzaguirre PB, eds. The biodiversity of traditional vegetables. Rome: International Plant Genetic Resources Institute, 1999.
8. Batugal PA, Ramantha Rao V, Bong C, eds. 1998. Promoting multipurpose uses and competitiveness of coconut. Proceedings of a workshop, 26–29 September 1996. Chumphon, Thailand: International Plant Genetics Research Institute Office for Asia, Pacific, and Oceania, Serdang.
9. Rao VR, Iwanaga M. Utilization of plant genetic resources. In: Watanabe K, Pehu E, eds. Plant biotechnology and plant genetic resources for sustainability and productivity. Austin, Texas, USA: R. G. Landes Company, 1997:29–56.
10. Landauer K, Brazil M, eds. 1990. Tropical home gardens. Tokyo: United Nations University Press.

A comment on how the nutritional impact of agricultural innovations can be enhanced

Suttilak Smitasiri

Abstract

The potential of agriculture still is not sufficiently appreciated by the nutrition community. The marriage of agriculture and nutrition in developing countries has been rare and often unsuccessful. There have been compelling reasons to find relatively quick ways to reduce malnutrition without treating the underlying causes. Thus, national and international nutrition leaders have focused their attention on medically oriented approaches. To many nutrition workers, improving nutrition through food-based approaches is a good idea in theory, but it is not feasible in terms of implementation. More emphasis should be placed on programmes and policies that involve non-staple plant foods, especially fruits and vegetables. For the poor, the cost of animal and fish products is simply too high. Micronutrient-rich vegetable sources are well within their purchasing power.

Education and promotion are essential elements for successful food and nutrition interventions. Agricultural innovations will be transferred more effectively and will have enhanced nutritional impact if researchers in agriculture, food policy, and nutrition can also be change initiators and catalysts for better implementation, along with governmental agencies, non-governmental organizations, and intended beneficiaries. Education and promotion do not always reach the more disadvantaged, who are often not well integrated into community power structures, which makes it difficult for them to participate in community activities. A special intensive programme for the poor is often necessary. It is very important that all involved work towards the same goals and use a common set of indicators in achieving change. A "decision-development-dissemination" framework is proposed for enhancing the nutritional impacts of agricultural innovations.

Introduction

In most developing countries, where nutritional deficiencies, including micronutrient deficiencies, remain significant public health problems, agricultural innovations leading to increased production and consumption of non-staple foods should play vital roles in the reduction of micronutrient deficiencies. However, as a nutrition worker from a developing country, I believe that the potential of agriculture is still not sufficiently appreciated by the nutrition community. The marriage of agriculture and nutrition in developing countries has been rare and often unsuccessful. In the past few decades, most national and international nutrition leaders have focused their attention on a medically oriented approach as a sound solution to nutrition problems. Because so many, especially mothers and children, suffer from malnutrition, there have been compelling reasons to find quick ways to reduce the deficiencies without treating the underlying causes. Dietary improvement is often mentioned as a long-term solution to nutritional problems, but it is considered too complex to be implemented in the short run.

Are we ready to accept the power of vegetable and fruit sources?

From what one can learn from papers presented in this section of the proceedings, it can be concluded that we should put more emphasis on programmes and policies that involve non-staple plant foods, especially fruits and vegetables. First, malnutrition is most often found in poor populations. For them, the cost of animal and fish products is simply too high. Micronutrient-rich vegetable sources are well within their purchasing power. Second, vegetables are the most economically efficient source of micronutrients, considering both per unit land required and per unit production cost. Third, the role of the vast diversity of minor traditional plant foods in meeting the nutritional needs of local communities deserves particular attention.

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Our experience in Thailand indicates that the poor can be key actors in vegetable production. Success from this activity can lead to self-efficacy, which can consequently lead to further nutritional development. In other words, agricultural innovations that promote vegetable and fruit production and consumption might be good strategies not only for improving nutrition, but also for inducing more community involvement by the poor and for the poor.

The importance of combining new knowledge with policy implementation

To be more successful in the future, we, the programme and policy designers and implementers, need to be responsible not only for development of new knowledge but also for *how* to implement programmes and policies. To many nutrition workers, improving nutrition through food-based approaches is a very good idea in theory, but it is not feasible in terms of implementation. It is simply too complex and requires sophisticated management.

Agricultural innovations will be transferred more effectively and will have enhanced nutritional impact if researchers in agriculture, food policy, and nutrition can also be change initiators and catalysts for better implementation with other stakeholders, i.e., governmental agencies, non-governmental organizations (NGOs), and intended beneficiaries. I do believe that more interaction between those working in agriculture, food policy, and nutrition will lead to new insights, better policy implementation, and a more sustainable approach to improving nutrition. I particularly like the approaches taken at the Asian Vegetable Research and Development Center (AVRDC) in Taiwan, which integrate plant-breeding, nutritional quality, and economic value, and at the International Plant Genetic Resources Institute (IPGRI) in Italy, where a holistic perspective, including nutrition, culture, and traditional knowledge, is valued.

Developing multidisciplinary and multilevel indicators

For agricultural, food policy, and nutrition researchers to work more effectively with the other stakeholders just mentioned, it is most important that all involved work towards the same goals and use a common set of indicators in achieving change. Therefore, the development of multidisciplinary and multilevel indicators is essential. I am particularly interested in indicators because they are often very powerful tools in the change process. Such indicators serve to activate all stakeholders to take collective action to enhance the nutritional impact of agricultural innovations. The suggestion that food variety and diet diversity might be useful as cost-effective, simple, and quick indicators for food and nutrition improvement seems particularly worth pursuing.

Understanding the role of education and promotion

Education and promotion is an essential element for successful food and nutrition interventions. The significance of this element needs more attention from agricultural and nutritional researchers as well as governmental organizations and NGOs working in food and nutrition development.

In the 1970s, the theory of "diffusion of innovations" was very popular in agricultural development and also in communications schools. According to this theory, once we have a technology, we can find ways to diffuse it. However, today problems are much more complex, and the diffusion of innovations has consequently become much more complicated as well. To be more successful, we need to be more strategic about our aims and objectives. We simply do not have enough resources to work on every innovation. Decisions need to be made and adequate efforts should be put into activities that promote the adoption of selected innovations.

For future innovation development, a thorough understanding of those we would like to assist should always be a prerequisite. How much do we really understand the poor? How much do we really take into account their needs and values when we develop agricultural innovations? We must put human faces into innovation development. Moreover, it is necessary to understand that successful education and promotion of agricultural innovations for the poor will be difficult to achieve. A well-thought-out series of steps is necessary to convince many stakeholders, i.e., the poor, their community leaders, and policy makers, to take action to improve food and nutrition.

Effective education and promotion to enhance the nutritional impacts of agricultural innovations

A "decision-development-dissemination" approach may be proposed as a generic framework for enhancing the nutritional impacts of agricultural innovations. This framework, shown in figure 1, suggests that an effective education and promotion programme should start with sound decision-making. In this process, initially some basic questions should be raised: Why is it necessary to invest in enhancing the nutritional impact of agricultural innovations? How much should be invested in such activities? If necessary resources

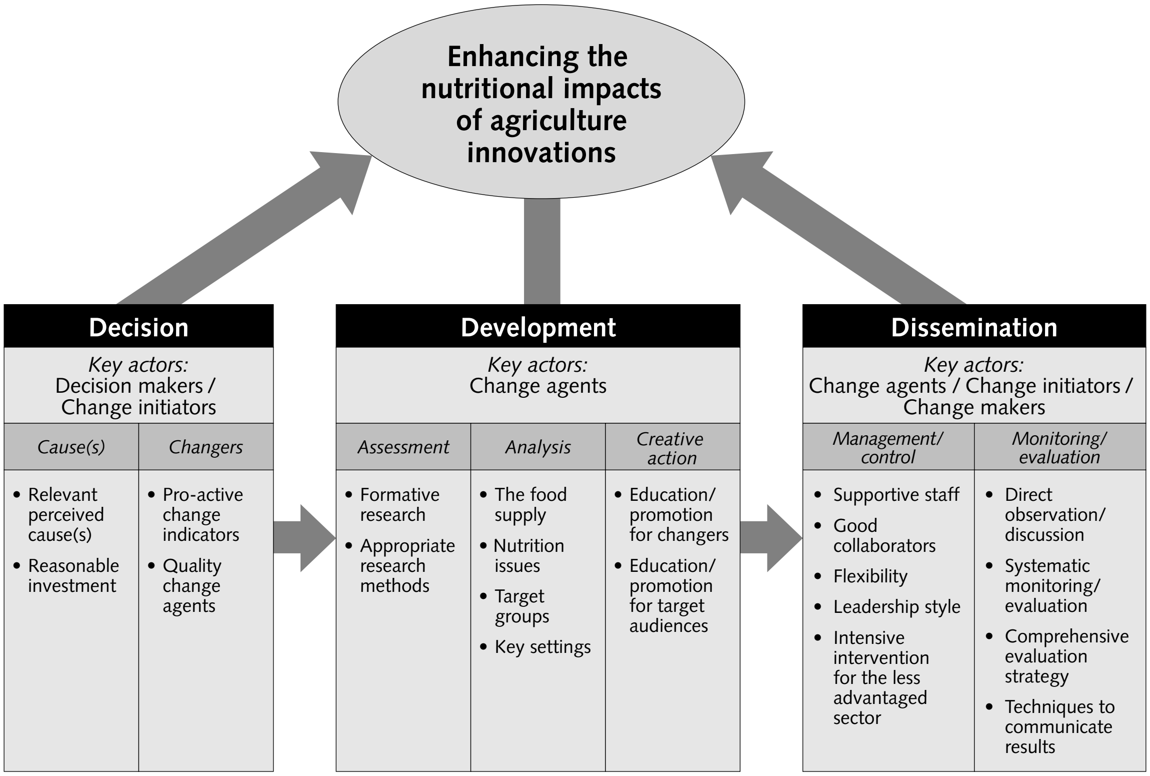

FIG. 1. The decision-development-dissemination approach as a generic framework for enhancing the nutritional impacts of agricultural innovations

are provided, will there be capable people to manage the expected changes?

Second, this generic framework emphasizes the importance of programme development. In addition to standard procedures for effective planning and implementation, it highlights three essential elements: assessment, analysis, and creative action. Assessment of contextual situations and stakeholder perceptions is the solid foundation required for a problem-solving process to be effective. Understanding the target population and its relation to the food supply, nutrition issues, target groups, and key settings is particularly critical for planning and implementing a national nutrition education programme. Many large-scale nutrition education programmes in developing countries did not use research to guide their intervention designs. Many programmes were more source oriented, rather than audience or target oriented. Lessons learned from successful programmes often indicate that if the programmes had used formative research to guide planning and implementation of the intervention, the programme would have had more chances of success. “Key settings” in the area of health and nutrition promotion mean important places, such as schools and workplaces, that can be used for venues of nutrition education.

Analysis is essential for planners to select the appropriate target groups, the appropriate settings and sectors for programme delivery, and a range of education, promotion, and support strategies appropriate to the target groups and settings. *Creative action* involves education and promotion actions both for change agents themselves and for target audiences at different levels. Education and promotion actions for change agents are necessary to maintain the level of knowledge and skills needed to implement a programme, to facilitate teamwork, and indirectly to cause change agents to recognize their importance to the programme. Education and promotion actions for the target audiences should be seen as a comprehensive multichannel and multiapproach intervention that is designed to maximize reach and effectiveness through the appropriate combination of community outreach, the use of mass media and folk media, and school programmes, as well as interpersonal communication.

Third, *dissemination* is crucial for promoting and securing sustainable change. This process consists of two major interactive elements: management and control, and monitoring and evaluation. In general, management and control of an education and promotion programme is likely to be successful if it has, at minimum, three characteristics: supportive staff, good collaborators, and flexible management and control. An effective leadership style and an interactive working environment are particularly crucial for securing programme staff support. Education and promotion interventions do not always reach the more disadvantaged, who often face what seem insurmountable constraints. In part, this is because they are often not well integrated into community power structures, which makes it difficult for them to participate in community activities. For these reasons, a special intensive programme for the less advantaged is necessary.

Effective management and control also relies on a good monitoring and evaluation process. The implementation team should always have a clear and accurate picture of the target population, their baseline situation, and how the situation changes as the programme is implemented. Direct observation of and regular discussions with target audiences themselves are helpful. Systematic monitoring and evaluation must be considered whenever it is feasible. A good education and promotion programme also needs a comprehensive evaluation strategy, one that combines appropriate quantitative and qualitative evaluation methods. In addition, techniques should be used to guarantee that evaluation results are effectively communicated to all involved, including the public, in order to stimulate further development.

Conclusions

We must find ways and means to promote the production and consumption of non-staple plant foods, especially vegetables and fruits. In my view, we need to work more on linking research to action. Agriculture, food policy, and nutrition researchers must work together as advocates to enhance the nutritional impacts of agricultural innovations. I believe that “critical mass building” research and development, resulting from collaboration between researchers and practitioners, can be an exciting area in which agriculture, food and nutrition researchers, and practitioners can all contribute. This type of research and development is very timely, since we have already acquired much useful knowledge and innovations in the past few decades. I suggest that this research and development activity should use a multidisciplinary approach, be action oriented and area based, and have a development focus. In addition, the work should be done with the assumptions that good assessment of local potential will lead to better design of food and nutrition implementation. More importantly, the poor, especially the women of poor communities, are key actors. They are our real agents for enhancing the nutritional impacts of agricultural innovations in developing countries. To be successful, we need to find ways and means to work with them more effectively.

The Philippine Plan of Action for Nutrition: An overview

Corazon Barba

Abstract

The Philippine Plan of Action for Nutrition (PPAN) is the blueprint for an integrated programme of nutrition interventions, formulated under the leadership of the National Nutrition Council (NNC), which serves as the coordinating body for the implementation of nutrition-related programmes and projects and has responsibility for monitoring and evaluation. The Governing Board of the NNC is chaired by the Secretary of Agriculture and nine cabinet Secretaries, and the heads of three private-sector institutions sit as members. The PPAN goals are consistent with the global call to eradicate malnutrition made during the 1992 International Conference on Nutrition. The PPAN also falls within the framework of the Medium-Term Philippine Development Plan. The PPAN aims to reduce protein–energy malnutrition among children, chronic energy deficiency among adults, and micronutrient deficiencies among all population groups, with specific targets to be reached by the year 2004. Iron-deficiency anaemia, vitamin A deficiency, and iodine-deficiency disorders remain serious public health concerns.

PPAN programmes are implemented in the following areas: home, school, and community food production; micronutrient supplementation; food fortification; food assistance; livelihood assistance; and nutrition education. To support the implementation of the above programmes, various enabling mechanisms have been or will be institutionalized: human resource development; advocacy; research and standards; overall planning, coordination, management, and surveillance; and resource generation and mobilization. The paper provides brief descriptions of all these programmes and enabling mechanisms.

Introduction

According to national nutrition surveys, persistent malnutrition problems, such as protein–energy malnutrition and micronutrient deficiencies (iron-deficiency anaemia, vitamin A deficiency, and iodine-deficiency disorders), continue to afflict a major proportion of Filipinos, particularly infants and pre-school children, pregnant women, and lactating mothers.

With cognizance of these problems, an integrated plan of action for nutrition was formulated by the local multisectoral nutrition community, consistent with the global call to eradicate malnutrition made during the International Conference on Nutrition (ICN) held in December 1992. Our Philippine Plan of Action for Nutrition (PPAN) is thus consistent with the ICN goals of promoting, achieving, and maintaining the nutritional well-being of individuals and also falls within the framework of the Medium-Term Philippine Development Plan. The signing of the Commitment makes nutrition a governmental priority, to be implemented by all branches of the executive, and integrating nutrition objectives into all the development efforts of the country.

Although the country's fight against malnutrition did not start with the signing of the Commitment, the formulation of the PPAN made for more harmonized policies, more focused programmes, and sustainable strategies that augur well for the reduction of malnutrition.

The Philippine food and nutrition situation

The Food and Nutrition Research Institute of the Department of Science and Technology is mandated to periodically undertake assessments of the country's food situation and the nutritional status of the Filipino population. Since 1978, five national nutrition surveys have been conducted at intervals of five to six years. The most recent and fifth survey in this series was undertaken in 1998–99.

The usual nutrition survey has four elements: the anthropometric survey, the food-consumption survey, the clinical assessment, and the biochemical survey.

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This approach to nutritional assessment, though comprehensive, is costly, tedious, and time-consuming. The sampling design is primarily oriented towards generating national estimates and, to some extent, regional estimates. Because of the demand for more frequent and more disaggregated data at the provincial level, anthropometric surveys of children up to 10 years of age are being conducted every 2 to 3 years.

Food-consumption pattern and nutrient adequacy levels

The trends in per capita consumption of various foods show a general decrease from 1978 to 1993 (table 1) [1, 2]. As a result of the general decrease in food consumption, intakes of energy and other nutrients, such as iron, calcium, and ascorbic acid, also decreased (table 2). Although protein and retinol intakes have increased, these increases are not statistically significant. The recent economic crisis and rising prices of food can explain the worsening diets.

Anthropometry

According to the 1998 update of the nutritional status of 0- to 10-year-old Filipino children, using the Food and Nutrition Research Institute Philippine Anthropometric Standards [3], about 9.2% of 0- to 5-year-old children were moderately or severely underweight, 5.4% were stunted, and 7.2% were wasted. Some 8.3% of 6- to 10-year-old children were moderately or severely underweight, 5.8% were stunted, and 8.7% were wasted. According to the National Center for Health Statistics (NCHS) standards, 31.8% of 0- to

TABLE 2. Comparison of mean one-day per capita nutrient intake: Philippines, 1987 and 1993

Nutrient	Intake 1987	Intake 1993	% change
Energy (kcal)	1,753	1,684	–3.9**
Protein (g)	49.7	49.9	0.4
Iron (mg)	10.7	10.1	–5.6**
Calcium (g)	0.42	0.39	–7.1**
Retinol equivalents (μg)	389.7	391.9	0.6
Thiamine (mg)	0.68	0.67	–1.5
Riboflavin (mg)	0.56	0.56	–0.0
Niacin (mg)	16.3	16.1	–1.2
Ascorbic acid (mg)	53.6	46.7	–12.9**

** Significant at α = 0.01.

TABLE 1. Comparison of mean one-day per capita food consumption: Philippines, 1978, 1982, 1987, and 1993

	Consumption (raw, as purchased) in grams						
					1993		
Food group/subgroup	1978	1982	1987	1993	Urban	Rural	% change 1987–93
Total food	897	915	869	803			
Cereals and cereal products	367	356	345	340	318	361	–1.4
Rice and rice products	308	304	303	282	273	290	–6.9*
Corn and corn products	38	34	24	36	17	55	50.0**
Starchy roots and tubers	37	42	22	17	13	21	–22.7**
Sugars and syrups	19	22	24	19	20	17	–20.8**
Fats and oils	13	14	14	12	14	10	–14.3**
Fish, meat, and poultry	133	154	157	147	161	133	–6.4**
Fish and fish products	102	113	111	99	98	100	–10.8**
Meat and meat products	23	32	37	34	44	23	–8.1
Poultry	7	10	9	14	19		
Eggs	8	9	10	12	15	9	20.0**
Milk and milk products	42	44	43	44	64	24	2.3
Dried beans, nuts, and seeds	8	10	10	10	11	8	0.0
Vegetables	145	130	111	106	98	113	–4.5
Green leafy and yellow	34	37	29	30	25	34	3.4
Other	111	93	82	76	73		
Fruits	104	102	107	77	82	73	–28.0**
Vitamin C–rich	30	18	24	21	27	15	–12.5
Other	74	84	83	56	55	58	–32.5**
Miscellaneous	21	32	26	19	23	16	–26.9**

** Significant at α = 0.01.

59-month-old children were underweight, 32.0% were stunted, and 6.6% were wasted.

Micronutrient malnutrition

The past five national nutrition surveys revealed a persistent micronutrient malnutrition problem among the most vulnerable population groups, particularly infants, pre-school children, and pregnant and lactating women. Iron-deficiency anaemia, vitamin A deficiency, and iodine-deficiency disorders remain serious public health concerns.

Iron-deficiency anaemia

Iron-deficiency anaemia, as evidenced by haemoglobin determination according to the cyanmethaemoglobin method, had a prevalence rate of 30.6% of the population surveyed in 1998 [4]. The highest prevalence, 56.6%, was observed among infants six months to one year of age, followed by pregnant and lactating women (50.7% and 45.7%, respectively).

Although the national prevalence of iron-deficiency anaemia declined significantly from 37.2% in 1987 to 28.9% in 1993 [5], in 1998 the prevalence rate increased slightly to 30.6% [6]. Iron-deficiency anaemia remains the most serious micronutrient problem among the country's vulnerable population groups.

Vitamin A deficiency

Vitamin A deficiency causes night-blindness, which may lead to xerophthalmia and eventually to total blindness. In the Philippines, many children go blind each day, and about 4 million pre-schoolers are at risk of going blind because of vitamin A deficiency.

This statement is based on the findings of the 1993 nutrition survey on the prevalence of vitamin A deficiency [2]. In this survey, night-blindness and Bitot's spots were noted in 1.2% of Filipinos, particularly those 6 months to 19 years old and pregnant and lactating women. Biochemical tests showed that among children aged 6 months to 6 years, the prevalence of deficient serum vitamin A levels (< 10 μg/dl) was 10.4%, and the prevalence of deficient to low serum vitamin A levels (< 20 μg/dl) was 35.3% [5]. These prevalence rates of vitamin A deficiency indicate a problem of public health significance, since they exceed the World Health Organization cut-off points of 5% and 15%, respectively [7, 8].

Iodine-deficiency disorders

Iodine deficiency may lead not only to visible goitre but also to impaired physical and mental development. Iodine deficiency is the most common cause of mental retardation and causes a number of serious disorders, such as deaf-mutism and cretinism, as well as being associated with an increased risk of spontaneous abortion, stillbirth, and birth defects.

The prevalence of iodine deficiency in the Philippines, as manifested by goitre, doubled from 3.5% in 1987 to 6.7% in 1993, with markedly higher prevalence rates among women than among men, particularly pregnant and lactating women [9].

From the data of the 1998 survey, the iodine-deficiency problem in the Philippines is of mild severity based on the median urinary iodine excretion of 71 μg/L and using the WHO/UNICEF/ICCDD criteria [10]. According to the percent distribution of urinary iodine excretion values, 35.8% of 6- to 12-year-old Filipino children have moderate to severe levels of iodine deficiency [6].

The Philippine Plan of Action for Nutrition

The Medium-Term Plan of Action for Nutrition, also known as the Philippine Plan of Action for Nutrition (PPAN), is the country's blueprint for achieving nutritional adequacy for all Filipinos, and the Philippine government's commitment to eradicating hunger and malnutrition [11].

The formulation of the Plan was spearheaded by the National Nutrition Council (NNC), which also serves as the coordinating body for the implementation of programmes and projects and for the monitoring and evaluation of nutrition-related activities in the country.

The NNC is a multidisciplinary, multilevel network established to promote the stable and equitable distribution of food and services to the Filipino population. The Council is composed of a Governing Board, which is the highest policy-making body of the NNC. It is chaired by the Secretary of the Department of Agriculture. Nine Cabinet Secretaries sit as members of the Governing Board, as well as the heads of three other private-sector institutions, the Koalisyon Para Alaggan at Isalba ang Nutrisyon (KAIN), the Nutrition Center of the Philippines (NCP), and the Rural Improvement Clubs of the Philippines (RIC).

The PPAN was formulated within the framework of the Philippine Medium-Term Development Plan. It upholds human development as the ultimate goal of all development efforts in the country.

The PPAN aims to reduce protein–energy malnutrition among children, chronic energy deficiency among adults, and micronutrient deficiencies, particularly vitamin A, iron, and iodine deficiencies, among all population groups. By the year 2004, it is hoped that the following targets will be achieved:

» reduction of the prevalence of protein–energy malnutrition among pre-school children by 20%, as measured by the NCHS standards for anthropometry cited above;
» reduction of the prevalence of chronic energy deficiency among adults by 20% ;

- reduction of the prevalence of iron-deficiency anaemia by 20%, as measured by blood haemoglobin;
- reduction of the prevalence of vitamin A deficiency, as measured by serum retinol in 6-month- to 6-year-old children, from 35.0% in 1993 to less than 15%;
- reduction of the prevalence of iodine-deficiency disorders, as measured by urinary iodine excretion among school-aged children, from 35.8% in 1998 to less than 20%;
- maintenance of the prevalence of overweight among pre-school children at 1.0%; reduction of the prevalence of overweight among schoolchildren by 58% and among adults by 20%;
- increase in the prevalence of exclusive breastfeeding of infants 0 to 6 months of age by 50%;
- 20% reduction in the proportion of families whose income falls below the food threshold.

The targeted percentage reductions are based on the 1993 and 1996 baseline data of the National Nutrition Surveys. However, when the complete results of the 1998 national nutrition survey are available, there may be a need for retargeting.

Programmes, projects, and activities

During the period from 1999 to 2004, the PPAN will continue to be operationalized vigorously in a number of impact programmes, as briefly summarized below. Detailed discussions of these programmes are given elsewhere in this issue [12–14].

The *Home, School, and Community Food Production Programme* is a long-term, sustained measure to alleviate protein–energy and micronutrient deficiencies among Filipinos. It involves the establishment of kitchen gardens in homes, schools, and communities, using biointensive agricultural technologies; the provision of the initial seed supply and gardening implements; the dissemination of the rearing of small animals; and the provision of water-supply systems.

The *Micronutrient Supplementation Programme* will target nutritionally at-risk groups, particularly infants, pre-schoolers, and pregnant and lactating women. Pharmaceutical preparations of vitamin A, iron, and iodine will be provided for the prevention and treatment of micronutrient deficiencies.

The *Food-Fortification Programme*, as a preventive and long-term food-based intervention, will be a continuing commitment. This is a collaborative undertaking between government and private-sector industry. To ensure commercialization of technologies on fortified foods, partnerships with the food industry will be undertaken.

The *Food Assistance Programme* consists of a social safety net for nutritionally vulnerable groups during periods of physical and economic displacement. The programme will include regular supplementary feeding schemes, emergency feeding, and food price discounts.

The *Livelihood Assistance Programme* provides capital loan assistance for small-scale income-generating projects, thus creating employment and generating additional sources of income for nutritionally at-risk families. Skills training is provided to sustain income-generating project initiatives.

The *Nutrition Education Programme* aims to increase the level of nutrition awareness and appropriate knowledge and practices to ensure nutritional well-being. It is an integral component of other impact programmes to ensure effectiveness.

Enabling mechanisms

To support and propel the implementation of the programmes, various enabling mechanisms have been or will be institutionalized.

Human resource development involves training of implementers, service providers, and managers in programme planning and project management, as well as monitoring and evaluation, to equip them with the necessary skills, knowledge, and attitudes for the effective delivery of nutrition services.

Nutrition advocacy shall include legislative advocacy for passing important nutrition bills, such as the Salt Iodization Law, Nutrition Labelling, and Food Fortification, among others. Policy advocacy shall be strengthened to ensure the integration of nutrition in all development efforts.

Nutrition research shall provide sound and scientific bases for continually improving the PPAN implementation in terms of policy decision and programme design. A five-year nutrition research agenda will be developed in the areas of food fortification, functional foods, standards and requirements formulation, nutrition intervention modeling, and nutritional assessment. Nutrition research and development will be led by the Food and Nutrition Research Institute.

Overall planning, coordination, management, and surveillance, as mandated, shall be conducted by the NNC, coordinating and orchestrating all nutrition activities from the national down to the *barangay* level of implementation.

Resources for the implementation of the PPAN will be generated from the pooled resources of the nutrition network, including private sector and international organizations supporting the PPAN.

Conclusions

The preliminary results of the Fifth National Nutrition Survey for some parameters show a deterioration in the nutrition situation of the country, despite the efforts of all the key players in nutrition. This could be attributed to the fact that the Philippines was not spared by the Asian economic recession, the regional currency crisis, and the effect of natural calamities (such as El Niño and La Niña). These setbacks should not discourage us but rather may serve as guides for the improvement of existing programmes and the design of new approaches and stronger policies on nutritional improvements.

References

1. Florentino RF. Nutrition situation: today and tomorrow. Occasional Paper No 9. Bicutan, Taguig, Metro Manila: Food and Nutrition Research Institute, 1996.
2. Villavieja GM, Cerdña CM, Molana WL, Laña RD, Boquecosa JP, Raymundo BE, Nones CA, Abaya HSP, Palafox EF, Chavez MC, Burayag GA, Pine CR, Recuenco JRD, Saturno DS, Delos Reys CM. Fourth National Nutrition Survey: Philippines, 1993. Part A. Food consumption survey. Philippine J Nutr 1997;XLIV(1-2):4–21.
3. Villavieja GM, Molano WL, Cerdeña CM, Laña RL, Constantino AS, Tarrayo ER, Concepcion DS, Juguan JA, Sario IS**.** Fourth National Nutrition Survey: Philippines, 1993. Part B. Anthropometric survey. Philippine J Nutr 1997;XLIV(1-2):36–48.
4. Madriaga JR, Cheong RL, Perlas LA, Desnacido JA, Marcos JM, Cabrera MIZ. Prevalence of anaemia among Filipinos. Paper presented during the Symposium on Initial Results of the Fifth National Nutrition Survey: Philippines 1998, held at the Manila Midtown Hotel, 19 October 1999.
5. Kuizon MD, Perlas LA, Madriaga JR, Cheong RL, Desnacido JA, Marcos JM, Fuertes RT, Valdez DH. Fourth National Nutrition Survey: Philippines, 1993. Part D. Biochemical nutrition survey. Philippine J Nutr 1997;XLIV(1-2):71–5.
6. Madriaga JR, Cheong RL, Perlas LA, Desnacido JA, Marcos JM, Loyola AS, Sison CC, Cabrera MIZ. Prevalence of iodine deficiency in the Philippines. Paper presented during the Symposium on Initial Results of the Fifth National Nutrition Survey: Philippines 1998, held at the Manila Midtown Hotel, 19 October 1999.
7. International Vitamin A Consultative Group (IVACG). Biochemical methodology for the assessment of vitamin A status. Washington, DC: Nutrition Foundation, 1982.
8. International Vitamin A Consultative Group (IVACG). Methodologies for monitoring and evaluating vitamin A deficiency intervention programs. Washington, DC: Nutrition Foundation, 1989.
9. Velandria FV, Magbitang JA, Tanchoco CT, Mendoza TS, Orense CL, Tango JB, Mendoza SM, Duante CA, dela Cruz EO, Abarra LV. Fourth National Nutrition Survey: Philippines, 1993. Part C. Clinical nutrition survey. Philippine J Nutr 1997;XLIV(1-2):60–2.
10. WHO/UNICEF/International Council for the Control of Iodine-Deficiency Disorders (ICCIDD). Indicators for assessing iodine deficiency disorders and their control through salt iodization. WHO/NUT 94.6. Geneva: World Health Organization, 1992.
11. National Nutrition Council. Medium-Term Philippine Food and Nutrition Plan, Manila: Philippines: National Nutrition Council—Department of Agriculture, 1994.
12. Bayani EM. Reducing micronutrient malnutrition: policies, programmes, issues, and prospects—dietary diversification through food production and nutrition education. Food Nutr Bull 2000;21:520–5.
13. dela Cuadra AC. The Philippine micronutrient supplementation programme. Food Nutr Bull 2000;21:511–13.
14. Solon FS. Food fortification in the Philippines: policies, programmes, issues, and prospects. Food Nutr Bull 2000;21:514–9.

The Philippine micronutrient supplementation programme

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Abstract

The Philippine micronutrient supplementation programme covers the three major international micronutrient deficiency problems: vitamin A, iron, and iodine. Supplementation is administered through provision of capsules and liquid preparations. There are two major occasions during which universal supplementation is conducted: National Immunization Day and National Micronutrient Day. On National Immunization Day, initially vitamin A supplements were given together with several vaccines. Starting in 1996, immunization was restricted to polio vaccine. Various types of micronutrient interventions are included in National Micronutrient Day, such as distribution of vegetable seeds and cuttings to promote home food production, education on proper nutrition, testing of salt for iodine, distribution of iodized salt to poor families, and promotion of fortified foods. Various health-related activities are also included. The existence of a well-functioning health infrastructure facilitated the establishment of the distribution system. Supplementation centres manned by volunteers were set up in neighbourhoods throughout the country. International organizations and other national governmental agencies contributed resources, not only to purchase supplements, but also to provide promotional materials and expertise in social mobilization. There was full media participation in the implementation of the programme. Funding limitations have led programme planners to prioritize target groups for supplementation. The campaign approach has been very effective for increasing the coverage levels for vitamin A and iodine capsules to well above 80% on average. There is the need to develop an effective record system at the field level to reduce the possibility that children will get high-dose supplements too frequently, which could result in toxicity.

Introduction

Micronutrient supplementation is the administration of pharmaceutically prepared vitamins and minerals to target individuals or groups for treatment and/or prevention of a specific micronutrient deficiency. The Philippine micronutrient supplementation programme is presently covering the three major international micronutrient deficiency problems: vitamin A, iron, and iodine. Supplementation is administered through provision of capsules and liquid preparations.

Vitamin A capsules contain large amounts of retinol, which is fat soluble. Once absorbed and stored in the liver, retinol is excreted slowly; enough retinol is stored to sustain vitamin A requirements for 4 to 6 months. Thus, capsules are given at 6-month intervals to priority target groups. A capsule containing 200,000 international units (IU) is given to children 12 to 59 months old and to breastfeeding mothers within 1 month of delivery. A 100,000 IU capsule is given to infants 6 to 11 months of age. Pregnant women are given 10,000 IU capsules for daily consumption.

Iron preparations consist of ferrous sulphate ($FeSO_4$) in tablet, syrup, and drop forms, which are intended to be administered daily for 2 to 5 months. Pregnant women are provided with 250 tablets, each containing 200 mg of ferrous sulphate. Breastfeeding mothers are given 120 tablets. Each tablet is equivalent to 60 mg of elemental iron and 400 µg of folate. Low-birthweight infants are provided with ferrous sulphate drops starting at 2 months of age. All infants may be given drops at 6 months of age for a period of 50 days. Pre-school children, especially those who are underweight, are provided with ferrous sulphate syrup for a period of 50 days.

Like retinol, iodine is excreted slowly, so that large doses are administered annually. Iodine supplements for adults, sometimes administered in oil form, contain a 200-mg dose of potassium iodate. A capsule form is available for women of reproductive age. A 250-mg dose of potassium iodate is administered to schoolchildren in liquid form.

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Strategies

Micronutrient supplementation is conducted through two major strategies: universal supplementation and targeted regular supplementation. Universal supplementation is the provision of the micronutrient supplement to all identified target groups nationwide on one occasion. There are two major occasions during which universal supplementation is conducted: National Immunization Day and National Micronutrient Day. Starting in 1993 on National Immunization Day, vitamin A supplements were given along with measles vaccine, diphtheria-pertussis-tetanus (DPT) vaccine, live oral poliovirus vaccine (OPV), and tetanus toxoid vaccine. During 1996–98, only poliovirus vaccine (along with vitamin A supplements) was given during National Immunization Day, renamed Knock Out Polio Day [1].

National Micronutrient Day, locally called *Araw ng Sangkap Pinoy*, during which the second six-month dose of vitamin A is given, also started in 1993. National Micronutrient Day is held in October to coincide with World Food Day. On National Micronutrient Day, iodine capsules are also given to women 15 to 40 years old. In 1996, iron tablets began to be distributed to all pregnant women in the form of starter packs [2].

Comprehensive approach

Although the highlight of National Micronutrient Day is the distribution of micronutrient supplements, it is not intended as a "magic bullet" approach. Other activities are included in National Micronutrient Day, such as distribution of vegetable seeds and cuttings to promote home food production, education on proper nutrition, testing of salt for iodine, distribution of iodized salt to poor families, and promotion of fortified foods [3].

Starting in April 1999, other health activities were integrated into National Immunization Day, including deworming of 2- to 5-year-olds, an important complement to iron supplementation in the control of anaemia; an expanded programme of immunization to include all the antigens; growth monitoring of 0- to 5-year-old children; distribution of free toothbrushes and promotion of dental care; information on safe and educational toys; promotion of naturally micronutrient-rich foods and fortified foods with the *Sangkap Pinoy* seal (the governmental seal of acceptance for fortified foods); information on hygienic practices, such as handwashing, cutting the nails, and wearing slippers; intensive promotion of exclusive breastfeeding of infants up to 6 months and complementary feeding starting at 6 months; and testing of salt in households and in markets. This set of prepackaged activities is termed *Garantisadong Pambata* (Preschoolers' Health Week).

Targeted regular supplementation

Targeted regular supplementation is conducted through the routine activities of the health system: annual mass weighing of children, regular growth monitoring, well-baby checkups, and regular consultation in all health facilities.

Factors contributing to the success of the programme

The Department of Health has given high priority to attacking micronutrient deficiency and has succeeded in gaining strong political support for its efforts, especially in the conduct of universal supplementation. A national advocacy meeting on Ending Hidden Hunger was conducted in June 1993, led by the President of the Philippines and attended by international experts, international funding agencies, local political leaders such as governors, mayors, and congressman, and representatives of local non-governmental organizations (NGOs). This culminated in the signing of a Memorandum of Agreement between the Department of Health and the local government executives for cooperation in implementing the supplementation programme.

The existence of a well-functioning health infrastructure facilitated the establishment of the distribution system [4]. Supplementation centres manned by volunteers were set up in neighbourhoods throughout the country to bring the services closer to the people. Supplementation centres were decorated with bunting and other festive decorations. Colourful parades served to initiate these activities, followed by ceremonial supplementation administered by local leaders.

In order to expand the numbers of people reached, the Department of Health tapped resources available from other projects to buy supplements. International organizations and other national governmental agencies not only shared their resources to purchase supplements themselves, but they also provided promotional materials and their expertise in social mobilization [5].

There was full media participation in the implementation of the programme. Press releases were evident both in the local and national newspapers. Radio and television broadcasts were aired, which reached even those in remote villages.

Limitations and lessons learned

Although the health infrastructure is sufficiently developed to reach most of the population, the success of micronutrient supplementation depends critically on the supply of supplements. Supplements are inexpensive on a per dose basis, but the required volume is large. Funding limitations led programme planners to prioritize target groups for supplementation. First-priority targets are those for whom supplementation will reduce mortality or prevent serious and permanent health complications. Second-priority targets are those for whom supplementation will reduce morbidity. Third-priority targets are those whose body stores will be increased by supplementation [2].

The campaign approach has been very effective for increasing the coverage levels of vitamin A and iodine capsules well above 80% (table 1). Such a high coverage rate does not apply to iron supplements, given that iron supplements have undesirable side-effects and lead to little visible or immediate positive change in well-being. Persuading mothers and their children to take the supplements regularly requires frequent contact and a strong relationship of trust between the fieldworker and the client.

TABLE 1. Percent coverage of National Micronutrient Day supplementation programmes, 1993–97

Year	Vitamin A capsules	Iodized oil capsules	Iron tablets
1993	90	86	—
1994	93	88	—
1995	88	81	—
1996	88	80	67
1997	78	54	58

Sources: ref. 3, p. 73; ref. 6, p. 22 and figs. 3 and 4; ref. 7, pp. 83–85.

There is the need to develop an effective record system at the field level to reduce the possibility that children will get the high-dose supplements too frequently, which could result in toxicity. There is a need to strengthen the system of reporting from the local level to the national level. Finally, there is a need to reduce the rapid turnover of field health personnel, necessitating frequent training.

Three important lessons, among others, stand out from the past seven years of experience with supplementation. First, the dedication of health workers to ending micronutrient malnutrition is imperative for the programme to succeed. Second, sustained logistical support from all levels (national governmental agencies, local governmental units, and NGOs) is necessary to achieve the desired goal. Third, monitoring and supervision activities should always be part of the programme in order to ascertain progress and failure, and as a basis for instituting corrective measures. After seven years of administering supplements, the primary concerns of the Department of Health are the sustainability of the programme, the provision of necessary logistical support, the commitment and dedication of field health personnel, the maintenance of high coverage of all target groups, and the sustaining of interagency collaboration.

References

1. Klemm RD, Villate EE, Lopez CT, Ramos AC, Burger S, West K, Bayugo G. Coverage and impact of adding vitamin A capsule (VAC) distribution to annual immunization day in the Philippines: Executive summary. Presented at National Feedback Conference, 16 April 1997. Manila: Helen Keller International.
2. National Nutritional Council. Philippine plan of action for nutrition. The Philippines national micronutrient operations plan, 1996–98. Manila: National Nutrition Council, 1996.
3. Ramos AC. Expansion of vitamin A supplementation and nutrition education interventions in three provinces in the Philippines: Overview. Presented at National Feedback Conference, 16 April 1997. Manila: Helen Keller International.
4. National Nutritional Council. Philippine plan of action for nutrition (PPAN): 1993–1998. Manila: National Nutrition Council, 1994.
5. UNICEF. Country Program for Children V: Programme of cooperation for child survival, protection, development and participation in the Philippines. Master plan of operations between the Government of the Philippines and UNICEF 1999–2003. Manila: UNICEF, 1998.
6. UNICEF. Country Program for Children IV: Fourth programme of cooperation for child survival, protection, and development in the Philippines. Volume 3, Nutrition, 1994–1998. Mid-Term Review. Manila: UNICEF, 1994.
7. Guillermo-Tuazon A, Briones RM. Comprehensive assessment of nutrition interventions. Report for UNICEF. Manila: UNICEF, October 1997.

Food fortification in the Philippines: Policies, programmes, issues, and prospects

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Abstract

Fortification is an important component of the Philippine Plan for Action on Nutrition. Several programmes are described for the fortification of commonly consumed foods, such as rice, margarine, sugar, salt, oil, and wheat flour, with essential micronutrients, especially vitamin A, iron, and iodine, to satisfy dietary gaps for these nutrients. The overall programme is designed to be spearheaded and implemented by the food industry, while the government is to provide necessary support through policy, technology development and transfer, and incentives to encourage the participation of food manufacturers.

The objective of the government's Sangkap Pinoy *seal programme is to encourage food manufacturers to market high-quality fortified food products. The seal is awarded to manufacturers who are able to meet standards for fortifying products with vitamin A, iron, or iodine. The seal makes the general public aware of the availability of fortified foods with assurance of quality and, thus, encourages consumption of fortified products.*

The prerequisites for a successful food-fortification intervention include advocacy, technology development and testing, stability studies, market testing, and field trials. Most fortification efforts have fulfilled these requirements, with the exception of a field trial to determine the efficacy of a fortified food in improving the nutrient status of a target group. Simple, rapid, and low-cost assessment methods to determine fortification levels must be developed to assist food manufacturers in their quality assurance monitoring activities. Moreover, the skills and abilities of village nutrition workers must be harnessed for monitoring fortified foods at the village or household level.

Introduction

The commitment of world leaders to the eradication of micronutrient malnutrition was consistently expressed in three international conferences: the World Summit for Children in 1990, the Montreal Conference on Ending Hidden Hunger in 1991, and the International Conference on Nutrition in 1992. The Philippine response to the global call to eradicate all forms of malnutrition by the year 2000 is the Philippine Plan of Action for Nutrition (PPAN) [1]. Its five impact programmes include food security, micronutrient supplementation and food fortification, credit assistance for livelihood, nutrition education, and food assistance. This paper will discuss fortification programmes in the Philippines.

Food fortification as a strategy to reduce micronutrient malnutrition

Definition

The Codex Alimentarius Commission of the United Nations defines food fortification as "the addition of one or more essential nutrients to a food, whether or not it is normally contained in the food, for the purpose of preventing or correcting a demonstrated deficiency of one or more nutrients in the population or specific population groups." The nutrients may be added as extracts or concentrates of materials of biological origin, or as products of chemical or biochemical synthesis.

Purposes

Food fortification aims to restore the nutrients lost during food processing by enriching a food with the depleted nutrient or increasing the level of the nutrient in the food. In both cases, fortification may increase the intake of specific nutrients identified as inadequate in a population [2].

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Requirements

To ensure that food fortification reaches the nutritionally vulnerable groups in the population, certain requirements must be met [3]. The food vehicle must be a staple food consumed widely throughout the year and must pass through central processing points. The level of fortification must contribute significantly to the nutritional requirements but must not exceed the safe upper limit. The fortificant must not alter the organoleptic properties, physical structure, or shelf-life of the vehicle. Control and monitoring procedures must be built into the manufacturing procedures to ensure that fortification levels are adequate.

Strengths

Food fortification is socially acceptable. It does not require the active participation of the consumers or any change in buying, cooking, or eating habits. Fortification, in most cases, does not affect the organoleptic properties of food products. It can be introduced quickly, and the benefits are readily visible. Of various interventions, food fortification is the least costly and the most effective way to eliminate dietary micronutrient deficiencies [2–7].

Limitations

Food fortification is less likely to benefit people who consume locally produced, unprocessed food, because it relies on centrally processed and marketed food vehicles. Fortified foods are accessible to both target and non-target groups and may not be the most economical way to reach the target groups. If the cost of fortification is passed on to target consumers only, purchasing patterns among the intended beneficiaries may change adversely. Fortification incurs additional costs for food manufacturers. Programme success is ensured only when political will, legislation, and enforcement are present [1, 4, 6].

The Philippine food-fortification programme

As a PPAN impact programme, food fortification aims to provide safe fortification of staples or commonly consumed foods (such as rice, margarine, sugar, salt, oil, and flour) with essential micronutrients, especially vitamin A, iron, and iodine, to satisfy dietary gaps for nutrients and to make these available and accessible to the population [7]. The programme was designed to be spearheaded and implemented by the food industry, while the government was to provide the necessary support through policy, technology development and transfer, and incentives to encourage the participation of food manufacturers.

Since PPAN's formulation in 1993, various food-fortification efforts have been undertaken. These include iron fortification of rice, iodization of salt, and vitamin A fortification of margarine, wheat flour, sugar, and cooking oil. Single or multiple nutrient fortification of several processed foods has also been conducted.

Fortification of rice with iron

In 1993, the Food and Nutrition Research Institute (FNRI) started the fortification of rice with iron. The effort included technology development and market testing in Nueva Ecija, the country's leading rice-producing province. A clinical trial was also done, with the objective of increasing the intake of bioavailable iron in the Filipino diet and to reduce anaemia among the population by fortifying rice at 3 mg per 100 g. The results of the study showed that the improvement of iron status and reduction of the prevalence of anaemia was 2.3 times higher for children given iron-fortified rice for four or five days than for those given non-fortified rice [8].

Iron-fortified rice has been introduced to the public, particularly in Sorsogon and Surigao del Norte, through the Enriched Rice for Anaemia Prevention programme, a rice subsidy programme of the Department of Social Welfare and Development and the National Food Authority [9, 10].

Iodization of salt

The Philippines is pursuing universal salt iodization through Republic Act No. 8172, the Act for Salt Iodization Nationwide, which was passed by Congress in November 1995 [11]. The law requires all producers, importers, and manufacturers of food-grade salt to iodize the salt they produce, manufacture, trade, or distribute. It sets standards, regulations, and incentives as well as sanctions and fines to violators. In support of the implementation of the law, the following activities have been undertaken: distribution of iodization machines, training on the technology of salt iodization and quality assurance, dissemination of information on the law and its implementing rules and regulations, installation of titration laboratories in all regions, community-based monitoring of iodized salt, and multimedia campaign to promote the consumption of iodized salt [10, 12].

It has been four years now since the approval of the law, yet its enforcement remains weak, with no strict monitoring for quality assurance, including quality control and iodine content of salt. Uniodized salt, which costs 50% less than iodized salt, still proliferates in public markets and retail stores throughout the country. It is no wonder that a 1997 survey by the Department of Health showed that iodized salt was utilized by only 15% of those surveyed [13].

In 1998, the Nutrition Center of the Philippines conducted a study to determine the stability of iodine in iodized salt sold through the *takal* system (the market vendor sells small quantities of salt from a larger package of salt). The results showed that despite the low quality of the iodized salt produced and its exposure to extreme environmental conditions, iodine levels remained within the limits set for iodized salt at the retail level [14]. This led to the issuance of a Department of Health circular that allows the selling of iodized salt through the *takal* system [15]. It is hoped that, through this circular, more salt retailers will be encouraged to sell iodized salt so more consumers will have better access to iodized salt.

Fortification of margarine with vitamin A

The fortification of coconut oil-based, shelf-stable, non-refrigerated margarine was initiated by its manufacturer, Procter & Gamble Philippines, in 1992 [16]. The stability study showed more than 50% vitamin A retention in the margarine after eight months of storage. Moreover, at least 80% of the vitamin A was recovered after cooking, reflecting good thermal stability [17]. The subsequent controlled field trial among three- to six-year-old rural children showed a significant increase in the mean serum retinol level as well as a 60% reduction in the prevalence of low serum retinol [18].

The vitamin A–fortified margarine was the first food product to be awarded with the Department of Health's *Sangkap Pinoy* (literal translation: Filipino or indigenous ingredients) seal, a mark of recognition from the government of a properly fortified, high-quality food product.

Fortification of wheat flour with vitamin A

In 1995, a feasibility study on fortification of wheat flour with vitamin A was conducted by the Nutrition Center of the Philippines with the participation of two millers and in collaboration with international agencies. The study showed that about 80% of the vitamin A added was retained in the flour and baked *pandesal* (most popular bread among Filipinos) over a period of one month [19]. The colour and odour of the flour and the flavour of the bread showed no significant changes.

Two years after, the effect of vitamin A–fortified *pandesal* on the vitamin A status of Filipino school children was assessed. The double-masked, randomized clinical trial involved provision of a 60-g piece of fortified or non-fortified *pandesal* to 835 children for six months. The results showed improved vitamin A status that was most evident by end-of-study differences in modified relative dose response, showing that intake of vitamin A–fortified *pandesal* halved the percentage of children with inadequate liver vitamin A stores [20].

However, despite the successful stability studies and efficacy trials, not all flour millers have decided to pursue wheat flour fortification. Of the 12 flour millers, only 4 are fortifying about 20% of all hard flour produced.

Fortification of sugar with vitamin A

The fortification of sugar with vitamin A was undertaken by the Victorias Milling Corporation, with technical assistance from the FNRI in 1996. The stability test showed that adequate vitamin A was retained in the vitamin A–fortified pure refined sugar stored for six months at room temperature. More than 80% of the vitamin A was also retained when the fortified sugar was used in the preparation of hot coffee, citrus juice, and cake. The colour and flavour of fortified sugar did not differ from that of unfortified sugar [21].

Vitamin A–fortified sugar was launched in the market in February 1997. In just a few months, however, the price of sugar in the world market plummeted and sent the already indebted Victorias Milling Corporation into further financial crisis. This halted the fortification of sugar with vitamin A, even before the programme could progress into full market scale. With the subsequent closure of four ailing sugar mills, further fortification efforts for sugar will have to wait until after the current sugar industry crisis in the Philippines is over.

Fortification of cooking oil with vitamin A

In 1997, the San Pablo Manufacturing Corporation, the manufacturer of Minola cooking oil, developed, tested, and adopted technology for the fortification of cooking oil with vitamin A. The FNRI and the Philippine Council for Health Research and Development provided technical assistance and funding support, respectively.

The stability test on vitamin A–fortified cooking oil revealed that vitamin A was stable from five months to one year whether it was packed in yellow plastic bottles, tin cans, or clear glass bottles. Free fatty acids and peroxide values during storage were within the acceptable limits. There were no significant differences in colour, flavour, and general acceptability between food products fried in fortified cooking oil and those fried in unfortified cooking oil. Vitamin A was substantially retained in fried banana, sweet potato fries, rice, and fish. A 15-g serving of oil provides one-third of the recommended dietary allowance (RDA) for vitamin A of the adult reference man [22].

Vitamin A–fortified cooking oil, which carries the *Sangkap Pinoy* seal, is now commercially available throughout the country. Upon the initiative of the Philippine Coconut Authority, an efficacy trial on the vitamin A–fortified cooking oil will be conducted.

Fortification of processed foods

As an accompanying programme to food fortification, the *Sangkap Pinoy* seal programme aims to encourage food manufacturers to market high-quality fortified food products. The seal is awarded to manufacturers who are able to meet the standards for fortifying products with vitamin A, iron, and iodine. The seal makes the general public aware of the availability of fortified foods with assurance of quality and thus encourages them to consume such products. It also provides a mechanism for the government to support the private sector in marketing fortified foods and serves as a venue for regular consultation and dialogue with the industry for public–private sector partnership for food fortification.

Presently, there are 21, 7, and 3 food products with the *Sangkap Pinoy* seal for vitamin A, iron, and iodine, respectively. These include sardines, instant noodles, cheese, juice drinks, chocolate drinks, weaning foods, biscuits, margarine, snack foods, condiments, hot dogs, and hotcake. A technical committee composed of experts from various governmental agencies regularly conducts quality assurance and control monitoring of these products.

Issues and challenges

Establishment of clear programme policy

The Philippine food-fortification programme remains a project under the PPAN [2] and the 1996–98 National Micronutrient Operations Plan [7], while the Bureau of Food and Drugs Guidelines on Micronutrient Fortification of Processed Foods serve as reference for the *Sangkap Pinoy* seal programme [23]. A comprehensive food-fortification programme, with specific policies, has yet to be developed. For instance, there are no clear programme policies regarding food items eligible for the *Sangkap Pinoy* seal, the conduct of food-consumption surveys for possible definition of required fortification levels in food products, the dissemination of research results, and the sharing of developed fortification technology, among others.

Targeting staple foods

One of the primary requirements to ensure effective food fortification is for the vehicle to be widely consumed by the population. Indeed, there have been efforts to fortify staple foods such as rice, sugar, flour and cooking oil. However, except for vitamin A–fortified cooking oil, iron-fortified rice, and vitamin A–fortified sugar and flour, these efforts have not gone to full market scale. At present, most of the fortified foods on the market with the *Sangkap Pinoy* seal are non-staples.

Legislation requiring the fortification of processed foods with essential micronutrients is now pending in the Philippines Congress [24, 25]. The bill specifically mandates the fortification of rice with iron, wheat flour with vitamin A and iron, refined sugar with vitamin A, and cooking oil with vitamin A. It is hoped that after the bill is passed, fortified staple foods will be readily accessible and available throughout the country.

Strict enforcement of food-fortification laws

The present status of the salt iodization law reflects the government's failure to implement the provisions of the law with its full authority. Although legislative commitment is strong, police commitment seems to be lacking. Legislative commitment is important but, in and by itself, cannot sustain any food-fortification programme. It is not enough that food-fortification laws are passed. The government must ensure that the provisions of the laws are strictly enforced.

Lessening the effect of foreign exchange

For most developing countries, foreign exchange determines the sustainability of a food-fortification intervention [2]. This is exemplified by our experience in sugar fortification, which failed because of foreign exchange-dependent factors. Foreign exchange also affects the cost of fortification, as in the case of wheat flour. In a developing country like the Philippines, where wheat does not grow and has to be imported, fortification brings a double constraint to flour millers, because foreign exchange is required for both the food vehicle and the fortificant.

There may be a need to search continuously for appropriate, locally produced food vehicles. Likewise, local sources of fortificants, testing kits, machines, and reagents may have to be identified. A special concern is to help small manufacturers to procure reasonably priced fortification machines and fortificants. These may all help to lessen the constraints imposed by the need to secure foreign exchange.

Conduct of efficacy and effectiveness studies

The prerequisites for a successful food-fortification intervention include advocacy, technology development and testing, stability studies, market testing, and field trials. Most fortification efforts have fulfilled these requirements except for the field trial, the purpose of which is to determine the efficacy of a fortified food in improving the nutrient status of a target group. This is the ultimate mark of a fortified food product. It is a valid basis for advertising claims that may increase the number of consumers, increase sales, and provide social and economic benefits to the manufacturer. Use of the product may be expanded and intensified because of its proved effectiveness.

Of the recommended vehicles for fortification, only iron-fortified rice, vitamin A–fortified margarine, and vitamin A–fortified wheat flour (as *pandesal*) have been tested by controlled field trials. All other fortified foods in the market, including those with the *Sangkap Pinoy* seal, have not been tested for their efficacy.

Establishment of quality assurance and monitoring procedures

Quality assurance and monitoring procedures at the production and retail levels must be set up to ensure adequacy of fortification. Simple, rapid, low-cost assessment methods to determine fortification levels must be developed to assist food manufacturers in their quality assurance and monitoring activities. Moreover, the skills and abilities of village nutrition workers must be harnessed for monitoring fortified foods at the village or household level.

Improving nutrient content of food through genetic modification

Food fortification, by practice or tradition, has involved the addition of chemical preparations of nutrients. The challenge for agriculturists worldwide is to increase the nutrient content or add more nutrients to plant products through either plant-breeding or biotechnology. Genetic modification of plant products is an emerging strategy to increase the amount of nutrients inherently found in plants or to add nutrients that are completely absent. For instance, the iron and zinc content of rice may be increased, its phytate content decreased, and β-carotene added. The iron, zinc, and folate contents of wheat flour may be increased, its phytate content decreased, and β-carotene added.

Conclusions

Micronutrient malnutrition must be addressed in a comprehensive manner. The interventions that already exist must be implemented according to the judgement of planners and programmers of the country in relation to the type of micronutrient deficiency, its severity, and the population groups affected. Food-based interventions must be the primary and long-term approach in the promotion of good nutrition. Food fortification, being a food-based approach, is seen as the most effective and sustainable strategy to increase the nutrient contents of food. However, the programme may be phased out eventually when agriculturists are able to improve the nutrient contents of foods through plant-breeding. Regardless of the plant-breeding method, whether traditional or biotechnological, the world population will be healthier if more nutrients are inherently present in foodstuffs.

References

1. National Nutrition Council. Philippine plan of action for nutrition 1993–1998. Makati, Metro Manila: NNC, 1994.
2. Nestel P. Food fortification in developing countries. Arlington, Va, USA: Vitamin A for Health Field Support (VITAL), 1993.
3. Bauernfeind JC, Arroyave G. Control of vitamin A deficiency by the nutrification approach. In: Bauernfeind JC, ed. Vitamin A deficiency and its control. Boca Raton, Fla, USA: Academic Press, 1986:359–84.
4. INACG. Iron deficiency in women. Washington, DC: International Nutritional Anemia Consultative Group, 1981.
5. Ventakesh Mannar MG. Control of iodine deficiency disorders by iodination of salt: strategy for developing countries. In: Hetzel BS, Dunn JT, Stanbury JB, eds. The prevention and control of iodine deficiency disorders. Amsterdam: Elsevier Press, 1987:111–25
6. Arroyave G. Alternative strategies with emphasis on food fortification. In: West KP, Sommer A, eds. Delivery of oral doses of vitamin A to prevent vitamin A deficiency and nutritional blindness—a state of the art review. Geneva: Administrative Coordinating Committee/Sub-Committee on Nutrition, 1987:87–91.
7. National Nutrition Council. The Philippine national micronutrient operations plan 1996–1998. Manila: NNC, 1997.
8. Florentino RF, Pedro RA. Clinical trials on iron-fortified rice. FNRI Technical Paper. Tagig, Philippines: Food and Nutrition Research Institute-Department of Science and Technology, 1995.
9. Flores MBT. Food fortification: PPAN's sustainable strategy to address micronutrient malnutrition. Paper presented during the update on the food-fortification programme in the Philippines at the Food and Nutrition Research Institute, 20 November 1998.
10. Bayani EM. Ending hidden hunger and food fortification. Paper presented during the dialogue with the chiefs of staff of senators at the Hyatt Hotel, Philippines. 17 May 1999.
11. Congress of the Philippines. Republic Act No. 8172: An act promoting salt iodization nationwide and for

related purposes (ASIN Law) and its implementing rules and regulations. Makati, Philippines: National Nutrition Council, 1996.

12. Flores MBT. Food fortification: PPAN's sustainable strategy to address micronutrient malnutrition. Paper presented during the update on the food-fortification programme in the Philippines at the Food and Nutrition Research Institute, 20 November 1998.
13. Office for Special Concerns-Department of Health. 1997 Status Report. Family planning, maternal and child health and nutrition. Manila: Department of Health, 1998.
14. Solon FS. Stability of iodine in iodized salt sold through the "takal" system at Amadeo, Cavite. Makati, Philippines: Nutrition Center of the Philippines, 1998.
15. Department of Health. Circular No. 206. Manila: Department of Health, 1998.
16. Solon FS. Food fortification program development in the Philippines: problems and progress. Proc Nutr Soc India 1996;43:1–18.
17. Solon FS. History of fortification of margarine with vitamin A in the Philippines. Food Nutr Bull 1998;19:154–8.
18. Solon FS, Solon MS, Mehansho H, West KP, Sarol J, Perfecto C, Nano T, Sanchez LE, Isleta M, Wasantwisut E, Sommer A. Evaluation of the effect of vitamin A–fortified margarine on the vitamin A status of preschool Filipino children. Eur J Clin Nutr 1996;50:720–3.
19. Solon FS, Solon MA, Nano TA, Limson ERP, Sanchez-Fermin LE, Wambangco LS. Wheat flour fortification with vitamin A: a terminal report. Makati, Philippines: Nutrition Center of the Philippines, 1996.
20. Nutrition Center of the Philippines. Fortified pandesal can save many of our children. Update for Nutrition Action 1999;4:1–2.
21. Marero LM, Florentino RF, Aguinaldo AR, Capanzana MV, Saises MC. Fortification of sugar with vitamin A: technology generation and transfer. Tagig, Philippines: Food and Nutrition Research Institute-Department of Science and Technology, 1997.
22. Marero LM, Saises MC. Fortification of coconut cooking oil with vitamin A: technology generation and transfer. Tagig, Philippines: Food and Nutrition Research Institute-Department of Science and Technology, 1997.
23. Department of Health. Guidelines on micronutrient fortification of processed foods. Manila: Department of Health, 1995.
24. Senate of the Philippines. Senate bill No. 1545. Manila, 1998.
25. House of Representatives. House bill No. 5915. Manila, 1998.

Reducing micronutrient malnutrition: Policies, programmes, issues, and prospects—dietary diversification through food production and nutrition education

Elsa M. Bayani

Abstract

This paper presents the Philippine experience in implementing the Home, School, and Community Food Production (HSCFP) and Nutrition Education impact programmes of the Philippine Plan of Action for Nutrition (PPAN). It describes some of the HSCFP and Nutrition Education models, programmes, and projects that have been implemented to address micronutrient malnutrition. When possible, the paper also presents indications of programme effectiveness. Some evaluation studies have proven the effectiveness of these models in improving either nutritional status or levels of knowledge and practice of nutrition. The lessons learned in implementing these models have also left a wealth of experience to build on. Sustaining and going to scale with these models are major challenges to be overcome for both the HSCFP and the Nutrition Education impact programmes. The paper stresses that addressing micronutrient malnutrition cannot be isolated from efforts to ensure food security. Thus, agricultural research should always have a nutritional perspective or mindset that automatically asks, "What would be the potential positive and negative effects on nutritional problems? On groups most affected by malnutrition?"

Introduction

One cannot and should not isolate the solutions to micronutrient malnutrition from ensuring food security, particularly at the household level. Achieving a well-fed and food-secure household would mean improving what people eat, in terms of quality, quantity, and variety [1]. This would require efforts related to increasing not only the available food supply, but also both physical and economic access to the food supply—efforts that in a developing country like the Philippines would necessarily relate to agricultural development, poverty alleviation, agrarian reform, infrastructure development, and environmental protection, among others.

However, dietary diversification through food production and nutrition education should complement these efforts. This paper presents key features of related programmes implemented in the Philippines over the past 20 years.

Food production in the Philippines

Food sources of micronutrients

Both animal and plant food are sources of vitamin A and iron. However, because of their relatively high cost, animal products are less accessible to the poorer segments of the population. Thus, plant sources of vitamin A and iron play a more important role in the diet of the majority of poor Filipinos.

Animal meats are good sources of both vitamin A and iron. Liver, other internal organs, and eggs are excellent sources of vitamin A and iron. Milk is a good source of vitamin A but not of iron.

Among the plant sources, green leafy vegetables (e.g., horseradish leaves, jute leaves, sweet potato leaves, malabar nightshade, chayote leaves, bitter melon leaves, and sweet pepper leaves) are rich sources of β-carotene and non-haem iron. Yellow or orange fruits such as mango, papaya, passion fruit, and jackfruit, fruit vegetables such as tomatoes, squash, and carrots, and root crops such as yellow sweet potatoes are also rich sources of β-carotene. Seeds and legumes such as chickpeas and lentils are good sources of non-haem iron.

Increasing the supply of these foods could help in addressing micronutrient malnutrition. However, access, especially economic access, to animal food sources should also be improved. For an agricultural country like the Philippines, a national agriculture programme, complemented by a nutrition programme, is important in achieving both concerns.

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The national agricultural programme

Various national agricultural programmes have been implemented in the past 25 years, following the thrusts of the government. At present, the *Agrikulturang MakaMASA* (literally, “pro-poor agriculture”) is the country’s Medium-Term Agricultural Development Plan, the banner programme for agricultural development. It aims to attain food security, poverty alleviation, increased net farm incomes, sustainability of the environment, and enhanced empowerment of people. *Agrikulturang MakaMASA* has programmes for rice, corn, fisheries, high-value commercial crops, livestock, sugar, and coconuts and for marginal uplands and poverty-stricken areas [2, 3].

With the recent adoption of the pro-poor thrust, the High-Value Commercial Crops Program (HVCCP) has been modified to include a system of production of food for home consumption. This includes efforts for the production of highly nutritious vegetables and root crops for the home table.

The home, school, and community food production programme of PPAN

The Home, School, and Community Food Production (HSCFP) impact programme of the Philippine Plan of Action for Nutrition (PPAN) for 1999–2004 complements the *Agrikulturang MakaMASA.* It aims to improve family food security through the establishment of kitchen gardens in the home, school, and community. The programme emphasizes the application of biointensive gardening and other regenerative agricultural technologies. It also includes caring for small animals (chicken, duck, swine, and goats) and fish in the home yard [4].

Implementation involves the distribution of planting materials, small animals, and garden tools. Local agricultural technicians provide limited technical support, especially for the application of biointensive gardening. With devolution, local governmental units play a lead role in implementing the programme, although several non-governmental organizations (NGOs) are also involved.

For two decades, various programmes and projects on small-scale food production have been implemented. These include the *Gulayan sa Kalusugan* or Vegetable Gardens for Health (DA-NAFC), and the Family Food Production Project (FFPP). In the mid-1970s, the “magic square” garden, a 1-m2 garden planted with green, leafy, and yellow fruits and vegetables and legumes was promoted. In the 1980s, the Agricultural Training Institute (ATI), then the Bureau of Agricultural Extension (BAEx), embarked on the KPMS [K for *kadyos* (pigeon pea), P for *patani* (lima bean), M for *malunggay* (horseradish), and S for *sitaw* (string/yard long bean)] programme, in cooperation with the two-million-strong national organization of rural women, the Rural Improvement Clubs (RICs) of the Philippines. The programme encouraged rural households to plant *kadyos* (pigeon pea), papaya, *malunggay* (horseradish), and *seguidillas* (winged bean) in their home yards. Although the programme was terminated with the change in function of the BAEx and with devolution, some RICs sustain the programme in their respective communities [5].

A government circular requires all public elementary schools to establish school gardens and nurseries to provide a continuous supply of fruits and vegetables, particularly green leafy vegetables, for school-feeding programmes. These gardens also serve as sources of herbal medicines and cut flowers.

Food production-related activities have also been integral to nutrition-related programmes. The National Micronutrient Day or *Araw ng Sangkap Pinoy* (ASAP) from 1993 to 1998 (usually on or about 16 October to coincide with World Food Day) included the distribution of seeds and seedlings of vegetables and fruits rich in vitamin A, vitamin C, and iron. Although most of the seeds distributed came from the Department of Agriculture, community members also contributed cuttings from their trees, e.g., *malunggay.* Furthermore, National Micronutrient Day promoted a specific vegetable for each year: *malunggay* for 1993 and 1996, *kangkong* (swamp cabbage) and *kamote* (sweet potato) tops for 1994, *saluyot* (jute leaves) for 1995, *kamote* (sweet potato) tops for 1997, and *ampalaya* (bitter melon) leaves for 1998. The distribution of seeds and seedlings through a micronutrient supplementation activity served as a reminder of the need for a food-based approach to prevent micronutrient deficiencies in the long term [6].

A highlight of this year’s Nutrition Month celebration (celebrated in July of each year to focus the attention of the public to nutrition and related concerns) was the launching by President Joseph Estrada of the FAITH (Food Always in the Home) Movement in Sta. Cruz, Laguna. The movement encourages households to grow fruits and vegetables as well as herbal plants and to raise small animals and, if possible, even rice and fish in the home yard.

Home gardening is also promoted in urban areas. A programme being implemented as a stopgap measure to provide part of the daily food needs of urban poor families and, to some extent, to augment family income is the *Gulayan at Bulaklakany* (Environmental Well-Being with Flowers and Vegetables) of the First Lady, Dr. Luisa Ejercito Estrada. This involves growing vegetables and flowers in small gardens or in pots, cans, or other containers. To sustain the project, participants are taught seed retention, composting, container gardening, and other gardening technologies.

Raising small animals and fish in the home yard is facilitated by the distribution of small animals and fingerling fish. Through the national government's livestock and fisheries programmes, small animals and fingerlings have been dispersed. The LAKASS (Lalakas angkatawang Sapat sa Sustansiya) program—a community-based nutrition programme designed to address the immediate and underlying causes of malnutrition—also includes projects related to animal dispersal. Some local governmental units have similar animal dispersal projects targeted to families with malnourished children.

Impact of home food-production programmes and projects

Very few studies have looked into the impact of home food production, particularly on home food supply and nutritional status. However, a study [5] on the nutritional impact of home gardening done by the Food and Nutrition Research Institute (FNRI) in 1993 produced the following results:

- » The vitamin A yield of home gardens averaged 134.6% of the recommended dietary allowance (RDA) per capita per harvest during the peak period and 84.3% of the RDA during lean months. Iron yield averaged 60.7% and 34.7% of the RDA per capita per harvest during the peak and lean months, respectively. The average vitamin C yield was three times the per capita requirement.
- » Furthermore, 34.4% of the total yield of home gardens was consumed in the household, while 41.9% was sold for cash and 17.4% was either thrown away or fed to dogs and pigs.
- » Pre-school children in households with home gardens consumed more vegetables and fruits, and consequently had higher intake of vitamin A, vitamin C, and iron than households without home gardens.
- » Home gardening also resulted in lower food expenditure.
- » Those with home gardens seem to have adopted a more varied diet.

The FNRI study concluded that the low-input, high-output cropping system of home gardening has the potential for nutrition improvement within the means of the rural poor.

Prospects and issues

Home, school, and community food production is envisioned to be a more visible PPAN programme within the next five years. In this regard, the issue of sustainability would have to be addressed properly. Note that none of the models developed for home food production in the past 25 years have been replicated and sustained on a nationwide scale. In fact, except for the KPMS project, most of the home food production programmes and projects have been limited to a few villages or *barangays*. To address this concern, the National Nutrition Council could encourage the RICs to lead in a nationwide campaign on home food production, possibly adopting the FAITH gardening system. Furthermore, local governmental units would have to be rallied to provide RICs with the needed support. In addition, the *Gulayan at Bulaklakan* project may be a model to develop for urban areas. These could be undertaken without discouraging local governmental units and NGOs from developing other innovative approaches.

Whatever model or scheme would be used, lessons from the past 20 years or so must be heeded. Thus, the following elements of success would have to be considered and factored into the programme or project design: the use of indigenous planting materials, fertilizers, and pesticides; practice of good seed retention; availability of area for production; positive attitude of clients; steady source of water; appropriation of funds for training on the use of new technologies; continuous technical assistance to clients; regular monitoring and evaluation; and provision of awards and incentives.

Nutrition education

Nutrition education is one of the impact programmes of the PPAN. It is the deliberate effort to promote the adoption of key nutritional and related behaviours as defined in the Philippine Nutritional Guidelines [4].

The focus on micronutrients and micronutrient malnutrition in nutrition education began in the early 1990s, in a way replacing the focus on protein–energy malnutrition characteristic of the 1970s and 1980s.

Substantive focus

The substantive content of nutrition education is drawn from a set of core messages based on the country's nutritional problems and needs, i.e., the priority nutrition messages from the early 1970s up to the early 1990s and the Philippine Nutritional Guidelines in the 1990s [7]. Very soon, we will be launching an updated version of the Philippine Nutritional Guidelines. The update includes the following guidelines that encourage consumption of foods rich in vitamin A and iron and their absorption enhancers: eat a variety of foods every day; consume, fish, lean meat, poultry, or dried beans; eat more vegetables, fruits, and root crops; and eat foods cooked in edible oil or cooking oil daily.

Targets

Since micronutrient deficiencies are more prevalent among infants and young children, and since mothers are usually the gatekeepers of foods and health care-seeking behaviours, they are the primary targets of nutrition education. Secondary and tertiary targets or those who can help reach the mothers include front-line health and nutrition workers and volunteers, agricultural technicians, media personalities, and local and national leaders in the executive and legislative branches of government and in business corporations, especially those in food manufacturing and salt production and trading.

Strategies and approaches in micronutrient-related nutrition education

Micronutrient-related nutrition education applies principles of adult learning and social marketing and uses a combination of approaches to reach the targets. In some instances, these strategies were packaged into a communication campaign specific to micronutrient or micronutrient-related services. Thus there were communication campaigns on the consumption of iodized salt, fruits, and vegetables; the use of fortified foods; and National Micronutrient Day. Micronutrient-related nutrition education was also integrated in the broader concerns of child growth and development, and in the care of pregnant and lactating women, or nutrition education in general.

Nutrition Month has been tapped too for micronutrient education. Its themes since 1994 have supported efforts to address micronutrient deficiencies by encouraging home food production and consumption of fruits and vegetables that are rich sources of vitamin A, vitamin C, and iron; the consumption of fortified foods bearing the *Sangkap Pinoy* seal; and the consumption of milk, not only for strong bones and teeth, but also for bioavailable vitamin A.

Interpersonal communication

Interpersonal communication continues to be a major mode of communicating about micronutrients to the target audience. This has been done at every possible opportunity through individual counselling during visits to the health centre, immunization rounds, regular weighing activities, or visits to households by technicians, health workers, or nutrition volunteers. Some projects that have integrated micronutrient-related messages have developed tools to facilitate the counselling process.

Mass media

Various radio and television plugs and print materials highlighting concerns related to micronutrient malnutrition have been developed and aired or published in connection with specific campaigns. To make the messages more credible, popular personalities, such as the First Lady, the chair of the National Nutrition Council, respected political leaders, or popular artists and athletes, have been tapped as endorsers.

A significant development in the 1990s was the increasing involvement of the private sector in nutrition education. Several food manufacturers, particularly those with *Sangkap Pinoy* seal-bearing products, adopted a nutrition angle in marketing their food products. Thus, print and broadcast advertisements highlighting the micronutrient content of products or the functions and importance of vitamin A, iron, and iodine have been developed and aired. In most cases, the commercial highlights the fact that the product is fortified and is accepted by the Department of Health. Since these are paid commercials, the sponsors can demand and have demanded airing at peak times of television viewership. Thus, these commercials have been helpful in increasing public awareness of the *Sangkap Pinoy* seal and its nutritional significance.

Some projects limited to particular areas have also used the local mass media. Media participation has also became more evident. Variety, talk, or magazine shows on both radio and television feature segments on micronutrient-related matters, e.g., the importance of micronutrients, or participation in National Micronutrient Day or Nutrition Month activities. In some instances, the producers of the show have done this on their own initiative or at the request of governmental agencies such as the Department of Health, the FNRI, or the National Nutrition Council. Major national and local dailies have also published news and feature articles on National Micronutrient Day, fortified foods, iodized salt, and micronutrient malnutrition, in some cases following a press conference. A major daily has consistently featured nutrition messages in one of its daily editorials in connection with the celebration of Nutrition Month.

Use of collateral or merchandising materials

There has been a growing reliance on the use of less costly but effective channels of communication, such as billboards, posters, streamers, flyers, tee shirts, calendars, tire caps, fans, buntings, and so forth.

Effectiveness of nutrition education

Several studies point to the effectiveness of nutrition education programmes in improving levels of knowledge and practice relative to nutrition. The Social Marketing Programme for Vitamin A in the Western Visayas region in the late 1980s showed that the use of radio, printed materials, nutrition education classes, and home visits improved mothers' knowledge about vitamin A and their attitudes and beliefs towards feeding children with vitamin A–rich foods. The use of cooking oil in the child's diet also increased as a result of exposure to the programme. However, changes in the amount of vitamin A–rich foods given to children were not observed [8].

In their 1993 study on child-feeding practices in three provinces in the Philippines, Klemm et al. [9] noted that women who participated in nutrition education classes, even after educational level had been controlled for, had significantly better complementary feeding practices, including the addition of cooking oil or fish or vegetables to rice porridge for six-month-old children.

Similarly, evaluations of Nutrition Month 1996, 1997, and 1998 showed an increase in awareness of the theme. On the average, awareness of the theme increased from about 45% before July to about 54% after July in 1995 and 1997 when the themes were milk and food safety, respectively. The results for 1996 registered a lower change in awareness from 75% to 78%, since the rounds of data collection were done after July. However, changes in the awareness of nutrition concepts related to, but “deeper” than, the theme were relatively lower, ranging from negative values to about 35%. This suggests that celebrations may function only to catch people’s attention, but there should be mechanisms to deepen understanding of nutrition concepts and practices related to the theme [10].

The high coverage of National Micronutrient Day was attributed to the massive information campaign, with front-line workers being important sources of information. Other important sources of information on National Micronutrient Day and micronutrients were radio, television, *barangay* officials, streamers, posters, church announcements, newspapers, and neighbours.

These and other findings from the international literature reinforce the importance of nutrition education in increasing the level of knowledge of nutrition and in influencing desirable behaviours.

Prospects and issues

Nutrition education will increasingly be based on the results of research, especially formative research. It will continue to be implemented, either as a single programme or project or as a partner programme of other PPAN impact programmes, or even of other development programmes, such as agriculture. It will continue to use the interpersonal communication and multimedia approaches. It will also continue to promote desirable dietary and lifestyle behaviours for nutrition improvement and the availability of key services provided by governmental organizations and NGOs.

Again, sustainability of nutrition education programmes is an issue to be addressed. Special time-bound campaigns such as Nutrition Month or those related to National Micronutrient Day or *Garantisadong Pambata* have a place in nutrition education. However, these campaigns should be supported by efforts to sustain the interest and awareness generated to eventually lead to changes in behaviour.

The role of academia in preparing professional nutritionist-dietitians to be effective nutrition educators and in providing the research base for nutrition education programmes will be strengthened. Similarly, nutrition education in the programmes and services of NGOs, including professional organizations of nutritionist-dietitians, will also be strengthened. Skills of front-line workers will be upgraded to make them more effective nutrition communicators.

Addressing micronutrient malnutrition in the Philippines: a synthesis

For the past six years, universal supplementation of vitamin A and selective supplementation of iodine using iodized oil capsules has provided immediate, although short-term, relief from micronutrient deficiencies. We have shown how such an effort can be mounted successfully through a National Micronutrient Day, but with the participation of national governmental agencies, local governmental units, local and international NGOs, the business community, and the people themselves. We have learned valuable lessons along the way, lessons that helped develop a more efficient system for procuring and distributing supplies, and more effective schemes of mobilizing participation to the activity. We have also shown that micronutrient supplementation can be integrated with other routine services of the health-care system. Micronutrient supplementation will continue to be an important intervention to address micronutrient malnutrition, shifting from a universal supplementation policy to a targeted one, within the next decade.

We have likewise set in motion actions to ensure that foods fortified with vitamin A, iron, and iodine will be available and accessible to the public, especially the nutritionally needy. Such actions range from technology development to technology testing, to market studies and clinical trials. Thus, today, we have a wider array of fortified foods in the market: iodized salt, iron-fortified rice, and vitamin A–fortified flour, sugar, margarine, cheese, milk, snack foods, instant noodles, and juice drinks, among others. Bringing fortified foods to the truly nutritionally needy, possibly through the mandatory fortification of staples like rice, flour, sugar, and cooking oil with iron and vitamin A, is a major challenge. We also need to further increase the demand for iodized salt, calling for the implementation and enforcement of a salt iodization law.

In the field of dietary diversification, we have enough models and experiences about home food production and nutrition education. Tapping into these experiences and using them as bases for the development and implementation of sustainable and integrated national and local programs is an agenda to pursue.

Nutritional and agricultural research in the prevention of micronutrient malnutrition

To us in the nutrition community, the question of whether the Consultative Group on International Agricultural Research (CGIAR) should have an explicit objective of improving human nutrition should not be debated. The issue for debate could be how the CGIAR would integrate nutritional concerns in agricultural research. In a way, the nutrition community is asking for a mindset that automatically asks the questions "What would be the potential positive and negative effect on nutritional problems? On groups most affected by malnutrition?"

Research that will improve the nutritional content of certain crops will be a significant contribution to prevent micronutrient malnutrition, provided costs are within the reach of the malnourished. Similarly, research that will improve the action of enhancers of nutrient absorption and limit the action of inhibitors of nutrient absorption will be a significant contribution. However, research that will improve a crop's yield, flavour, resistance to diseases and insects, or tolerance to herbicides, or that will allow a crop to grow under a wide variety of physical conditions [11–13] or will improve post-harvest handling and management of fruits and vegetables, could also make a dent in the nutrition situation. The key would be to focus on crops that are commonly eaten by the population at risk or affected by malnutrition and that are, at the same time, significant contributors to a nutrient deficient in a diet. Another key would be to focus on concerns that would improve the income levels and, therefore, the chances of better access to quality foods of groups at risk or affected by malnutrition [14, 15].

I hope this conference will be instrumental towards planting and nurturing a nutrition mindset in the field of agriculture and agricultural research.

References

1. International Life Sciences Institute (ILSI)/Food and Agriculture Organization. Preventing micronutrient malnutrition: a guide to food-based approaches: a manual for policymakers and program planners. Washington, D.C., 1997.
2. Department of Agriculture. Agrikulturang Maka-MASA—Pagkaing Sapat Para sa Lahat. Accomplishment Report, Quezon City, Phillipines, 1998.
3. Department of Agriculture. Agrikulturang Maka-MASA—Pagkaing Sapat Para sa Lahat. Information Kit, Quezon City, Phillipines, 1999.
4. National Nutrition Council. Philippine plan of action for nutrition, 1999–2004. Draft. Manila, 1999.
5. Bayani EM. Relevance of home gardening to human nutrition and food security. Paper presented during the International Training Course and Workshop on Household Food Security Through Home Gardening, 27 November–15 December, IIRR, Cavite, Philippines.
6. Flores M-BT. Preventing micronutrient deficiencies through food-based approaches—the Philippine experience. Paper presented during the FAO Regional Experts Consultation of the Asia-Pacific Network for Food and Nutrition on Food-Based Approaches to Address Micronutrient Deficiencies, 4–7 March, FAO-Regional Office for Asia and the Pacific, Bangkok, Thailand, 1997.
7. Bayani EM. Nutrition education in the Philippines and its role in improving nutritional status. Paper presented during the Regional Experts Consultation of the Asia-Pacific Network for Food and Nutrition Education, 23–26 July, FAO, Thailand, 1996.
8. David FP. An evaluation of the effectiveness of the social marketing program for the prevention and control of vitamin A deficiency in Region VI. Technical Report Series No. 6. Manila: Helen Keller International and Department of Health, 1990.
9. Klemm RDW, Villate EE, Tuason-Lopez C, Ignacio MSE. Weight-for-age status, infant feeding practices, and participation in nutrition education: VITEX Baseline Survey. Manila: Helen Keller International and Nutrition Service, Department of Health, 1997.
10. National Nutrition Council. Results of the evaluation of nutrition month for 1995, 1996, 1997. (Unpublished.)
11. Asian Food Information Center. Asian consumers and food biotechnology: What do they really think? Food Facts Asia, Singapore, Asian Food Information Center, Second Quarter 1999.
12. Asian Food Information Center. Our evolving food supply: genetically modified foods. Food Facts Asia, Singapore, Asian Food Information Center, Second Quarter 1999.
13. Asian Food Information Center. What you should know about biotechnology. A primer. Singapore, Asian Food Information Center, May 1999.
14. International Food Policy Research Institute. Population and food in the early twenty-first century: meeting future food demand of an increasing population. Washington, DC: IFPRI, 1995.
15. United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition. Enrichment of food staples through plant breeding. A new strategy for fighting micronutrient malnutrition. SCN News 1995;12.

Possible contributions of the Philippine agricultural research system to improving human nutrition

Gelia T. Castillo

Abstract

The need for participatory approaches has been mentioned several times. For the skeptics about the role of participation in research, let me say that participation is not a substitute for science. It enhances the practice of science, because it elaborates on its human purpose. About research partnerships, please look beyond the national agricultural research institutes. We have excellent researchers, many of whom are not in the national agricultural research institutes. But please treat national researchers as partners. We must do more adoption and impact-assessment studies so that our evaluation culture will grow, and press releases do not substitute for impact. Please do all you can to keep research output in the public domain so that the poor can afford them.

Nutritional status should be the bottom-line indicator of human development. In presenting statistics on micronutrient deficiencies, we need to give these numbers a human face—most likely a female face. I have always believed that research must have a human purpose, and when the best of science and scientists are devoted to the problems of those who have less in life, that is ethics and equity at its best. Nutritional status is about as human as we can get.

I am not a plant breeder; I am not a nutritionist; I am not a biotechnologist. But in my pedestrian mind, nutritional status should be the bottom-line indicator of human development. When a person is poor, has no land, and has little education, the most important capital he has in life is his body. Although almost everyone believes in nutrition, this does not always translate into political and financial support. It is encouraging to see the community of nutritionists, plant breeders, and biotechnologists in one room. This is indeed a rare happening. For the life of me, I cannot understand why a marriage between agriculture and nutrition has not taken place, not even an affair.

In presenting the case for reducing micronutrient malnutrition, citing specific numbers of millions of people suffering from vitamin A, iron, and zinc deficiencies is useful for improving general, initial awareness, but it is less useful for doing something about it. We need to give these deficiencies a human face—most likely a female face. Like the poor who used to be anonymous, the malnourished have no identity, no name, no address. Who are they? Where are they located geographically, agroecologically, culturally, and socio-economically?

In the case of poverty, the poor have gradually emerged from their statistical anonymity to empirical reality through the efforts of researchers, non-governmental organizations (NGOs), and some policy makers. For example, the Philippine Institute of Development Studies has a very interesting project called MIMAP (Micro Impacts of Macro Adjustment Policies) that measures various impacts, including nutritional status. At the community level, there are 33 minimum basic needs indicators, several of which are nutrition related. Although the economists think 33 is too many, social development workers argue that income is an insufficient indicator for choosing courses of action to meet minimum basic needs.

The task of putting a human face to these micronutrient deficiencies belongs to the national research system, preferably in collaboration with local governmental units and NGOs. The Human Development Network in the Philippines has produced two Human Development Reports, the first on human development by province, and the second a Gender Development Index. A third report, on education, will be launched sometime this month. All these have disaggregated data. How about a Philippine Human Nutrition Report by province two years from now?

The need for participatory approaches has been mentioned several times in the past two days, so that nutritionally improved crop varieties will be accepted by farmers. I believe that the Micronutrients Project

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investigators of the Consultative Group on International Agricultural Research (CGIAR) chose their rice, wheat, maize, bean, and cassava conduits on the basis of what is known about acceptability. But I agree with Dr. Robin Graham that they need to address problems of bioavailability, nutrient density, yield, etc. prior to stakeholder involvement.

All CGIAR centres have included participatory and gender issues in their research agendas. We have an Asian network called UPWARD, a collaborative project of the Centro Internacional de la Papa (CIP) and the Netherlands that focuses on users' perspectives from the diagnostic phase, to action research and technology development, and then to local research and development management. The Philippines has a number of participatory research and development initiatives. We also have thousands of NGOs. The CGIAR also has a Participatory Research and Gender Analysis programme, although I have a bit of discomfort about gender analysis that stops at analysis—in this case, only the analyst benefits. Those who have been gender-analysed do not benefit. The situation becomes worse when the analysts are from the North and those analysed are from the South.

For the skeptics about the role of participation in research, let me say that participation is not a substitute for science. As a matter of fact, it enhances the practice of science, because it elaborates on its human purpose.

About research partnerships, please look beyond the national agricultural research institutes. We have an excellent core of nutrition researchers and world-class economists many of whom are not in the national agricultural research institutes. But please treat national researchers as partners, not as hired hands or data gatherers. To do this, you must invest in capacity building, not just in publishing, so we can at least have a research collaboration of equivalence, if not of equality.

Studies of farming communities have shown that on-farm income is just one source of income for farm households. Hence we must look at livelihood systems, not just cropping or farming systems. We need a livelihood calendar against which to look at food-consumption patterns. Incidentally, let us never forget the role of production in ensuring food consumption. It is probably the best social safety net that exists, but let us stop calling it subsistence production, because this connotes a subsistence mentality. This "own-production" is household food security that enables rural households to take risks on cash crops and other non-food sources of income. We must do more adoption and impact assessment studies so that our evaluation culture will grow, and press releases do not substitute for impact.

Although I do not understand all the technicalities of bioavailability, nutrient density, and other terms mentioned during our discussions, I think I appreciate their significance. It is delightful to see the collaboration with advanced plant research institutes, which guarantees that the best tools of science can be brought to bear on nutrition problems. I am also very pleased that all the rhetoric on conservation of plant genetic resources has application for the micronutrient improvement projects. We need to do case studies on these so that these types of projects can have an added argument for more funding.

In the Philippines, there is a very strong lobby against biotechnology and, more specifically, transgenics. Unless field testing is allowed, the products of biotechnology may not be able to get out of the container facility. But then it has been mentioned that conventional tools will always have their place in research. Conventional tools used by nonconventional scientists could be as powerful in the future as in the past. I would like to make a plea to the scientists that if any products emerge from the research, please do all you can to keep them in the public domain. The poor cannot afford Monsanto.

Finally, let me say that it has been worth three days of my time to listen and learn. I have always believed that research must have a human purpose, and when the best of science and scientists are devoted to the problems of those who have less in life, that is ethics and equity at its best. Nutritional status is about as human as we can get.

Comments on possible contributions of the Philippine agricultural research system to improving human nutrition

Bienvenido Juliano

Abstract

The Philippine agricultural research system already collaborates with the International Rice Research Institute (IRRI) on evaluation of iron-dense rice lines in areas of mutual interest and expertise, particularly in the field testing of the lines developed at IRRI. High and stable grain yields are required of these lines if they are to receive approval for release. If lines are to be released for their superior nutritional content, then higher levels of micronutrient content and demonstrable bioavailability also need to be established.

Introduction

The Consultative Group on International Agricultural Research (CGIAR) is undertaking a laudable effort to improve the micronutrient density of major staple foods, with emphasis on vitamin A, iron, and zinc. Breeding, genetic, nutritional, and other basic exploratory studies [1] are preferably done by the International Agricultural Research Centres because of their greater resources. National agricultural research systems can collaborate with international agricultural research centres primarily with respect to the application of findings from basic research. National agricultural research systems have limited nutritional expertise and consequently will need to collaborate with non-agricultural nutrition institutions on nutrition-related issues.

IRRI–Philippine agricultural research service collaboration

Micronutrient-dense entries from the International Rice Research Institute (IRRI) need to be evaluated in the National Cooperative Testing (NCT) Project of PhilRice if they are to be eventually released in the Philippines. The first example of such an evaluation by the National Cooperative Testing Project is provided by the high-iron IR68144-2B-2-2-3, which was tested as a special-purpose rice, a category that includes glutinous (waxy), pigmented, and aromatic rices (properties that are readily discerned by the consumer, in contrast to high iron and zinc, which require chemical analysis to verify). IR68144-2B-2-2-3 is aromatic and has intermediate amylose content and an intermediate gelatinization temperature of starch [2]. According to data from the National Cooperative Testing Project, the yield of IR68144-2B-2-2-3 was 67% that of the IR64 check, averaged over two locations and three seasons in Luzon (table 1). To receive approval from PhilRice for release, the varieties being tested must be sufficiently profitable (determined by a combination of yield level and stability, sale price, and input use) that a large number of farmers would be likely to adopt them.

Nutritional contribution of rice

According to the 1993 national nutrition survey [3], the adequacy of the Filipino diet for nutrients based on recommended dietary allowances (RDAs) was 88% for energy, 106% for protein, 65% for iron, 68% for calcium, 88% for vitamin A, 68% for thiamine, 57% for riboflavin, 88% for niacin, and 73% for ascorbic acid. Rice contributed 56% of the energy, 38% of the protein, 26% of the iron, 18% of the calcium, 41% of the thiamine, 24% of the riboflavin, and 46% of the niacin in the diet. Even with 50% increase in the iron content of milled rice, the diet will still be only 73% adequate in iron. The iron content of the milled rice used in the survey (1.15 mg/100 g) is similar to that reported experimentally [1].

Field studies are complicated by multiple deficiencies in diets. For example, in one study adequate growth response to higher-protein rice in pre-school children

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TABLE 1. Comparative mean rough rice yield (tons/ha) of high-micronutrient-density (high-iron) line IR68144-2B-2-2-3 with IR64 check in national cooperative trials

	PhilRice Maligaya		DA-ILIARC Dingras, IL	
Season	IR68144-2B	IR64	IR68144-2B	IR64
1997 dry	4.13	6.74	4.80	6.06
1997 wet	2.16	2.85	4.73	6.97
1998 dry	3.56	6.07	3.19	4.64
Mean	3.28 (62.8%)[a]	5.22	4.24 (72.0%)[a]	5.89

Source: ref. 2.

a. Mean percent yield relative to IR64 check. Overall mean percent yield relative to IR64 for two locations and three seasons was 67.4%.

was absent without supplementation with 5 mg zinc daily [4, 5]. The implication is that additional zinc intake in the Philippines would be beneficial.

On the other hand, a study of rice fortification in 29 villages in Chiangmai, Thailand, in 1971–75 showed a lack of nutritional effects on pre-school children. Two interventions—one with lysine, threonine, thiamine, riboflavin, vitamin A, and iron, and the other with thiamine, riboflavin, vitamin A, and iron—had no effects on nutritional parameters, including haemoglobin [6]. The fortified pre-mix increased the overall iron content of the rice by 2 mg/100 g. In another study, iron absorption by Filipino women from an iron-fortified rice diet was reported to be 5.4% and that from the check milled rice diet was 6.9% [7].

Brown rice

Consumption of brown rice to improve micronutrient intake was recently suggested to PhilRice by the National Nutrition Council as an alternative to iron fortification of milled rice. Redpericarped rices are popular among upland rices and are consumed as undermilled rice with some residual pigment still present. There are no nutritional studies on brown rice and rice bran in human subjects in the Philippines. Thai studies showed that in a rice-pork-Chinese cabbage diet, the percentage of iron absorbed from the brown rice diet was one-third that from a milled rice diet (table 2) [8]. However, addition of green collard to the diet, which contributed 50 mg of ascorbic acid, significantly increased iron availability of the brown rice diet (table 2). In Brazil, a powder supplement to the usual diet that contained rice/wheat bran, cassava/sweet potato leaf flour, pumpkin/watermelon seeds, and egg shell resulted in nutritional improvement [9]. Presumably the addition of cassava/sweet potato leaf flour counteracted the binding of minerals by rice bran.

The poor bioavailability of minerals in brown rice has been blamed on phytic acid [8] and dietary fibre [10], both of which decrease in residual rice grain on milling [11], together with the level of trace minerals [12].

We are collaborating with Dr. J. R. Hunt at the US Department of Agriculture Grand Forks Human Nutrition Research Center to estimate the bioavailability of zinc to rats from cooked brown rice (27 ppm zinc), undermilled rice (19 ppm zinc), and milled rice (16 ppm zinc). Iron will not be bioassayed, because rats cannot be used to assess the quantitative importance of dietary factors in human iron nutrition [13].

Brown rice also has problems of poorer shelf life, longer cooking time, and poorer acceptability of appearance, off-white colour, nutty taste, and rougher texture of cooked grain relative to milled rice The medicinal properties of phytic acid and other components in rice for disease prevention [14], particularly cancers, make us rethink the role of phytic acid as an antinutritional factor alone. Phytate should probably not be completely removed from the bran.

TABLE 2. Iron and phytate content and iron absorption of brown and milled rice diets in Thai adults

		Content in meal (mg)		Iron absorption	
Diet	No. of subjects	Iron	Phytate	mg	% ± SEM
Brown rice[a]	11	3.6	175	0.27	7.5 ± 1.5
Milled rice[a]	8	3.2	35	0.71	22.1 ± 3.3
Brown rice[b]	11	3.6	175	0.23	6.4 ± 0.9
Brown rice[b] + green collard	11	3.6	175	0.49	13.7 ± 1.7

Source: ref. 7.

a. With pork and Chinese cabbage.

b. With or without added green collard to provide 50 mg ascorbic acid to the diet. Green collard corresponding to 25 mg ascorbic acid only increased iron absorption to 8.8 ± 1.3%.

References

1. Sendahira D, Gregorio GB, Graham RD. Breeding iron and zinc dense rice. Paper presented at the International Workshop on Micronutrient Enhancement of Rice for Developing Countries in Stuttgart, Ark, USA, 3 September 1998.
2. Rice Varietal Improvement Group. Semi-annual meeting, National Cooperative Testing Project, 1998 Dry Season Trials, PhilRice Maligaya, 11 November. PhilRice Maligaya, 1998:319–22.
3. Villavieja GM, Cerdeña CM, Molano WL, Laña RD, Boquecosa JP, Raymundo BE, Nones CA, Abaya HSP, Palafox EF, Chavez MC, Burayag GA, Pine CR, Recuenco JRD, Saturno DS, de los Reyes CM. Fourth national nutrition survey Philippines, 1993. Part A. Food consumption survey. Food and Nutrition Research Institute, Tagig, Metro Manila, 1995.
4. Roxas BV, Intengan CL, Juliano BO. Effect of zinc supplementation and high-protein rice on the growth of preschool children on a rice-based diet. Qual Plant Plant Foods Hum Nutr 1980;30:213–22.
5. Pereira SM, Begum A, Juliano BO. Effect of high protein rice on nitrogen retention and growth of preschool children on a rice-based diet. Qual Plant Plant Foods Hum Nutr 1981;31:97–108.
6. Gershoff SN, McGandy RB, Suttapreyasri D, Promkutkao C, Nondasuta A, Pisolyabutra U, Tantiwongse P, Viravaidhyaya V. Nutrition studies in Thailand. II. Effect of fortification of rice with lysine, threonine, thiamine, riboflavin, vitamin A and iron on preschool children. Am J Clin Nutr 1977;30:1185–95.
7. Valdez DF, Mallillin AC, Cruz EM, Kuizon MD, Cabrera MIZ. Iron absorption from FVRice-Iron Fortified. Philipp J Sci 1996;125:291–9.
8. Tuntawiroon M, Sritongkul N, Rossander-Hulten L, Pleehachinda R, Suwanik R, Brune M, Hallberg L. Rice and iron absorption in man. Eur J Clin Nutr 1990;44:489–97.
9. Brandao CTT, Brandao RF. Alternative nourishment. An educational program on nutrition based on regional solutions and simplified technology (in Portuguese). Banco do Brasil, Brasilia DF, Brazil: Banco do Brasil, 1996.
10. Gordon DT, Stoops D, Ratliff V. Dietary fiber and mineral nutrition. In: Kritchevsky D, Bonfield C, eds. Dietary fiber in health and disease. St. Paul, Minn, USA: Eagan Press, 1993:267–93.
11. Juliano BO. Rice in human nutrition. Rome: Food and Agriculture Organization, and Los Baños, Philippines: International Rice Research Institute, 1993.
12. Villareal CP, Maranville JW, Juliano BO. Nutrient content and retention during milling of brown rices from the International Rice Research Institute. Cereal Chem 1991;68:437–9.
13. Reddy MB, Cook JD. Assessment of dietary determinants of nonheme-iron absorption in humans and rats. Am J Clin Nutr 1991;54:723–8.
14. Tsuno Foods & Rice. Abstracts. First International Symposium on Disease Prevention by IP6 & Other Rice Components, Takaragaike, Kyoto, Japan, 8–9 June 1998. Ito-gun, Wakayama, Japan: Tsuno Foods & Rice, 1998.

Micronutrient interventions: Options for Africa

Ifeyironwa Francisca Smith

Abstract

In recent years, increasing attention has been drawn to the relatively slow pace of progress in intervention efforts against micronutrient deficiencies in sub-Saharan Africa. Recent data indicate that the problem of micronutrient deficiencies remains severe, a situation compounded by inadequacy of institutional capacities and resources required for implementing well-defined control strategies. Supplementation programmes started in earnest after the 1992 International Conference on Nutrition. More recently, there has been an increase in the rate of coverage of vitamin A supplementation of children under five years of age, attributed to the integration of vitamin A capsule distribution into national immunization days. However, a major constraint to vitamin A capsule delivery is a poorly functioning health infrastructure. Transportation facilities are poor, and there are shortages of equipment and trained personnel.

Food fortification, which was initially not considered a front-line approach because of the lack of infrastructural facilities in most countries, is currently being pursued with new ideas for adapting existing technologies to local resources and needs. Early attempts at developing food-based strategies involved promoting the production and consumption of vitamin A–rich foods as well as encouraging small-scale animal production. A major shortcoming of these earlier food-based interventions is a lack of quantifiable and convincing data demonstrating impact. There is a growing movement to involve women in intervention programmes. Africa is primarily agrarian. Micronutrient intervention efforts have not fully exploited the untapped potential of the existing food systems and the immense human resources of the agricultural sector.

Introduction

In the early 1990s, ambitious goals were set for the total elimination of vitamin A and iodine deficiencies and for the reduction of iron-deficiency anaemia by one-third of the 1990 levels, goals that were expected to be achieved by the end of that decade. According to UNICEF [1], despite substantial success with reducing iodine deficiencies through salt iodization, the end-of-the-decade nutritional goals for vitamin A and iron nutrition would not be met in sub-Saharan Africa. In recent years, increasing attention has been drawn to the relatively slow pace of progress in intervention efforts against micronutrient deficiencies in Africa, in contrast to the encouraging reports of progress in Asia and Latin America [1]. There is thus a call for national governments, donor agencies, and international organizations involved in micronutrient interventions to review their intervention strategies and to redouble their efforts in Africa.

This paper gives an overview of micronutrient intervention activities in sub-Saharan Africa, identifies the front-line actors in the micronutrient scene, and explores available intervention options. Recent data from UNICEF [2] indicate that the problem of micronutrient deficiencies remains acute in the subcontinent, a situation compounded by inadequacy of institutional capacities and resources required for implementing well-defined control strategies. For the purpose of this overview, nutrient supplementation (vitamin A and iron) is categorized as a non-food-based approach, whereas food-based approaches include food production and preservation, food fortification, and promotion of dietary diversification, as well as aspects of nutrition education related to improving diets.

Prevalence rates of micronutrient deficiency

A major impediment to establishing micronutrient intervention programmes in sub-Saharan Africa is

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a lack of data on the prevalence of micronutrient deficiencies. Because prevalence surveys are not available in several countries of the subcontinent, there is very little information with which to gauge the impact of any large-scale interventions. Nevertheless, what prevalence data are available from the Micronutrient Initiative iron-deficiency anaemia database [3] for sub-Saharan Africa, mostly available from the 1980s and early 1990s, show very high prevalence rates of iron-deficiency anaemia among children and among non-pregnant and pregnant women. Because of the economic downturn in most countries of the subcontinent, very little positive change is expected more recently in the prevalence picture.

In West and Central Africa, the reported prevalence rates of iron-deficiency anaemia range from 7% (Nigeria) to 78% (Liberia) among pregnant women, from 8% (Cameroon) to 64% (Ghana) among non-pregnant women, and from 38% (Cameroon) to 58% (Togo) among children under five years old. In East and Southern Africa, reported prevalence rates range from 6% (Ethiopia) to 88% (Malawi) among pregnant women, from 8% (Ethiopia) to 69% (Burundi) among non-pregnant women, and from 14% (Malawi) to 67% (Tanzania) among children under five years old.

Supplementation programmes

Supplementation programmes in parts of Africa started in earnest after the 1992 International Conference on Nutrition. Helen Keller International initiated supplementation activities in 1994 in Niger, in 1997 in Mozambique, and in 1999 in Mali [4].* Information from the Micronutrient Initiative's vitamin A deficiency database [6] shows that during 1996–97, although 45% (18 out of 40) of countries in the subcontinent had in place national policies on vitamin A supplementation for children under five years and postpartum women, only 33% had some data on the percent coverage of children. Six countries (15%) had data on coverage of postpartum women supplemented during the first eight weeks after delivery. The reported coverage rates [7] for under-five children during this period ranged from 10.5% in Mali and Somalia to 87% in Mauritania. Coverage rates during the same period for postpartum women ranged from 10% in Somalia and Zambia to 90% in Nigeria. The estimated regional average coverage rate, based on available data, is 47% for children under five years.

A more recent report from UNICEF [2] provides vitamin A supplementation coverage data for under-five children in 20 (50%) countries in sub-Saharan Africa during 1998 and shows a regional average coverage rate of 68%. These data suggest an increase in the rate of coverage of vitamin A supplementation of children under five years. This increase is to a large extent attributed to the integration of vitamin A capsule distribution into national immunization days. In spite of this improvement in the logistics of capsule distribution, low coverage rates are still recorded in several countries [2]. Although relevant data are still not available in over 40% of the countries, supplementation has been shown to be cost effective in the short term [8], relative to some food-based approaches.

Supplementation interventions have relatively rapid start-up times and can produce quick results, so that their impact is discernible within a short period of time. However, a major constraint to vitamin A capsule delivery in sub-Saharan Africa is a poorly functioning health infrastructure to administer capsule distribution. Transportation facilities are poor, and equipment and trained manpower are lacking or inadequate. The experience of Helen Keller International in Niger clearly reflects this problem. Their 1998 report [4] indicated that the organization's initial capsule distribution strategy relied on existing health facilities and recorded a coverage rate of 20%. When capsule distribution was integrated with National Immunization Days, coverage rates increased to 70% for infants 6 to 12 months of age but remained low (25%) for children 6 to 59 months of age. Ninety percent coverage was achieved four years later as a result of increased advocacy and technical and financial support to the government.

An epidemiologic study in Ghana [9] reported that the incidence of vitamin A deficiency was highest in children 2 to 4 years old, and in sub-Saharan Africa, higher prevalence rates are reported in children within this age range. This is thus an ideal age to target children for vitamin A supplementation. However, because of the long distances mothers have to walk to attend immunization clinics, mothers in Africa tend to stop regular attendance at these clinics after their children reach nine months, when the infant would have completed the first round of immunizations. So, even though capsule distribution is tied to National Immunization Days, a large proportion of the older infant target population is still not covered, as Helen Keller International observed in Niger.

Turning to treatment of iron deficiency, women are routinely supplemented with ferrous sulphate and folic acid tablets during pregnancy [3]. Information on rates of coverage is available for 15 (37%) of the countries, with reported coverage rates ranging from 20% in Somalia to 90% in Zimbabwe. However, in the light of evidence [10] of low compliance with tablet intake among pregnant women, reports of high cover-

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* Helen Keller International, a major player in vitamin A capsule distribution, started providing assistance in distributing vitamin A capsules to the Bangladesh government in 1970 and to the Indonesian government in 1974 [5].

age rates with little or no reliable back-up data may be misleading. Iron supplementation programmes for children exist in only four (10%) of the countries.

Although a lack of funds and technical expertise has hampered supplementation programmes in several countries of the subcontinent, at the same time the sustainability of capsule supplementation in Africa is a major concern. As countries face social and economic crises, the ability of governments to sustain ongoing supplementation programmes is questionable, and thus the increasing call within international development and international health circles for all concerned to actively explore other intervention options.

Food-based approaches

A fundamental strategy for solving nutrient deficiency problems in any population or group on a sustainable basis is to ensure adequate intakes of foods containing a range of specific nutrients. Food-based intervention strategies thus aim to increase the production of, availability of, and access to local foods rich in micronutrients; the consumption of locally available micronutrient-rich foods by the target population; and the bioavailability of micronutrients in the diets of target communities.

Food-based approaches have a greater potential to address vitamin A deficiency than iron deficiency, because iron absorption from plant foods is significantly hampered by the presence of inhibitors, particularly in these staple foods.* In sub-Saharan Africa, early attempts at developing food-based strategies involved promoting the production and consumption of vitamin A–rich foods as well as encouraging small-scale animal farming or other activities targeting dietary diversification. These activities were initially piggy-backed on other public health programmes [12] or vitamin A supplementation programmes [13]. There were also community-based intervention trials, such as occurred in Malawi [14].

A major shortcoming of these earlier food-based interventions is a lack of quantifiable and convincing data demonstrating impact on the target populations. As indicated by Ruel and Levin [15] in a recent review of food-based strategies, studies of these projects do not provide answers to the vital questions of their efficacy and effectiveness. This notwithstanding, food-based approaches are receiving increasing attention in sub-Saharan Africa. Home-gardening initiatives are still being pursued, and methods of delivering nutrition education and information have improved.

Food-fortification programmes

Food fortification is considered a viable, cost-effective option for meeting the daily iron and other micronutrient needs of a large percentage of the target population [11]. However, it requires adequate legislation and an effective system for controlling the fortification process.

Food fortification is a relatively new phenomenon in sub-Saharan Africa. Food fortification, which was initially not considered a front-line approach because of the lack of infrastructural facilities in most countries, is currently being actively pursued with new ideas of adapting technologies to local resources and needs. Although some fortified food products (hot and cold breakfast cereals, wheat flour and pastas, margarine, and pasteurized milk and milk products) are available in some countries, they are either imported or are manufactured within the countries by subsidiary food companies. Such industry-established fortification activities are often not under the firm control of host governments, as there are as yet very few established and operational food quality-control laws and statutes. Furthermore, these food products are outside the economic reach of populations targeted for micronutrient intervention programmes.

There exist in some countries small, pilot-scale fortification studies or programmes [7, 16]. These include fortification of weaning food in Botswana and Ethiopia, curry powder in South Africa, maize meal in Zambia and Zimbabwe, and drink mixes in Tanzania. The successful fortification of sugar with vitamin A in Zambia [17] has put more impetus into ongoing or planned fortification programmes. There are plans under way [7] for the fortification of sugar in Mozambique, Uganda, and South Africa. Fortifying staple foods with vitamin A and iron is a major challenge for most countries in the subcontinent because of the lack of centralized food processing operations.

There is also a lack of information on appropriate processing technology and fortifying agents. The Canadian International Development Agency, working through the Micronutrient Initiative and some Canadian non-governmental organizations (Oxfam Canada, CARE Canada, and World Vision Canada), is attempting to overcome existing constraints to small-scale fortification. There are ongoing pilot projects in Zimbabwe and Zambia [18–20], as well as a feasibility study for the Republic of Benin under review [21]. These ongoing pilot intervention studies have built-in monitoring and evaluation components, which should overcome a major shortcoming of earlier food-based studies. Although these ongoing and planned interventions are small in scale, it is encouraging to note the current trend towards exploring options to complement supplementation efforts.

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* For example, this view is expressed in an FAO/WHO report [11] that indicated that vitamin A deficiency is the most amenable of the micronutrient deficiencies to agriculturally based interventions.

Women's participation in food-based intervention activities

There is a growing movement in sub-Saharan Africa to involve women in intervention programmes. Given women's key roles in household nutrition and decision-making, these women-centred intervention studies [22–25] aim to mobilize women as change and intervention agents. A study of a project in Tanzania [22] examined the effects of a technology package (provision of solar dryers, nutrition and health education, and business management training) aimed at increasing the vitamin A dietary intake of young children. Although the impact of the intervention package on vitamin A nutrition of the target population was not quantified by biochemical indicators, the nutrition education component of the intervention had a larger effect on the main nutritional outcome (increased Helen Keller International dietary scores) than did the use of improved solar dryers.

Another intervention project in Ethiopia [23] built on an earlier effort aimed to empower women economically by increasing their access to productive assets (dairy goats). In the original project, it was assumed that ownership of goats would improve household income, which would in turn facilitate the purchase and consumption of milk, meat, and other foods, as well as the use of health services. The new project thus focused on improving women's knowledge and skills regarding the production and consumption of vitamin A–rich foods and the use of health-promoting services. This project provided evidence in support of three hypotheses:

» Agriculture-focused interventions can increase production, but they do not necessarily lead directly to improved consumption;

» Strategies specifically aimed to increase consumption are needed in order to yield nutritional benefits;

» Providing women with a package of resources enables them both to produce food and to feed it to their families.

An ongoing study [25] in Burkina Faso also found that investments in reducing women's resource constraints are a viable way to link food production to improved nutritional outcomes. The results of these intervention studies underscore the benefits of providing women with resources to ensure not only food availability at the household level, but also behavioural changes that promote dietary diversification and the consumption of micronutrient-rich foods.

The Ethiopian study reported that the risk of vitamin A deficiency differed significantly between study participants and non-participants, and Helen Keller International food-frequency data showed increased vitamin A consumption due to the project, but clinical examinations still showed high numbers of children with vitamin A deficiency in the participant group. It is possible that the inclusion of biochemical indicators of vitamin A status would have provided more concrete evidence of the impact of the intervention. Another study in Kenya [24] also used Helen Keller International food-frequency scores as the main nutrition outcome indicator. Although these reported studies provide more evidence that should help in improving subsequent food-based intervention programming, the validity of the nutritional outcomes remains in question because biochemical indicators were not used. These indicators were not measured, perhaps because of funding constraints and a lack of on-site laboratory facilities for sample analysis, which make it difficult for intervention studies to adopt biochemical methods. The Helen Keller International food-frequency survey is thus the next best option. There is, however, an obvious need for these studies to establish, in the most convincing manner, the efficacy and effectiveness of food-based interventions. Donors need to commit to this and provide the required funding.

Plant-breeding strategies

Plant-breeding strategies aim to increase the supply and bioavailability of micronutrient-rich foods in the diets of target communities. To date, plant-breeding strategies have not assumed any prominence in the list of micronutrient intervention options in sub-Saharan Africa, as they are still considered long-term options. Although plant-breeding has been used to improve yields and disease resistance of traditional food crops (sorghum, millet, and cowpeas in particular), breeding for micronutrient density or reducing antinutritional factors has not been the focus of agricultural research in the subcontinent. However, the Organization of African Unity's Scientific, Technical and Research Commission (OAU/STRC) in Ouagadougou, Burkina Faso, is working in collaboration with International Agricultural Research Centres to explore the possibilities of selective breeding of staple food crops to improve their micronutrient density.

Although this may today still be considered a long-term measure in the light of other intervention programmes, several papers in this volume show that significant progress has been made in breeding programmes for wheat [26], maize [27, 28], rice [29], phaseolus beans [30], and cassava [28, 31]. However, although maize, rice, and cassava are important staple crops in sub-Saharan Africa, indigenous foods—millet, sorghum, hungry rice (*Digitaria exilis*), and cowpeas or black-eyed beans (*Vigna unguiculata*)—are also major staple food crops, and they seem to have been neglected in current research efforts. Sorghum, millet, and hungry rice provide over 50% of the daily food energy needs of the populations in the Sahel [32]. Sorghum, millet, and maize are also staples in some parts of eastern and southern Africa. These minor cereals (as they are often called), with cowpeas and other indigenous bean varieties, constitute major food sources for a significant proportion of the population currently targeted for micronutrient interventions. It thus advisable that these food crops also be included in the current breeding efforts of the Consultative Group on International Agricultural Research (CGIAR).

What options for sub-Saharan Africa?

Africa presents a singular challenge for improvement of micronutrient deficiencies. There is a growing consensus that active integration of the various intervention strategies is required, the appropriate mix depending on the local environment. Although supplementation activities have met with bottlenecks, targeted supplementation is needed. For example, the Ethiopian intervention project [23] initially did not consider capsule supplementation as an option, primarily because of the absence of a community-based health-care structure and the lack of community access to fixed health-care sites. Furthermore, the supply of capsules, according to the study report, was unreliable even at fixed sites. However, the report noted that vitamin A deficiency was of such magnitude that the project intervention alone could not completely overcome it in the short term. The report therefore suggested that efforts be made to address the problem in the short term through supplements, even while working towards long-term sustainable strategies.

Africa is primarily agrarian. Micronutrient intervention efforts have not fully exploited the untapped potential of the existing food systems and the immense human resources of the agricultural sector. Although a large number of projects and studies are still ongoing, and pilot projects are yet to be scaled up, the trend is towards more reliance on food to solve the micronutrient problems of the subcontinent.

The involvement of women in intervention activities will significantly increase the level of impact of intervention programmes. Women are not only involved in food production, they dominate the food-processing industry and are the major food distributors. Empowering rural women, as some of these projects have done [22–24], should yield large benefits in the very near future. Studies have also highlighted the complementary effect of nutrition education programmes. It has become increasingly clear that communities need to be mobilized through information, education, and communication strategies to produce and consume locally available micronutrient-rich foods.

Finally, a very basic, though not often discussed, constraint on earlier efforts at dietary diversification is the dearth of information on the nutrient contents of most commonly consumed foods (raw, processed, and cooked) in sub-Saharan Africa. This lack of reliable information may also inhibit progress in establishing levels at which foods should be fortified. Such information is also indispensable for planning and developing strategies for nutrition education and community mobilization.

References

1. UNICEF. Annual report: nutrition program overview. New York: UNICEF, 1998.
2. UNICEF. The state of the world's children: statistical tables. New York: UNICEF, 2000.
3. Micronutrient Initiative Iron Deficiency Anemia Database. Ottawa, Canada: Micronutrient Initiative, 1999.
4. Helen Keller International. Annual report. New York: Helen Keller International, 1998.
5. Helen Keller International. Overview of HKI programs. New York: Helen Keller International, 1998.
6. Micronutrient Initiative Vitamin A Deficiency Database. Ottawa, Canada: Micronutrient Initiative, 1999.
7. UNICEF. Field office report 1996/97. New York: UNICEF, 1997.
8. Phillips M, Sanghvi T, Suarez R, McKigney J, Fiedler J. The cost and effectiveness of three vitamin A interventions in Guatemala. Soc Sci Med 1996;42:1661–8.
9. Ross DA. Vitamin A supplementation in northern Ghana: effect on clinic attendance, hospital admissions and child mortality. Lancet 1993;342:7–12.
10. Schultink W. Iron deficiency alleviation in developing countries. Nutr Res Rev 1996;9:281–3.
11. Food and Agriculture Organization/World Health Organization. International Conference on Nutrition. Major issues for nutrition strategies. Theme Paper No. 6. Presenting specific micronutrient deficiencies. Rome: FAO/WHO, 1992.
12. World Vision Canada. MICAH—Malawi quarterly report, January–March '98. 1998.
13. World Vision Canada. MICAH—Ethiopia quarterly report, October–December '98. 1998.
14. Gibson RS, Yeudall F, Drost N, Mtitimuni B, Cullinam T. Dietary interventions to prevent zinc deficiency. Am J Clin Nutr 1998;68(suppl):484S–7S.
15. Ruel MT, Levin CE. Assessing the potential for food-based strategies to reduce vitamin A and iron deficiencies: a review of recent evidence. Food Consumption and Nutrition Discussion Paper 92. Washington, DC: International Food Policy Research Institute, 2000.
16. UNICEF. The progress of nations. New York: UNICEF, 1996.
17. United States Agency for International Development. The OMNI experience 1993–1998: using global lessons to move local programs. OMNI Final Report. Washington, DC: USAID, 1998.

18. CARE Canada. Nutrition initiatives in communal areas. Project FC5878 PN29, 1999.
19. Oxfam Canada. Zimbabwe nutrition and health programme. Project 694/M361, 1998.
20. Micronutrient Initiative. Fortification trial of maize meal at Hammer mill level in Zambia. Project MI-5600-0005-12-30. Ottawa, Canada: Micronutrient Initiative, 1999.
21. Micronutrient Initiative. Improving the iron status of lactating and under-five children in the Republic of Benin through iron fortification of maize flour—a pilot study (study proposal under consideration, 2000).
22. Mulokazi G, Mselle L, Mgoba C, Mugyabuso JKL, Ndossi GD. Improved solar drying of vitamin A rich foods by women's groups in Singida District of Tanzania. ICRW/OMNI Research Report Series No. 5. Washington, DC: International Center for Research on Women, 2000.
23. Ayalaw W, Gabriel ZW, Kassa W. Reducing vitamin A deficiency in Ethiopia: linkages with women focused dairy goat farming project. ICRW/OMNI Research Report Series No. 4. Washington, DC: International Center for Research on Women, 1999.
24. Hagenimana V, Oyuinga MA. The effect of women farmers' adoption of orange-fleshed sweet potato: raising vitamin A intake in Kenya. ICRW/OMNI Research Report Series No. 3. Washington, DC: International Center for Research on Women, 1999.
25. Micronutrient Initiative. Crude palm oil for vitamin A in the Sahel? A pilot project. Project MI-5500-0003-45-300. Ottawa, Canada: Micronutrient Initiative, 1999.
26. Monasterio I, Graham RD. Breeding for trace minerals in wheat. Food Nutr Bull 2000;21:392–6.
27. Bänziger M, Long J. The potential for increasing the iron and zinc density of maize through plant-breeding. Food Nutr Bull 2000;21:397–400.
28. Maziya-Dixon B, Kling JG, Menkir A, Dixon A. Genetic variation in total carotene, iron, and zinc contents of maize and cassava genotypes. Food Nutr Bull 2000;21:419–22.
29. Gregorio GB, Senadhira D, Htut H, Graham RD. Breeding for trace mineral density in rice. Food Nutr Bull 2000;21:382–6.
30. Beebe S, Gonzalez AV, Rengifo J. Research on trace minerals in the common bean. Food Nutr Bull 2000;21:387–91.
31. Chavez AL, Bedoya JM, Sánchez T, Iglesias C, Ceballos H, Roca W. Iron, carotene, and ascorbic acid in cassava roots and leaves. Food Nutr Bull 2000;21:410–13.
32. Reardon T. Cereal demand in the Sahel and the potential impacts of regional cereal protection. World Dev 1993;21:17–35.

Micronutrient policies for agriculture in Latin America

Ricardo Bressani

Abstract

A key distinguishing feature of Latin America is that 75% of the population is urban, and this proportion is projected to rise to 82% by 2025. Because markets for processed foods are more developed in urban than in rural areas, fortification has a comparative advantage in Latin America relative to other regions. In fact, fortification has been highly successful in Latin America. Salt iodination programmes are the most widespread, followed by fortification of sugar with vitamin A; fortification of wheat with thiamine, riboflavin, niacin, and folic acid; and fortification of margarine. At least 13 Latin American countries now have vitamin A supplementation programmes, which are relatively new to Latin America. A mix of types of fortification, supplementation, and food-based interventions will be needed in the future. Efforts should continue in the implementation of activities such as home gardens, small-animal production, and promotion of edible, native plants. Genetic manipulation through plant-breeding can alter in a positive way desirable functional properties of foods as well as the concentration and properties of macro- and micronutrients. The benefits of functional characteristics bred into plants have been clearly demonstrated (e.g., fatty acid profiles, delayed ripening), but not the benefits for human nutrition, except in laboratory situations. The plant-breeding approach needs additional, interdisciplinary research at various points in the food chain to establish the benefit for human nutrition.

Introduction

In Latin America, micronutrient deficiencies were recognized as early as the 1950s. At this time, research groups in various countries initiated activities to understand the biological significance of such deficiencies and to find appropriate solutions. However, these activities have been given a new impetus and much higher priority during the 1990s as a result of the relatively recent surge of new knowledge about micronutrient deficiencies.

A significant aspect to be taken into consideration in reviewing possible micronutrient interventions is that Latin America is the most highly urbanized region of the developing world, with around 75% of the population living in urban areas. Projections indicate that by the year 2025, about 82% of Latin Americans will live in urban areas. It is important to note that levels of poverty and malnutrition among the urban poor are often worse than those found among the rural poor. Urban dwellers have better access to processed food products than rural residents. Other factors, such as time limitations for food preparation and demand for convenience, mean that more foods made available through the food industry will be consumed in urban areas. The high proportion of the population living in urban areas, then, confers a comparative advantage to fortification in Latin America—a higher likelihood that fortification will be successful relative to other regions.

Per capita agricultural production in general, and per capita cereal grain and food legume production in particular, have been declining over time, a trend that, if not reversed, could result in greater food insecurity for the poor and increasing malnutrition. Investments in agricultural research in many countries have been reduced significantly, which is an underlying cause of declining per capita food production.

Prevalence of micronutrient deficiencies

In 1997 information was presented at the Latin American Congress of Nutrition, held in Guatemala, that in 13 of 15 Latin American countries studied, iron deficiency was a national-level problem; vitamin A deficiency was a national-level problem in 6 of these countries; and iodine, folate, niacin, and riboflavin deficiencies

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were a national-level problem in only 1 country each. This information is shown in table 1. Iodine deficiency was present in particular geographical areas of 11 countries. Various population groups in 8 countries showed deficiencies in at least one micronutrient. Low intakes of at least one micronutrient were widespread in 7 countries [1–3].

Food fortification

Central and South America historically have had very high prevalences of iodine-deficiency disorders. Implementation of salt iodination in Latin America represents a remarkable achievement that will have lasting effects on the lives of many people. Over one-half of the countries in the Americas now iodize more than 90% of their salt; in the remaining countries between 75% and 90% of the salt is iodized. Alliances between government and industry have reduced the prevalence of endemic goitre in Guatemala from 38% in 1962, to 14% in 1965, to 1% in 1967 [4]. In 1994, 23.1% of the population in the Americas was at risk for iodine deficiency; in 1997, only 6.6% of the population was at risk [3]. This success can be attributed in part to effective legislation and sound research studies.

Fortification of sugar with vitamin A was initiated in Guatemala in 1974 [5]. The national-level prevalence of vitamin A deficiency, as measured by plasma levels in children, was reduced from 3.3% to less than 0.2% within two years. The Guatemalan fortification experience has given valuable guidance for other Central and South American countries that have or are planning sugar fortification [2, 6], although sugar is not the only vehicle being fortified with vitamin A.

In 1993 Venezuela started a fortification programme with industrial pre-cooked degermed maize flour used for preparation of *arepa* (a flat maize bread), which was fortified with vitamin A, vitamin B_1, vitamin B_2, niacin, and iron. A survey carried out in Caracas showed that the prevalence of iron deficiency and the prevalence of anaemia were reduced from 37% and 19%, respectively, in 1992 to 15% and 10% in 1994 [7]. More recently, lime-treated corn flour has been fortified with multiple vitamins and iron in Mexico and Guatemala [8]. Milk is also fortified with iron in Chile [9], and various milk-derived products fortified with iron are available in Brazil.

In 12 countries in Latin America, fortification of wheat flour with thiamine, riboflavin, niacin, and

TABLE 1. Micronutrient deficiencies in selected Latin American countries

Country	National deficiency	Regional deficiency	Deficiency in some populations	Widespread low intake
Argentina	Iron	Iodine	Iron	Vitamins A, C, and E
Bolivia	Iron	Iodine, vitamin C	Vitamin A	Calcium; vitamins B_1 and B_2; niacin
Brazil	Iron	Iodine, vitamin A	Vitamin A	Vitamins B_1, B_2, B_6, and C
Chile			Iron	Vitamins A, B_1, and B_2; niacin
Colombia	Iron	Iodine		
Costa Rica		Iodine		
Dominican Republic	Iron, vitamin A, folate	Iodine		
Ecuador	Iron, vitamins A and B_2; niacin	Zinc	Zinc	
El Salvador	Iron, vitamin A, iodine			
Guatemala	Iron, vitamin A, iodine			
Honduras	Iron, vitamin A	Iodine		
Mexico	Iron, vitamin B_2	Iodine, calcium, niacin	Vitamin C, folate	Vitamins A, B_1, B_2, and C; niacin; zinc
Nicaragua	Iron, vitamin A	Iodine	Vitamin B_1, niacin	
Panama	Iron	Iodine	Vitamin A	
Peru	Iron, iodine	Vitamin A	Folate, vitamin B_{12}, zinc	Calcium; vitamins B_1 and B_2

Source: ref. 1.

folic acid is compulsory. There is also compulsory fortification of margarine in 10 countries [10]. In at least six countries in Latin America, commercial, high-quality vegetable protein mixtures that have been fortified with vitamins and minerals are available [8]. In school-feeding programmes in some countries, snack items, such as cookies, are made from micronutrient-enriched wheat or maize flour.

Supplementation programmes

At least 13 Latin American countries now have vitamin A supplementation programmes [11]. In some countries, women and children also receive iron supplements. Programmes for Central America are relatively new, starting in 1994.

Production of foods with relatively high micronutrient contents

Fortification and supplementation programmes do not reach every sector of the population. Therefore, efforts have been made in Latin America to provide micronutrient-rich foods at the community and household levels. Examples include programmes to promote home vegetable gardens, production of poultry and other small-animal species, production of vegetables through hydroponic technologies, and fruit production. Native vegetables, such as amaranth and chaya, are more nutritious than many commercially available vegetables that are replacing these native vegetables in the diet. Programmes should promote the production and consumption of these native vegetables. Other food-based activities include information dissemination campaigns targeted at specific nutrients, such as carotenoids and iron. These programmes sometimes lead to the development of commercial products that can be promoted on the basis of their nutrient content because of these public nutrition education programmes [12, 13].

Agricultural approaches to improving micronutrient content in plants

The chemical composition and the nutritive value of plants are influenced by environmental growing conditions, cultural practices, and the genetic makeup of the plant. As discussed in many papers in this issue, genetic modification through plant-breeding can be used to alter important macronutrients and micronutrients in food crops, thereby improving the dietary status of the consuming population.

Many possible examples may be cited. Carbohydrates, proteins, and fats in plants are significant yield components. Plant breeders have worked to improve maize and legume seed protein, increasing the levels of lysine and tryptophan (e.g., see Vasal [14] in this volume). Driven by consumer demand, private-sector research efforts have altered the fatty acid profiles of oils, lowering levels of saturated fatty acids and erucic acid and increasing oxidative stability. Starch and fibre composition have been improved. Genetic manipulation of plants has also resulted in materials with desirable functional characteristics, such as reduced allergenicity and toxicity, delayed fruit ripening, and longer shelf-life.

Micronutrient content has not received much attention, because micronutrients are not major yield components, and so are difficult to exploit commercially. Although cereal and legume grain crops show variability in trace mineral content, fruits and vegetables offer intriguing possibilities, since they contain high levels of other important micronutrients, such as carotenoids and vitamin C, which enhance biological utilization of mineral micronutrients. The effectiveness of a strategy of breeding for higher micronutrient content will be better for foods with reduced handling and processing, so that micronutrients are not milled, washed away, or otherwise destroyed.

Genetic variability has also been reported for the concentration of antinutritional substances in food crops, which, if eliminated by breeding, could result in improved nutritive value through increased bioavailability of nutrients (see Raboy [15] in this volume). Low phytic acid in maize will be useful for populations that consume whole maize, such as in lime-treated maize, but not for those that consume degermed maize flour.

Conclusions

Food fortification to reduce micronutrient deficiencies in Latin America is a success story in many countries. The knowledge and experience that have been obtained in these programmes to date will lead to expansion of this approach to reduce other vitamin and mineral deficiencies as well. Although fortification has proved very effective, there is no guarantee that it will reach everyone at risk.

There is no doubt that genetic manipulation can alter in a positive way desirable functional properties of foods, as well as the concentration and properties of macronutrients and micronutrients. The benefits of functional characteristics bred into plants have been clearly demonstrated (e.g., fatty acid profiles, less fat absorption from potato starch, and delayed ripening), but not the benefits for human nutrition, except in laboratory situations. The plant-breeding approach needs additional interdisciplinary research at various points in the food chain to establish the benefit for human nutrition: stability of nutrients under storage, changes due to industrial processing, changes taking place during transformation into edible products, relationship of minerals and vitamins with other compounds favouring or inhibiting their bioavailability, and forms in which the food is consumed.

A mix of types of interventions will be needed. Efforts should continue in the implementation of activities such as home gardens, small-animal production, and promotion of edible native plants.

In many Latin American countries, an adequate supply of micronutrient-rich foods is available in the market. The problem is that because of poverty and lack of education, many people do not have access to diets of sufficient quality. Although the main role of agriculture continues to be the increase in crop productivity to meet the demand for a wide range of foods, an additional objective of both private and governmental agricultural research stations should be to introduce desirable functional and nutritional characteristics, as needed and demanded by the consumer.

References

1. Nilsen A, Piza J. Food fortification: a tool for fighting hidden hunger. Food Nutr Bull 1998;19:49–60.
2. Mora JO, Mora OL. Micronutrient deficiencies in Latin America and the Caribbean: iron deficiency anemia; vitamins, iodine, calcium and zinc. Washington, DC: Pan American Health Organization and World Health Organization, 1998.
3. ACC/SCN. The Third Report on the World Nutrition Situation. Micronutrients. Chapter 2. Geneva: Administrative Committee on Coordination/Sub-Committee on Nutrition, 1997:19–52.
4. Noguera A. Eliminación de la deficiencia de yodo: un reto de fin de siglo. Boletín Oficina Sanitaria Panamericana 1994;117:483–94.
5. Arroyave G. Evaluation of sugar fortification with vitamin A at the national level. Scientific Publication No. 384. Washington, DC: Pan American Health Organization, 1979.
6. Layrisse M, Martines-Torres C, Renzi M, Velez F, Gonzalez M. Sugar as a vehicle for iron fortification. Am J Clin Nutr 1976;29:8–18.
7. Layrisse M, Chávez JF, Méndes-Castellano H, Bosch V, Tropper E, Bastardo B, González E. Early response to the effect of iron fortification in the Venezuelan population. Am J Clin Nutr 1996;64:903–7.
8. SUSTAIN. Fortification of corn masa flour with iron and/or other nutrients. A literature and industry experience review. Washington, DC: SUSTAIN, 1997.
9. Olivares M, Walter T, Hertromph E, Pizarro F, Stekel A. Prevention of iron deficiency by milk fortification. Acta Paediatr Scand 1989;361(suppl):109–13.
10. Lutter CK, Huffman SL, eds. Special issue on Processed Complementary Foods in Latin America. Food Nutr Bull 2000;21:3–100.
11. Caballero E, Rivera G, Nelson DP. Encuesta nacional sobre la vitamina A en Panama. Boletín Oficina Panamericana de la Salud 1996;120:181–8.
12. Peña-Rosas JP, Pizarro F. Hierro y nutrición. Conocimientos actuales. Memorias del Simposio Dr. Miguel Layrisse, 16 September 1999, Caracas, Venezuela. Archivos Latino Americanos de Nutrición 1999;49(suplemento 2):75–515.
13. Latin American Congress on Food Carotenoids (14–17 September 1998). Archivos Latino Americanos de Nutrición. 199;49(suplemento 1):55–1075.
14. Vasal SK. The quality protein maize story. Food Nutr Bull 2000;21:445–50.
15. Raboy V. Low-phytic-acid grains. Food Nutr Bull 2000;21:423–7.

Agriculture for consumers: Experiences from Norway

Wenche Barth Eide

Abstract

Interest in the linkages between nutrition and agriculture from the late 1960s initially revolved around the opportunities for breeding grains of higher or better nutrient contents, mainly protein and amino acids. In the 1970s, that particular concern faded with the recognition that protein quality in grains was not a limiting factor for human nutrition. In the wake of growing interest in nutrition planning at the time, the concept of "nutrition in agriculture" also matured. Community nutritionists today understand this concept as the interaction between the broader sets of biological and societal processes that determine the optimal or suboptimal nutritional status of human beings. There is, however, a communication gap between nutritionists outside the laboratory and contemporary plant breeders for micronutrient content, which may risk reducing the concept once again to "nutrients in agriculture." The gap should be bridged in order to exploit all opportunities for linking up with broader thinking around food systems, health determinants outside the traditional health field, behaviour, culture, role analysis, power and control over resources, and hence also potential conflicts of interest—at domestic as well as at higher levels of human organization. We lack a common framework to facilitate communication and systems thinking that would help extend technical considerations into policy formulations. The paper describes recent efforts by the Norwegian Ministry of Agriculture to promote "whole-food-chain thinking," where the interest of consumers will be explicitly in focus, including their participation in setting goals of agricultural policy to promote food and nutritional security.

A retrospective glimpse

It is always useful to go back in history and see what we can find in terms of precursors of today's concerns, debates, and action. Let me commemorate an authority from earlier in the twentieth century, Professor André Mayer, one of the founding fathers of the Food and Agriculture Organization (FAO), whose call for "a marriage between food and agriculture" has been cited in numerous publications and documents since 1935 [1]. Although today we think of nutritional status as also determined by other things besides food intake, before the Second World War and for many years thereafter, "food" was almost synonymous with nutrition in the way both nutritionists and people in general thought about it. Professor Mayer's concern must therefore be understood as a hope for a better relationship between agriculture and what it ought to mean for human nutrition, which could not only be dealt with as a health concern per se. This was later reflected in the FAO constitution, whose mandate begins with "to raise levels of nutrition and standards of living," followed by "to improve agricultural productivity, and to better the condition of rural populations."

In 1937, the League of Nations issued a report linking the health, economic, and agricultural sectors and indicated the need for intersectoral approaches [2]. This could have led to a realistic integration of agricultural policy with health and nutrition policies. The Second World War, to some extent, enforced such a trend, at least in some European countries, through the need for, and effectuation of, food-rationing systems to stretch scarce resources. However, postwar concerns necessarily reflected preoccupations with emergencies and reconstruction, and nutrition subsequently fell back to its primary health dimensions. This was typically extended into technical assistance programmes for emerging nations in the developing world, as they progressively freed themselves from colonial rule beginning in the late 1950s and early 1960s.

Interest in nutrition in agriculture was renewed in the 1970s, in part in the wake of the so-called national nutrition planning movement, and grew as we went into the 1980s. Breeding for better protein quality in grains had, as we know, been one of the linkages, but

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the interest faded with the final declaration of "the great protein fiasco" by Dr. Donald McLaren in his milestone article in the prestigious British medical journal *The Lancet* in 1974 [3].

In search of a new paradigm

In place of the more simplistic "nutrients in agriculture," there followed a search for alternative approaches to "*nutrition* in agriculture," nutrition here being understood as the convergence of the broader set of combined societal and biological processes that ultimately lead to an optimal or suboptimal nutritional status of human beings. A more comprehensive primer on this from the nutritionists to their plant colleagues might have been useful in this conference. The summary report and recommendations from the Consultative Group on International Agricultural Research (CGIAR) conference in 1984 made available to the participants here are helpful, but 15 years of further thinking and battling with the issues lie in between. Assumptions are often made—so also in this conference—that may need clarification and understanding from both sides to be able to move ahead and plan for a real marriage. In so doing, we must admit that if the relationship has not been up to expectations during the years of engagement, we need to change—although not necessarily change the expectations! A family counsellor might have inquired about the *language* we use when we talk to each other. People in love may still contribute to misunderstandings between them if they talk past each other, *thinking* they mean the same things by using the same terms.

As a nutritionist who has been deeply interested in the links between human diets and the origin as well as the nature of the food supply, as determined by agricultural practices and policies, I am increasingly having problems with the interpretation of "nutrition in agriculture." Why so, after having devoted a lot of time over the years joining in the efforts to bridge the language and practice of precisely the two corresponding constituencies?

When I and fellow community-oriented human nutritionists say "nutrition," we carry with us years of mental adaptation to a constantly maturing and richer concept, which includes—but goes way beyond—the narrow meaning of "nutrient." This has meant a new potential for linking up with broader thinking around food systems, health determinants outside the traditional health field, behaviour, culture, role analysis, power and control over resources, and hence also potential conflicts of interest, at domestic as well as at higher levels of human organization.

The signals I get when plant breeders use the same term "nutrition," however, continue to reflect "nutrients." But nutrients are only one part of the nutrition paradigm as it has developed to date, albeit a very important one.

Need for a common framework

I firmly believe that we lack a relatively simple, common conceptual framework within which we can share, in broad terms, what we now recognize as a complex web of determinants of human nutritional status. Such a framework would allow us to further explore the linkages between the single nutrient with its possible antinutrient substances, and both proximate or more distant factors and processes that contribute to determining human nutritional status.

Note that human nutritionists have themselves greatly advanced since they finally agreed on a common theoretical fundament—and here many will know that I am thinking of the often referred-to conceptual framework for the causes of malnutrition—or in its positive version, the conditions for good nutrition, first launched by UNICEF. It defines determining factors at the immediate, underlying, and basic levels and embraces food, health, and care as major categories of processes whose effects combine to determine human nutritional status. Yet we may need to go even beyond this to improve our technical communication with agricultural colleagues.

An expansion of the UNICEF framework has been proposed by our Norwegian colleague Dr. Arne Oshaug (Deputy Director-General, Department of Food Production and Health, Royal Norwegian Ministry of Agriculture). He felt the need to strengthen the pillars of the bridge over to his agriculturalist colleagues when he moved from his university-based nutrition location to a leading position in the Ministry of Agriculture in Norway. Figure 1 widens the conceptual food, health, and care clusters to apply to animals, to plants, and to humans alike.

Although Oshaug's framework depicts a primary concern for good nutrition of human beings, he presupposes that plants and animals are being cultivated and cared for in the interest of the human being—or of the *consumer*.

I find "the consumer" a conceptually more relevant target for agriculture than "the human being." This is because agricultural policy and practice cannot affect the human organism directly, but it can relate to a *consumption unit*, a *household*, or an *interest group* as rational human actors, who should be considered part of the *system* that ultimately impacts on the human organism.

Systems thinking

A major shortcoming with our efforts to come to grips with nutrition in agriculture—or agriculture for

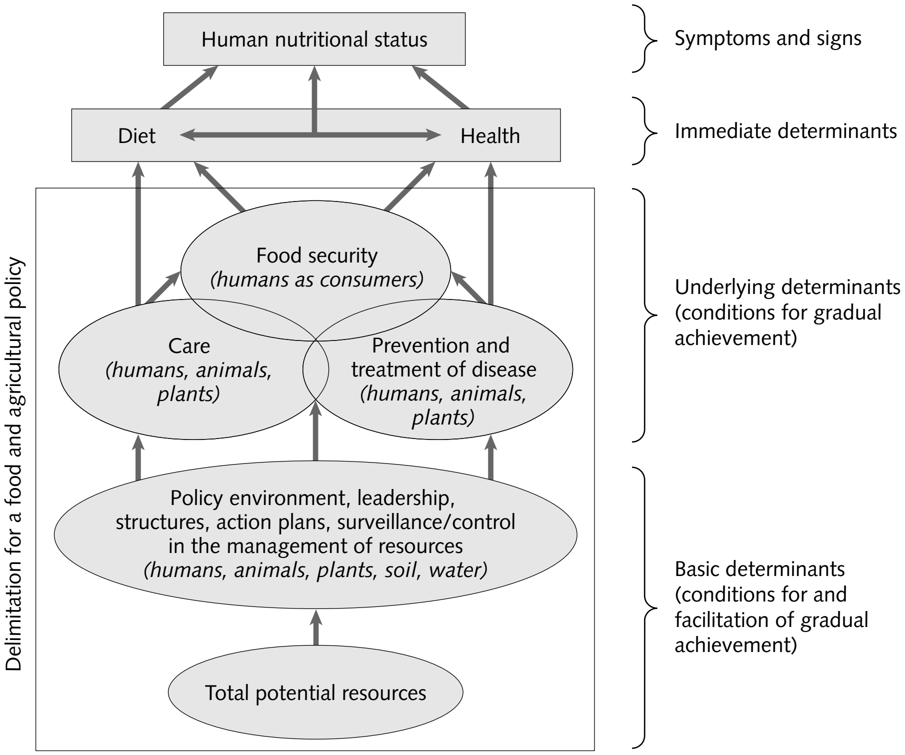

FIG. 1. Factors and boundaries for a food and agricultural policy affecting human nutritional status. A conceptual framework originally developed by A. Oshaug, as adapted from U. Jonsson, Nutrition and the United Nations Convention on the Rights of the Child. Innocenti Occasional Papers, Child Rights Series 5. Florence, Italy: 1993

consumers—is the lack of *system thinking*. I think we have had several examples in this conference of how desirable it would be to think in terms of systems from the beginning whenever we want to extend our technical considerations into policy formulations. It is therefore satisfying that a number of agricultural scholars and university centres are now stressing the need for systems thinking, often under the term "agroecology" [4]. I make a plea that such approaches should increasingly be used to frame conferences such as this one.

In practical terms, it is not uncommon to talk about the *food chain*, which we may conceive of as the vertebrae of a food system. Take the example of breeding for a higher absorptive capacity of a nutrient that gets into the aleurone layer of a grain, as was illustrated in the paper by Bänziger and Long [5] presented at this conference. It is tempting and exciting to think that this will have a direct effect on human nutritional status, while in reality it may be eliminated in the milling process! Of course, the bran could be used for the cow. But under such circumstances one may be allowed to ask whether it was in fact the bran for the cow that was the actual goal and expected outcome, or the improved micronutrient status of the human being? In the reported case, the outcome may have come as a surprise and disappointment. It teaches us that a consumer approach would entail seeing the needs and interests of the consumer at all points in the food chain.

But then many would say, "Impossible! The implications are too complex! Each of us is a specialist and cannot afford to spend time on other parts of whatever system we may belong to." I buy that to a certain extent, but am nevertheless persuaded that someone, somewhere must construct and promote that common trust within which each of us can find our place while understanding better where the linkages are, where the potential impact is, the limitations of that impact, and whether another approach would in fact be better from the outset.

Some experiences from Norway

I am happy to report on some emerging experiences from Norway regarding the growing concern by our agricultural authorities with the role of consumers as major targets for agricultural development, and at the same time as major supporters in helping to orient agricultural policies.

A Parliamentary White Paper was recently presented that explicitly considers the partnership between agriculture and consumers (see the paper by Oshaug referred to in the last footnote). On the one hand, closer linkages between agriculture and consumers are important in sorting out Norway's response to European regulations and to the work of the Codex Alimentarius,* in the wake of World Trade Organization negotiations and related matters. But there are also genuine concerns for the access to food and nutritional health and well-being of the population per se.

For many years, we have had in our country a comprehensive nutrition policy promoted by the National Nutrition Council. The agricultural move towards an explicit consumer orientation has a virtue of its own, a move that one would wish to see happen in all countries. We would indeed have come a long way if agricultural authorities everywhere could formally decide that they wanted to work in the interests of the consumers at all points in the food chain. It would make it easier to delineate the most critical aspects of food, dietary, and consumption systems and with it also the most relevant research to conduct.

The Norwegian Ministry of Agriculture has taken initiatives for brainstorming and dialogue with consumer groups, and they explicitly want consumers to participate actively in the relevant international forums where issues of concern for their access to adequate food and health are being debated and decided upon. There is an emphasis on aspects such as full transparency in all public information and affairs at all points in the food chain, and genuine consumer participation in the shaping of agricultural and food policy. There is also full recognition of food security as a concept involving much more than food production and taking into account both short-term and longer-term issues of access and environmental sustainability.

At the same time, a growing number of consumers demonstrate their concern with the increasingly complex food chains, which carry greater risks of food contamination and progressively alienate the conscious consumer from the product. Rapid technological developments in genetic engineering have given rise to fear that there may not be sufficiently strong legal mechanisms to regulate their use in the interest of consumers everywhere. The growing interest in organically grown foods has its parallel in parastatal control and authorization mechanisms for the cultivation of such foods. The government is ensuring special support to farmers wishing to change over to ecological farming, still of course by far a minority but a growing one. The fact that consumers are taking genuine interest in these issues reflects their concern with a development over which they may have less and less influence.

My government recognizes this and has decided to establish a continuing dialogue with the consumers. How far this move will extend in practice, especially how far into primary production, remains to be seen. What is certain is that there is a genuine will and that consumers should be involved at all points in the food chain.

In a recent paper, our former Director-General of the Norwegian Food Control Authority, now Senior Adviser to the Ministry of Agriculture, expressed it this way:

> Consumers constitute the target group of food policy. Alliances and arenas or concerted action, much more effective than the current ones, need to be set up involving the relevant authorities, trade and industry, and consumer advocates. In many countries and international fora, openness towards and cooperation with consumers never pass the word stage. To be taken more seriously—they rightly deserve so—consumer representatives will need stronger backing from their professional/expert communities. Trust building can only occur through alliances that are recognized by all parties involved.... Coordinated and even joint information campaigns between authorities, consumer organizations and industry/trade should be encouraged. [6]

The triad of actors

I think what this reflects is an understanding of the triad of actors that we need to recognize and understand in relation to each other: the state, the civil society, and the private sector. These are the divisions delineated, e.g., by the United Nations Development Programme for its sustainable human development policy considerations, as well as policies to merge human development with human rights [7]. They are useful also for considering what kind of research is needed in terms of who or what drives research, who funds it, and who decides on the issues to be researched. The interplay between the various clusters and constituencies, or various specific units that can be disentangled within each of them, is important to understand. They may reflect vested and often conflicting interests where concern for the consumer is not necessarily the driving force, even if it may appear as such, often in persuasive scientific language.

Such a dynamic triad model should come in addition to those linking sectors or issue areas that we think ought to interface with each other. I believe that unless we begin to talk more in terms of a spectrum of actors, interests, and control, we may simply end up sitting back with our pet research interests—unaware of the forces that ultimately will turn the results of our research into something good, neutral, or adverse for human nutritional status.

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* The Codex Alimentarius, or the food code, is the seminal global reference point for consumers, food producers and processors, national food-control agencies, and the international food trade. It was established during the years 1961–63 as an intergovernmental commission under the joint leadership of FAO and WHO.

Someone in nutrition once paraphrased the old saying: the proof of the pudding lies in its eating—and in its subsequent metabolic effects! Our clients should be those who eat, and the conditions for this to happen at all—and for the desirable metabolic effects to result—should be our common concern. We would do well to have this notion in the back of our heads in our joint efforts to recommend strategies for the Consultative Group on International Agricultural Research (CGIAR) system to be more active in linking up with nutritionists and consumer organizations, and thereby help improve the nutritional conditions of human beings as consumers everywhere. The same applies to capacity-building and the strengthening of human resources to enable this to happen. We will have different roles to play, but the framework in which we do so must be both wider and more coherent than it is today.

References

1. Fontaine M. Notice sur la vie et les travaux de André Mayer. Paris: L'Institut de France, l'Academie des Sciences, 1958.
2. League of Nations. Nutrition—final report of the Mixed Committee of the League of Nations on the relations of nutrition to health, agriculture and economic policy. Geneva: League of Nations, 1937.
3. McLaren D. The great protein fiasco. Lancet 1974;2:93–6.
4. Oshaug A. The concept of food security in defining the role of the state. Presentation at the symposium on Food Safety and Food Security, Eighth European Nutrition Conference, Lillehammer, Norway, 16–19 June 1999.
4. Bänziger M, Long J. The potential for increasing the iron and zinc density of maize through plant-breeding. Food Nutr Bull 21:397–400.
5. Ørbeck-Sorheim A. Food safety policy at the doorstep into a new millennium. Presentation at the IFAS international workshop "Markets, Rights and Equity: Rethinking Food and Agricultural Standards in a Shrinking World," Michigan State University, East Lansing, Mich, USA, 31 October–3 November 1999.
6. United Nations Development Programme. Integrating human rights with sustainable human development. A UNDP policy document. New York: United Nations Development Programme, 1998.

Agriculture–nutrition linkages and the US Department of Agriculture: A global view

Barbara O. Schneeman and Eileen Kennedy

These remarks were made during the opening session of the conference. In that practical examples are presented of integrating agriculture and nutrition research, these remarks fit well in this portion of the proceedings.

Abstract

The Consultative Group on International Agricultural Research (CGIAR) system, like the US Department of Agriculture (USDA), has been successful in using research to improve the yield and efficiency of food systems. Our systems must now move beyond a focus on simply producing enough food to address fundamental issues of how to make the food system better able to meet the nutritional needs of consumers and contribute to sustainable environmental quality. Success in this endeavour will be determined by multidisciplinary research efforts. This is an area where more specific collaboration between the CGIAR and the USDA will be essential. The USDA Agricultural Research Service has been experimenting with these multidisciplinary partnerships for at least 60 years. Some examples from USDA's experience are given.

Much of our ability to tackle malnutrition (including micronutrient malnutrition) rests with systematic investment in research. Thus, research is almost always a key part of the answer to solving malnutrition. However, we believe there are three key issues as we examine the potentially high payoff areas of agriculture and nutrition research.

First, the evolution of agricultural research in the United States illustrates a pattern of development that demonstrates the vital link between agriculture and the quality and safety of the food supply.

The first era of research emphasized increasing yield, using the development of germplasm and production methods to provide sufficient food (a parallel in international development is the Green Revolution). The second era has brought efficiency into focus, using technology and research innovations to maximize output and minimize inputs. The third era is emerging and focuses not only on yield and efficiency, but also on the quality and safety of our food production system, which includes the nutritional value of food and insuring the quality of our environment.

The Consultative Group on International Agricultural Research (CGIAR) system, like the US Department of Agriculture (USDA), has been successful in using research to improve the yield and efficiency of its food system. Our systems must move beyond a focus on simply producing enough food to address fundamental issues of how to make the food system better able to meet the nutritional needs of consumers and contribute to sustainable environmental quality.

Technology, derived from research on biological systems, genetics, and consumer needs, will drive this new era of development. The research challenge is great: we must sustain our achievements in yield and efficiency while improving the quality and safety of the food system.

Second, success in this third era will be determined by multidisciplinary research efforts, and this effort is where more specific collaboration between the CGIAR and the USDA will be essential. The Agricultural Research Service (ARS) has been experimenting with these multidisciplinary partnerships for at least 60 years, and they are essential for designing viable solutions. The following are some examples from USDA's experience.

The Plant, Soil, and Nutrition Laboratory was established in Ithaca, New York, with a specific charter to create a multidisciplinary interface between plant

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Eileen Kennedy is the Deputy Under Secretary, Research, Education and Economics, in the US Department of Agriculture.

and nutrition science. Pioneering work identified selenium-depleted soils and brought into focus the nutritional importance of selenium in health. Current research has focused on improving the delivery of micronutrients from plants.

The Children's Nutrition Research Center in Texas includes in their scientific staff a group of plant scientists whose fundamental interest is in understanding nutrient transport systems in plants. Obviously this knowledge is critical for the growth and development of plants, but it is also the key to understanding the movement of nutrients to the edible portion of the plant. In other words, to insure that plant foods support the growth and development of our children, the USDA wanted a group of plant scientists interacting with human nutrition scientists so that, working together, they can advance our understanding of nutrient availability from food systems.

The Western Human Nutrition Research Center was recently relocated to the Davis campus of the University of California. This move has created a new partnership between a large and diverse programme in agricultural sciences and human nutrition. This interaction is necessary if we are to understand the role of powerful new tools, such as biotechnology, in meeting the nutritional needs of consumers. The ability to genetically modify plants and animals for improved nutrient content is only one step in the process of identifying new roles for agricultural commodities in improving health and nutrition.

At the Beltsville Human Nutrition Center, a phytochemical laboratory has been established that enables plant chemists and nutrition scientists to interact in understanding the role that secondary plant compounds may play in human health. Research in this programme has advanced our knowledge of the carotenoid content of foods and the mechanisms to increase carotenoid content in plants as appropriate for addressing nutrition issues.

USDA research discussed at this workshop presents examples of collaboration with the CGIAR and illustrates the value of these partnerships and collaboration in achieving our goals of improving the quality of the food system. This research effort becomes a model for developing criteria to evaluate the benefits of genetic engineering and breeding technology for nutritional improvement. The geneticists and plant scientists have been able to determine the variability in micronutrient content related to genetics as well as the stability of these genetic traits in various environments. The nutritionists have been able to design test systems to determine the availability of the micronutrients and their likelihood of having an impact on nutritional status. In addition, we have been able to evaluate various strategies for focusing on certain nutrients by looking, not only at increasing the concentration of the nutrient in question, but also at factors that promote or inhibit utilization of the nutrient (e.g., phytate and ascorbic acid relative to iron). Moreover, our approaches to improve the nutritional value of crops take into account the need for food systems to contribute to sustainable environmental quality, as evidenced by Dr. Raboy's research on the phytic acid content of crops [1]. Reducing phytic acid not only can lead to improvements in zinc and iron bioavailability, but also will help reduce phosphorus excretion when these crops are used for animal feeds.

Although the focus in this workshop is on pre-harvest modification to plant systems for improved nutrition, we should not lose sight of post-harvest modifications that can have an impact. Fortification of foods has been an obvious route by which nutrient content can be augmented. However, more sustainable approaches will include examination of storage and handling conditions as well as processing technology to enhance nutrient delivery.

Third, more and more agricultural research will be called upon not simply to address nutrient deficiencies but, from the point of view of the consumer, to promote health.

Areas such as nutritional genomics will take on increasing importance to the consumer. We have some evidence that this is happening already. Although per capita food expenditures in the United States have been relatively flat over the past 15 years, there has been an exponential growth in expenditures on so-called functional foods, illustrating consumer interest and demand for foods associated with health promotion. Nutritional genomics and food as part of overall wellness will take on increasing importance worldwide, and several factors are catalyzing this change.

The discovery of new functions for nutrients, as well as the discovery that secondary plant compounds stimulate physiological responses when consumed by humans and may have health-promoting and disease-preventing effects in humans, brings into focus the importance of food-based strategies for addressing nutrition-related problems worldwide.

Research on nutrient metabolism is revealing new functions for known essential nutrients. As knowledge advances, we are discovering that vitamins and minerals not only function to prevent deficiency diseases, but also have important functions in the prevention of chronic diseases associated with an expanded life span (for example, selenium and folic acid). This research has tremendous value, because as we conquer disease due to infection and nutrient deficiency and increase the life span, it is essential that we understand the dietary factors that will contribute to maintaining productivity and avoid new burdens on the health-care system.

These advances in our knowledge of nutrition are linked to the success of our food-production system and should guide agricultural policy and the potential value of nutritional genomics.

In conclusion, one of the discussion questions raised by the organizers is whether breeders should be asked to include nutritional components in breeding strategies. In reply to that question, we think we are learning that we cannot afford not to include such consideration. Nutritional quality must be considered, as should environmental impact, if we are to move forward into the next era of developing agriculture. Such research is essential for food security.

These challenges are daunting, but the opportunities are tremendous. If we were to reconvene in another 15 years, we would hope, because of our collaborative efforts in research, that we would continue to add to our long list of successes.

Reference

1. Raboy V. Low-phytic-acid grains. Food Nutr Bull 2000;21:423–7.

Improving human nutrition through agriculture: The role of international agricultural research. Conference summary and recommendations

Howarth E. Bouis

Abstract

This paper reports the conference recommendations for priorities for future research and follow-up actions. It also summarizes the paper presentations and key points made by participants during the course of the conference. It includes partial transcripts of invited remarks made by several participants who were not asked to submit research papers. With respect to research, participants recommended continued efforts on breeding for nutritionally improved crop varieties, evaluation of the impact of the Consultative Group on International Agricultural Research (CGIAR) activities on nutritional outcomes, and new work on communication and outreach related to nutrition. Interdisciplinary research collaboration with non-CGIAR partners in these three broad areas was stressed. The need for a shift in emphasis from protein–energy malnutrition to micronutrient malnutrition was recognized. With respect to institutionally related follow-up actions, formation of an interdisciplinary task force was recommended to implement a process for development of a multidisciplinary common conceptual framework describing agriculture–nutrition linkages, which could then be used for evaluating integrated approaches to nutrition improvement; and to seek approval from the CGIAR Technical Advisory Committee for a system-wide initiative on human nutrition that would include partners from outside the CGIAR. Progress since the conference is reported.

Introduction

A primary objective of this final chapter in the conference proceedings is to report the results of the group discussions—identification of research gaps and recommendations for priorities for future research and follow-up actions—which took place on the last day of the conference. In this context, it also useful first to summarize and highlight key points made by participants during the course of the conference.

Summary of Consultative Group on International Agricultural Research (CGIAR) research related to human nutrition and outside perspectives on that research

An overview of agriculture–nutrition linkages and micronutrient malnutrition: institutional and disciplinary perspectives

On the first morning of the conference, the First Lady of the Philippines, Dr. Luisa P. Ejercito Estrada, gave the keynote address on "The Political Commitment to Improving Nutrition" to open the conference. At the end of the morning session, four persons gave invited remarks on "Perspectives from Outside the CGIAR." Following are selected excerpts from these presentations and from several of the papers, which help to motivate a summary of key points made during this morning session follow.

Luisa P. Ejercito Estrada, First Lady of the Philippines

As a medical doctor, I am committed to helping save lives and improving the health of people. As First Lady, I am often moved especially to improve the health and quality of life of our poor citizens. I fully support our President in his fruitful undertakings, more specifically in providing health and medical services to poor families and communities. One of my regular projects is to bring medical and relief missions throughout the country, particularly to poor communities that are not reached by the regular public health and medical centres. The "Wheat Flour Fortification with Vitamin A Project" was one of the first major activities of the Estrada administration in its first 100 days.

There is certainly no doubt that agriculture has to be listed as a viable input in the campaign against micro-

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nutrient malnutrition. After all, agricultural crops and products are what provide the basic micronutrients needed for nutrition and better health. To achieve this, two basic strategies should logically be pursued. First, breed and develop more nutrient-dense crops, especially rice, corn, and root crops. Second, promote and encourage the production of micronutrient-rich food products, including livestock, poultry, fish, and certain vegetables and fruits, especially those that can be easily raised in backyards and community gardens.

Muhiuddin Khan Alamgir, State Minister for Planning, Bangladesh

Bangladesh's Constitution has recognized "raising of the level of nutrition and improvement of public health" as "among primary duties" of the state. The usual perception that nutrition status cannot be improved without prior income generation and poverty reduction was *not* given operational significance. Based on experience in the recent past in application of direct health and nutritional measures, the programmes taken up underscored the need for simultaneous approaches covering all relevant areas and long- and short-term activities. In all these, emphasis has been on coordinated actions instead of vertical and stand-alone programmes. The role given to agriculture in this Policy and Plan of Action is thus vital, complementary, and cohesive. An important component is an approach integrating public food security support and agricultural extension services with the health- and nutrition-related programs (deworming and immunization, for instance).

In pursuing these programmes in the field of agriculture, cooperation and support from international research institutions are called for in a number of areas. They include improvement of food grain quality with more digestible protein, integrated plant nutrients and soil quality, higher photosynthetic efficiency, nitrogen fixation by non-legumes, development of stress-tolerant strains of seeds, management of soil and plant nutrients based on balanced use of organic nutrients, and genetic engineering and technology as of special importance.

Barbara Schneeman, Assistant Administrator for Human Nutrition, US Department of Agriculture–Agricultural Research Service (USDA-ARS), and Eileen Kennedy, Deputy Under Secretary, Research, Education, and Economics, US Department of Agriculture

The first era of research in the United States emphasized increasing yield, using the development of germplasm and production methods to provide sufficient food (a parallel in international development is the Green Revolution). The second era has brought efficiency into focus, using technology and research innovations to maximize output and minimize inputs. The third era is emerging and focuses, not only on yield and efficiency, but includes the quality and safety of our food production system, which includes nutritional value of food and insuring the quality of our environment.

Our systems must move beyond a focus on simply producing enough food to address fundamental issues of how to make the food system better able to meet the nutritional needs of consumers and contribute to sustainable environmental quality. Technology, derived from research on biological systems, genetics, and consumer needs, will drive this new era of development. The research challenge is great—we must sustain our achievements in yield and efficiency while improving the quality and safety of the food system.

Success in this third era will be determined by multidisciplinary research efforts and this effort is where more specific collaboration between the CGIAR and USDA will be essential. ARS has been experimenting with these multidisciplinary partnerships for at least 60 years—they are essential for designing viable solutions. More and more agricultural research will be called upon to not simply address nutrient deficiencies, but, from the point of view of the consumer, to promote health.[1]

Yang Weimin, Director, Agriculture and Social Sectors Department (East), Asian Development Bank

The Bank is proud of its annual commitment to support research through the CGIAR institutes, because the research relates to core Bank objectives: first, reduction of poverty by raising the productivity of staple crops and the household incomes of poor farmers and by lowering consumer prices for the poor working classes, especially in urban areas. Second, environmental protection, by paying special attention to the rational use of water resources in agriculture and the natural resource management of fragile ecosystems, such as forests, coastal, and upland habitats. Third, economic growth. A recent Bank review of the future prospects for rural Asia stressed the critical role of agricultural research and biotechnology to support social stability, integrate food markets, and promote rising incomes as rural and urban Asia become increasingly interlinked.

It seems to us that the issue of dietary quality and dietary diversification cannot simply be left to the market, where income dictates effective demand. The poor will be left behind. Their quality of life will improve disproportionately if agricultural research and technology produce seeds that will enrich the micronutrient content of affordable staple foods, especially rice.

Robert Bertram, Office of Agriculture, US Agency for International Development (USAID)

Our agency has been associated with the effort to bring agriculture and nutrition closer together for many years. USAID supports agricultural research for three reasons: alleviation of hunger, increasing incomes and creating economic growth, and protecting the environment and conserving natural resources.

We recognize that these three objectives are interdependent…. But fundamentally, I would argue that it is the first objective—hunger, pervasive, chronic, food insecurity—that is the strongest factor generating support and interest from a development agency like USAID. What we are really talking about is human welfare—what it takes for people to live a healthy, productive, and even happy life. This is where nutrition comes in—the linkages among diet, health, and human development. We want to ensure that our investment in agricultural research leads to the most positive outcome for people. The issues that we are going to discuss this week are at the heart of this human connection to agriculture. A workshop such as this ensures that nutritional objectives remain squarely on the screen of agricultural researchers and the CGIAR in particular. At the same time, we hope that agricultural interventions will remain important arrows in the quiver that nutritionists consider when thinking how best to solve a problem.

Per Pinstrup-Andersen, Director-General, International Food Policy Research Institute (IFPRI)

What is different now 15 years after the last CGIAR-wide meeting on nutrition?… New and more powerful plant-breeding techniques are available today. The use of biotechnology is a much-debated and highly visible topic…. Our understanding of the nature of human nutrition problems is more complex. Micronutrient deficiencies are high on the public health agenda, alongside energy. Food-production, environmental, and human nutritional and health systems are increasingly strained as a consequence of population growth and the closing of the land frontier. Consequently, in finding solutions to problems that arise within these systems, it is more difficult today to ignore interdependencies among these systems. [2]

Barbara Underwood, President, International Union of Nutritional Sciences

Sustaining the progress that has been achieved will depend on underpinning the medical model with food-based approaches, which address multiple nutrient and phytochemical needs for optimal health. Agriculture by investing in the green revolution can rightly be credited for its contribution to reducing food shortages and the protein–energy malnutrition problem. A similar opportunity exists now for agriculture to invest in developing more micronutrient-dense staple crops, while not neglecting continued research on livestock and small animals, fish, vegetables and legume production. Education and awareness of the public is also crucial. The public must not be considered only the "target" of imposed interventions. Civil society must become engaged in the process.[3]

Ross Welch, Plant Physiologist, Plant, Soil, and Nutrition Laboratory, US Department of Agriculture–Agricultural Research Service, and Robin Graham, Professor, Department of Plant Science, University of Adelaide*

Forging linkages among agriculture, nutrition, and health is necessary to nullify the adverse effects of past policies for global agriculture, nutrition, and national development that have fostered only short-term, unsustainable solutions to starvation, malnutrition, underdevelopment, and high human fertility rates. To do so would be to support a new paradigm for agriculture—the food systems paradigm—an agriculture that aims not only for productivity and sustainability but also for better nutrition, important objectives for the entire human race.[4]

Lawrence Haddad, Director, Food Consumption and Nutrition Division, International Food Policy Research Institute (IFPRI)

By way of income generation and food price reduction, it is clear that agricultural research has contributed to significant reductions in malnutrition. Food availability has improved in no small part due to agricultural research, despite rapid population growth in developing countries and severe constraints to increased production through land expansion. The question the participants at this conference must ask themselves is, "Can agriculture—helped by agricultural research—do even more?"[5]

Summary of opening session

The opening session laid out the broad policy environment for the presentations and discussions to follow. The following key trends and conditioning factors are noted:

1. There has been a shift in focus away from protein–energy malnutrition to micronutrient malnutrition.
2. Cereal prices, adjusted for inflation, have fallen substantially over time as a result of the Green Revolution.
3. More powerful plant-breeding techniques are being developed, including but not restricted to biotechnology.
4. There is a better understanding of and increasing appreciation for the significance of interdependencies among nutrition, health, how food is produced and processed, what food is produced, and the environment.

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* The paper by Welch and Graham [4] was not presented at the conference but is included in this volume to provide a plant scientist perspective along with those of a nutritionist and an economist.

5. The problem of nutrition, and micronutrient malnutrition in particular, has the attention of government leaders and donor agencies.

The following points of agreement on policy are noted:

6. There is much that can be and must be done now to reduce malnutrition among the poor without waiting for increases in income, although higher incomes help to reduce malnutrition; targeting women through better education, among other means, is a key element.

7. Fortification and supplementation programmes are part of the answer to micronutrient malnutrition, but so is improved dietary quality; agriculture has been an important element of the strategy for addressing protein–energy malnutrition in the past (although protein–energy malnutrition persists) and will be an important element of the strategy for addressing micronutrient malnutrition in the future.

8. Greater integration of agriculture into the mix of policies for reducing malnutrition will require a greater degree of interdisciplinary communication and coordination among government, non-profit, and private agencies.

9. The required degree of coordination cannot be achieved without strong political support; securing this political support will depend in turn on public education about the costs of malnutrition and the benefits that agriculture and other interventions can provide.

The following points of disagreement as to degree are noted:

10. The extent to which the interdependencies cited in point 4 and collaboration and coordination cited in point 8 can be successfully addressed, as a practical matter.

11. The usefulness of pursuing "partial" solutions, while foregoing a holistic, food systems approach. A partial solution might include, but is not restricted to, treating single-nutrient deficiencies.

The conference recommendations indicate quite clearly the need for development of a common conceptual framework as a basis for better understanding and communication, research collaboration, and programme and policy coordination among disciplines.

CGIAR research on staple food crops

In the first morning session, enthusiasm was expressed for incorporating agricultural strategies into the mix of interventions for reducing malnutrition. The next 17 papers in the proceedings present evidence on various aspects of one such strategy: breeding for nutritionally improved, micronutrient-dense staple food crops.

Bouis et al. provide the general arguments underpinning such a strategy, which are reproduced here:

The combining of benefits to human nutrition and agricultural productivity, resulting from breeding staple food crops that are more efficient in the uptake of trace minerals from the soil and that load more trace minerals into their seeds, results in extremely high *ex ante* estimates of benefit–costs ratios for investments in agricultural research in this area. This finding derives from the confluence of several complementary factors:

» The rates of micronutrient malnutrition are high in developing countries, as are the consequent costs to human welfare and economic productivity.

» High trace mineral density in seeds produces more viable and vigorous seedlings in the next generation, and efficiency in the uptake of trace minerals improves disease resistance, agronomic characteristics that improve plant nutrition and productivity in trace-mineral-"deficient" soils.

» A significant percentage of the soils in which staple foods are grown are "deficient" in these trace minerals, which has kept crop yields low. In general, these soils in fact contain high amounts of trace minerals. However, because of chemical binding to other compounds, these trace minerals are unavailable to staple crop varieties presently used.

» The adoption of nutritionally improved varieties by farmers can rely on profit incentives, either because of agronomic advantages on trace-mineral-deficient soils or incorporation of nutritional improvements in the most profitable varieties being released.

» Because staple foods are eaten in large quantities every day by the malnourished poor, the delivery of enriched staple foods (fortified by the plants themselves during growth) can rely on existing consumer behaviour.

» The benefits from relatively small investments in agricultural research may be disseminated widely, potentially accruing to hundreds of millions of people and millions of acres of croplands.

» Breeding advances are derived from initial, fixed costs, with low recurring costs, and thus tend to be highly sustainable as long as an effective domestic agricultural research infrastructure is maintained.[6]

The three basic breeding strategies are to increase nutrient density, reduce antinutrients or inhibitors, and increase promoting substances. Papers by Gregorio et al. [7], Monasterio and Graham [8], Beebe et al. [9], Bänziger and Long [10], Cakmak et al. [11], Graham and Rosser [12], Chavez et al. [13], and Maziya-Dixon et al. [14] investigate the first strategy—that of increasing nutrient density for iron, zinc, and β-carotene in rice, wheat, maize, beans, and cassava. The topics addressed are the degree of genetic variability in these nutrients, the stability of genotype–environment interactions, and the genetics of high nutrient density. In general, genetic variability is sufficiently high and genotype–environment interactions are sufficiently moderate that breeding for high nutrient density is deemed feasible and worthwhile. What data are available on genetics suggests that breeding for high levels of β-carotene, in particular, would be relatively easy.

The evidence on agronomic aspects of the breeding strategy, then, is very favourable. In fact, for rice, a high-yielding, disease-resistant, aromatic variety, already in the International Rice Research Institute (IRRI) testing programme, was serendipitously discovered—after a high correlation was found between the high-iron trait and aroma. Initial tests indicate that this rice delivers up to 80% more iron after milling than standard modern varieties.

A remaining question critical to the eventual success of the breeding strategy is the degree to which the extra iron and zinc in high-mineral-concentration seeds is bioavailable to humans. Papers by Welch et al. [15], King et al. [16], and Haas et al. [17] directly address this question, using increasingly realistic, but increasingly expensive, methodologies to test bioavailability. Welch et al. used a rat model. A small number of human subjects consuming single-food test meals were examined in a laboratory setting by King et al. Both of these studies used radiolabelled grain, the cost of which limits the amount of grain that can be used. Feeding trials of a relatively large sample of human subjects in the Philippines eating "normal" meals along with high-iron rice are planned by Haas, del Mundo, and Beard. The available evidence, although promising, is not yet definitive.

The second strategy, that of reducing antinutrients, is discussed in the paper by Raboy [18], who has pioneered the development of low-phytic-acid lines of maize and other cereals. The advantage of this strategy is that bioavailability may be increased simultaneously for a range of trace minerals. A disadvantage is perhaps a negative effect on productivity in phosphorus-deficient soils, although this aspect still requires additional research. As already mentioned, breeding for increased levels of trace minerals improves plant nutrition and productivity. The effects of breeding for higher levels of β-carotene are not expected *a priori* to be either positive or negative, although this issue has not been studied in depth. Breeding for higher levels of β-carotene changes observable consumer characteristics (colour), requiring consumer education, effects which are not an issue for breeding for lower phytates or increased trace minerals.

Hagenimana and Low [19] forego plant-breeding altogether, which results in considerable savings in terms of money for breeding research and the time it takes for their intervention to reach consumers. They follow a strategy of selecting improved orange-fleshed sweet potatoes that are already high in β-carotene; they implement a nutrition education programme to convince rural women to switch away from production of presently preferred white sweet potato varieties over to the orange-fleshed varieties. The design of their education programme is key to the success of their strategy. A similar approach could also be taken with maize, cassava, and wheat, since high-β–carotene lines already exist [12].

Vasal [20] discusses the history of the quality protein maize (QPM) breeding programme at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) that predated efforts to breed for micronutrient density. Because of the initial trade-off between high-lysine and lower yields and undesirable consumer characteristics associated with high-lysine content, breeding of high-yielding, high-lysine lines with desirable consumer characteristics has been a long and arduous, but eventually successful, process. Livestock that consume QPMs thrive, making combined production of QPM and livestock profitable. Apart from relieving protein constraints to better human nutrition (e.g., provided in maize-weaning foods in parts of Africa), lysine (a sulphur-containing amino acid) may improve the bioavailability of minerals in human diets.

These first 15 papers concentrate on the use of conventional breeding or selection techniques. The final two papers, by Datta and Bouis [21] and Phillips [22], discuss the application of biotechnology to improving the nutritional quality of food staples. The potential benefits to consumers are great; some nutrition-improvement objectives may be met through biotechnology that cannot be addressed using conventional techniques. Other nutrition objectives may be met more quickly at lower cost once techniques are further refined. Nevertheless, use of conventional breeding and biotechnology should be seen as complementary techniques, which eventually can be used in tandem for maximizing a range of desirable nutritional characteristics in the same crop.

In getting plants to fortify themselves through plant-breeding, is it optimal to treat only single nutrient deficiencies, when better public health requires better provision of multiple mineral and vitamins? Indeed, this question may be raised of most conventional fortification and supplementation strategies in place today. Graham and Rosser [12] raise the possibility of nutritional synergies to be attained by simultaneously breeding for enhanced levels of iron, zinc, and β-carotene. This is seen as a high-priority research area involving feeding trials to identify the optimal breeding strategy that would maximize gains to nutritional improvements.

CGIAR research on livestock, fish, vegetables, and other non-staple food crops

Breeding for nutritionally improved staple food crops is only one relatively narrow, although apparently high-payoff, activity in the broad spectrum of agriculture–nutrition linkages. This is brought out clearly by Haddad [5] in his conceptual framework, which provides examples of CGIAR research in a number of diverse areas: the time-allocation patterns and decision-making power of women, who are the primary care providers for children and other family members; nutrient losses during processing and preparation of food; health environmental effects of agricultural production; income generation for those engaged in agriculture; the effects on diets of changes in food prices and on own-consumption of producers whose cropping patterns have changed; and the effects of changing work patterns on nutrient and energy needs.

It is in this broader context that the eight papers presented on the afternoon of the second day of the conference should be seen. Eight papers cannot cover the entire spectrum of topics. Nor, as is pointed out later in the final plenary discussion on the third day, does stock-taking of CGIAR research at this conference cover all work that is being done by the CGIAR related to nutrition. Several, but not all, of the papers are commodity-focused, as are the mandates of the individual centres where the authors work. These papers demonstrate an impressive range of research activities related to human nutrition encompassed by CGIAR centres.

Ali and Tsou [23] and Fassil et al. [24] discuss a broad spectrum of centre-wide nutrition-related activities that are undertaken by the Asian Vegetable Research and Development Center (AVRDC) and the International Plant Genetic Resources Institute (IPGRI). The AVRDC has given a high priority to the human nutrition impacts of its research on vegetables. Some of these activities might well have been described in the previous section of these proceedings—breeding for nutrient-dense genotypes and testing bioavailability. However, vegetables are considered to be inherently rich sources of vitamins and minerals. Efforts to increase their consumption should have a beneficial impact on micronutrient status. Other agronomic-related research activities involve not only increasing vegetable yields and lowering unit production costs, but also finding ways to extend growing seasons and reduce the extreme seasonality in vegetable prices.

Socio-economic research has also been undertaken to analyse vegetable consumption patterns and the factors that drive these patterns. A model is proposed for assigning economic values to various nutrients contained in foods, values which in turn point the direction in which resources should be invested for maximizing nutrition benefits. Indeed, the model is used for assigning priorities for AVRDC research.

Cardwell [25] and Abd El Moneim et al. [26] describe plant-breeding activities of the International Institute of Tropical Agriculture (IITA) and the International Center for Agricultural Research in the Dry Areas (ICARDA) that are directed not at micronutrient deficiencies but at reducing compounds that are detrimental to health in other ways—mycotoxins in maize in the case of Cardwell's research and a neurotoxin in grasspeas that can cause irreversible paralysis in the case of the research by Abd El Moneim et al. Although plant-breeding research is one approach being followed by the IITA to address the mycotoxin problem in maize, farmer participatory methods are also used to improve storage practices to reduce levels of mycotoxins in grains. In addition, an epidemiological study is under way to examine the effect of exposure to aflatoxin in maize-based production systems on the growth of children and on the immune response to vaccination.

A primary reason why the prevalences of micronutrient deficiencies are high in developing countries is that meat, dairy, and fish consumption is low. These products are highly desired but expensive. Not only are minerals and vitamins present at higher concentrations in meat, dairy, and fish products, but they are more highly bioavailable than minerals and vitamins contained in plant foods. Moreover, consumption of these products in the same meal with plant foods improves the absorption of minerals from plant foods. Ahmed et al. [27] and Prein and Ahmed [28] report on ongoing research related to human nutrition at the International Livestock Research Institute (ILRI) and the International Center for Living Aquatic Resources Management (ICLARM). Although ILRI and ICLARM activities that have led to growth in the supply of livestock and fish products can be presumed to have had substantial beneficial nutritional impacts on consumers, past research at these centres apparently has not given high priority to measuring these nutritional effects in the search for ways to enhance nutritional impacts.

Effects on dietary quality and other aspects of household resource allocation decisions are still being analysed. ICLARM research on measuring nutritional impacts is equally in its formative stages. A few studies have looked at the effects of projects on fish consumption itself but have not taken the further step of measuring impacts on the overall diet and then the impact of diet on measures of nutritional status.

The Bouis study in Bangladesh [29] of the nutritional effects of adoption of improved vegetable varieties and polyculture fish pond production is one of the first not only to measure the impacts of adoption on household income and food consumption, but also to link individual diets to blood haemoglobin, a proxy measure for iron status. By surveying both adopting households and a carefully selected sample of comparable non-adopting households, a reasonable assessment can be made of the impact of adoption on micronutrient status. The impact is small, primarily because the incomes of adopters are highly diversified. Although both technologies are apparently highly profitable, they as yet do not constitute the major income-earning activity. Also, most of the extra production of these micronutrient-rich foods is sold—to the benefit of consumers. This is shown by regression estimations that link consumption of various foods to measurable impacts on blood haemoglobin.

Smitasiri [30], who has worked extensively on the promotion of food-based interventions for nutritional improvement through communication and education, commenting on the CGIAR presentations, argues that the cost of animal and fish products is simply too high for the poor, but that micronutrient-rich vegetable sources are well within their purchasing power. She points out that education and promotion are essential elements for successful food and nutrition interventions—education of the poor, education of various groups in the community, and education of the public at large.

Once resources are invested in food-based strategies, many operational issues, such as those raised by Smitasiri, arise as how best to optimize nutritional impacts. It may well be that the research should not concentrate on adopting households, but rather on the much larger number of poor consumers who benefit through lower food prices.

Merging agricultural strategies with existing supplementation, fortification, and dietary diversification programmes

Whereas the presentations reviewed above involved, for the most part, CGIAR scientists talking about contributions that their research could make to improving nutrition, there was a need to inform CGIAR scientists about the strengths and drawbacks of existing strategies and to discuss how agricultural strategies could be integrated in the present mix of interventions in a complementary way. The three broad types of interventions currently being emphasized to address the problem of micronutrient malnutrition are supplementation, fortification, and dietary diversification through nutrition education. There was a general consensus among the participants that no one particular type of intervention, including agricultural strategies, was the lone solution to the problem.

An in-depth case study of the Philippine micronutrient strategy

Overview of Philippine policies and programmes

Presentations were given by Corazon Barba [31], director of the Food and Nutrition Research Institute, on an overview of Philippine nutrition programmes, by Alex dela Cuadra [32] of the Department of Health on supplementation programmes in the Philippines, by Florentino Solon [33], director of the Nutrition Center of the Philippines, on fortification programmes, and by Elsa Bayani [34], director of the National Nutrition Council, on food production and nutrition education policies, projects, and programmes. These four presentations were followed by shorter talks by six speakers representing various stakeholder organizations involved in various aspects of fighting micronutrient malnutrition. Brief excerpts from their remarks are given below.

Bayani provides a useful summary of the four initial presentations:

> For the past six years, universal supplementation of vitamin A and selective supplementation of iodine using iodized oil capsules has provided immediate, although short-term, relief from micronutrient deficiencies. We have shown how such an effort can be mounted successfully through a National Micronutrient Day, but with the participation of national governmental agencies, local governmental units, local and international NGOs, the business community, and the people themselves. We have learned valuable lessons along the way, lessons that helped develop a more efficient system for procuring and distributing supplies, and more effective schemes of mobilizing participation to the activity. We have also shown that micronutrient supplementation can be integrated with other routine services of the health-care system. Micronutrient supplementation will continue to be an important intervention to address micronutrient malnutrition, shifting from a universal supplementation policy to a targeted one, within the next decade.
>
> We have likewise set in motion actions to ensure that foods fortified with vitamin A, iron, and iodine will be available and accessible to the public, especially the nutritionally needy. Such actions range from technology development to technology testing, to market studies and clinical trials. Thus, today, we have a wider array of fortified foods in the market: iodized salt, iron-fortified rice, and vitamin A–fortified flour, sugar, margarine, cheese, milk, snack foods, instant noodles, and juice drinks, among others. Bringing fortified foods to the truly nutritionally needy, possibly through the mandatory fortification of staples like rice, flour, sugar, and cooking oil with iron and vitamin A, is a major challenge. We also need to further increase the demand for iodized salt, calling for the implementation and enforcement of a salt iodization law. [34]

Corporate perspective: Benjamin Ynson, Genie Food Corporation

Snack foods. They are the most controversial products on the market shelves today. On the one hand, they make you feel guilty to eat them. On the other hand, you have to have them. Should we ban them? Or could we reform them? We at Genie Foods believe that it is possible to re-engineer so-called junk foods and make them into a far better product, as close as possible to multivitamin tablets. We were able to enhance our snack product, which is the first snack to be approved by the Department of Health. It is fortified with vitamin A, iron, and iodized salt.

Consumer perspective: Jamie Manuel, National Consumer Affairs Council

The National Consumer Affairs Council, created under the Consumer Act of the Philippines, is mandated to improve the management, coordination, and effectiveness of consumer programmes not only in governmental agencies but in non-governmental agencies as well. October was declared Consumer Welfare Month by the President. This is the time when concerted efforts are made to assert consumer rights. During this month there are several agencies conducting seminars in coordination with our office on the topic of food safety that includes nutrition. We have also, through the assistance and advice of the Department of Education, adopted a programme to integrate the concept of consumer education in the curricula of public, elementary, and secondary schools, including private institutions.

University perspective: Demetria Bonga, University of the Philippines at Diliman

Academia has a cadre of technical people who can help rationalize and promote national nutrition intervention programmes such as the ones already discussed. We are recognized as a partner in discussions of policies and issues related to nutrition.

First, in the conduct of research work, universities can evaluate the extent of utilization of fortified foods and keep track of trends through time. The Department of Health plans to phase out supplementation. When should that happen? We don't know. We have to monitor the extent to which fortified foods are being consumed. For example, what is happening in the rural areas where micronutrient malnutrition is more severe? At the moment, fortified foods are more available in the urban areas. It is necessary to test whether fortified foods perform well in clinical trials. Academia can also assist in this. We need to know the extent to which fortification has reduced the prevalences of specific micronutrient deficiencies.

Second, universities have experts in mass communication who can design effective information dissemination campaigns for fortified foods. They can also help to develop appropriate information materials on fortified foods using a range of media outlets.

Cost-effectiveness: Dyezebel Dado, Department of Health

Initiated in 1993, the Philippine National Vitamin A Supplementation Program (NVASP) is one of the oldest, most mature, and most comprehensive of its kind. Originally the NVASP was to be maintained for three years. With the programme now entering its sixth year, the government is wavering in its commitment to continue financing. We conducted a cost-effectiveness analysis of NVASP and a hypothetical programme of vitamin A fortification of wheat flour to see what policies might work best or how they could be modified.

The effectiveness indicator used for the fortification programme was the number of people who consumed less than 70% of the recommended daily allowance of vitamin A. The analysis found that fortification is more than twice as cost-effective in reducing inadequate vitamin A intake as is the NVASP. However, fortification alone does not appear to be adequate. At what is considered the maximum acceptable fortification level, there would still be 2.2 million Filipino children aged 12 to 59 months (29%) who would have inadequate vitamin A intake.

An investigation of the cost-effectiveness of geographically targeted supplementation programmes covering urban areas, rural areas, and the poorest rural areas reveals that maintaining a universal supplementation programme in urban areas and only the poorest rural areas would reduce the total vitamin A programme (supplementation and fortification) costs by 30% and reduce the number of Filipino children with inadequate vitamin A intake to 900,000 (12%). These results suggest recommendation of a strategy that combines fortification and supplementation.

NGO Perspective: Naida Pacsion, Chairperson, KAIN

KAIN is a coalition of 14 local and international non-governmental organizations (NGOs) that work together on nutrition issues.

The goals of KAIN are to serve as a coordinating body for nutrition-related activities among NGOs in the country; to enhance the capability of member NGOs in the areas of programme planning, management, and institution-building; and to provide technical assistance to national and local governments, other NGOs, and people's organizations for nutrition-related interventions.

The NGO–government partnership works well, because the NGOs have close links with the grass-roots people—links that government agencies cannot have. NGOs have a proved capacity to mobilize communities. We have flexibility and the capacity to test innovative approaches without the burden of bureaucracy. We can pilot test programmes, find ones that work, and then bring them to the government for institutionalization.

International aid perspective: Nancy Haselow, Helen Keller International

Micronutrient malnutrition is a multifaceted problem that rarely stems from a single cause. Like the problem, the solution requires a multifaceted approach if we are to make sustainable strides towards reducing micronutrient malnutrition in countries, in communities, in families, among those most at risk and vulnerable. The solution requires that we forge alliances, build partnerships, and join forces with other stakeholders to use relevant research findings to design, test (pilot and evaluate), and implement a mix of effective interventions that can all combine to alleviate micronutrient malnutrition.

International agencies can contribute to this end by translating academic research into pilot strategies for scale-up once proved to be effective. In this regard, nutrition research findings from the vitamin A supplementation impact studies (conducted in Indonesia, Nepal, India, etc.) were used to advocate for further investigation into the extent of vitamin A deficiency within many countries, which in turn provided fuel to convince policy makers to develop policies and national programmes to control vitamin A deficiency. Innovative interventions to control vitamin A deficiency, such as universal supplementation during National Immunization Days, home gardening reinforced with nutrition education, and social marketing of various fortified foods, developed and tested within the context of one country, have been adapted for use to other countries.

Integrating Agriculture into the Philippine Strategy

Juliano [35] pointed out that the Philippine agricultural research system already collaborates with the International Rice Research Institute (IRRI) on the development of high-iron rice in areas of mutual interest and expertise, particularly in the field testing of the lines developed at IRRI. High, stable grain yield is required of lines if they are to receive approval for release. If lines are to be released for their superior nutritional content, then higher levels of micronutrient content and demonstrable bioavailability need to be established. Castillo [36] spoke about the need for a broader collaborative effort between IRRI and national scientists that would reach well beyond the government agricultural research institutions.

Micronutrient policies, programmes, and strategies in other parts of the world

The Philippine micronutrient programme reflects to some degree the opportunities and constraints faced by governments throughout Asia. Presentations were next made summarizing micronutrient policies, programmes, and strategies in Africa and Latin America. Historical experience and comparisons were also discussed for developed countries.

Sub-Saharan Africa

In general, Africa lags behind Asia in the range of interventions being implemented and the length of time that they have been in place. Smith [37] emphasized the lack of trained personnel and other infrastructure. Supplementation programmes started in earnest after the 1992 International Conference on Nutrition. More recently, there has been an increase in the rate of coverage of vitamin A supplementation of children under five years of age, due to the integration of vitamin A capsule distribution into national immunization days. Food fortification was initially not considered a front-line approach because of the lack of infrastructural facilities, but it is now getting a close look.

Micronutrient intervention efforts have only begun to exploit the untapped potential of the existing food systems, for example, the dissemination of high-β-carotene sweet potatoes discussed by Hagenimana and Low [19]. There is a growing movement to involve women in intervention programmes.

Latin America

Bressani [38] points out that a key distinguishing feature of Latin America is that 75% of the population is already classified as urban, and that this proportion is projected to rise to 82% by 2025. Because markets for processed foods are more developed in urban than in rural areas, fortification has a comparative advantage in Latin America relative to other regions. Indeed, most past interventions discussed involve fortification. Successful salt iodization programmes are the most widespread, followed by fortification of sugar with vitamin A; fortification of wheat with thiamine, riboflavin, niacin, and folic acid; and fortification of margarine. Breeding for nutritionally improved foods, which may be viewed as a fortification strategy (getting plants to fortify themselves), therefore is also applicable to this region.

Europe–Norway

Eide [39] begins with a global perspective. Community nutritionists today understand nutrition as the complex interaction between a broad set of biological and societal processes. There is, however, a communication gap between nutritionists outside the laboratory and contemporary plant breeders for micronutrient content that may risk reducing the concept of nutrition to “nutrients in agriculture.” Recent efforts by the Norwegian Ministry of Agriculture to promote “whole-food-chain thinking” are described, including the participation of the consumer in setting goals of agricultural policy to promote food and nutritional security.

Micronutrient interventions and strategies: Implications for CGIAR research

In general, there is relatively little recognition of the *indirect* effects of agricultural research, which can be considerable. Increasing the aggregate supply of a particular micronutrient-rich food, and so *ceteris paribus* lowering its price in the market, will increase consumption. This applies both to investments in long-term increases in supply and to efforts to dampen seasonal fluctuations in prices of vegetables, fruits, and other foods through improved storage and marketing infrastructure, increased interregional and even international trade, and breeding of varieties that grow in the off-season.

Moreover, the role of agriculture is not just a matter of providing nutrients, as pointed out by Barth Eide [39] and as is clear from Haddad's [5] conceptual framework. Better health and better child care are the direct inputs that are also required. Health and child care, in turn, are affected at one level by how and what foods are produced, and at another level, by innumerable characteristics of the natural resource base and the cultural, political, and economic system of the society in which the agricultural sector is embedded. Therefore, many levers for influencing nutrition outcomes are available to agricultural policy, agricultural projects and programmes, and agricultural research.

Recommendations for priorities for CGIAR research and follow-up action

On the third day of the conference in an initial plenary session, five speakers were invited to give their views on a subset of these questions of their own choosing. Excerpts from their remarks are given below. During the break-out sessions, each of the four research-question groups was asked to identify at least three priorities for research and one specific follow-up action. Each of two institutional-question groups was asked to identify at least three follow-up actions. The groups could add, delete, or modify questions as they chose.

The following suggested questions were posed to the break-out groups:

Research agenda 1: Increasing the supply of foods rich in bioavailable nutrients

1. Does CGIAR research related to specific crops, fish, and animal products have more potential for improving nutrition than others?
2. To what extent do producers of vegetables, fish, and livestock products consume their own produce and so improve the nutritional status of family members?

Research Agenda 2: Consumer aspects of plant-breeding and nutrition education

1. How crucial is nutrition education as a complementary activity to plant-breeding?
2. What is the scope for developing consumer demand for more nutritious genotypes of specific crops which are identifiable, say by an orange or yellow colour, but which may be more expensive in the market, or which may be less preferred because of their colour?

Research agenda 3: Policies and programmes that may indirectly impact nutrition: The interface of economic factors and nutrition outcomes

1. What is the role of agricultural investment and price policies in improving nutrition?
2. Providing better-quality diets through agriculture, and raising farm productivity and lowering food prices in the process, provides a range of nutrients and benefits to rural households in a number of ways not directly related to nutrition, e.g., by raising household income. Supplementation and fortification programmes have narrower objectives and typically provide only one nutrient. Is it possible to compare these broad strategies in terms of their cost-effectiveness or benefit–cost ratios? If not, how can the best mix of interventions to improve nutrition be identified?

Research agenda 4: The impact of the Green Revolution on micronutrient malnutrition

1. Has the Green Revolution improved or worsened micronutrient malnutrition?
2. How has the Green Revolution changed the diets of the poor? Cereal prices are lower. In some countries, non-staple food prices are higher. What are other major factors (e.g., population growth and urbanization) that have influenced present diets?
3. Are modern varieties of the same crop more or less nutritious than traditional varieties, with respect to their contents of trace minerals and vitamins, phytate and other antinutrients, sulphur-containing amino acids, and other promoters?

Institutional issues 1: Intra-CGIAR coordination of research activities related to human nutrition

1. Should the CGIAR take on the explicit objective of improving human nutrition? Are there compelling reasons for doing this, e.g., cost-effectiveness relative to supplementation and fortification? What are the constraints to doing so, e.g., funding? Do CGIAR plant breeders already have enough breeding objectives without having to worry about nutritional quality? Will this slow down progress in achieving other breeding objectives? Will the international nutrition community recognize the CGIAR as an important partner in fighting malnutrition?
2. Who should pay for plant-breeding with a nutritional objective? Should this (new) objective be taken on entirely by traditional CGIAR funding sources? Can some of the funding burden be shared with bilateral and multilateral organizations that fund nutrition interventions?
3. Should a formal Intercentre Initiative on Human Nutrition be created within the CGIAR?

Institutional issues 2: CGIAR collaboration with external organizations

1. What institutional arrangements would work best for providing human nutrition expertise (i.e., interdisciplinary collaboration) to the CGIAR?
2. In breeding for nutritionally improved staple food crops, how should collaboration with national agricultural research centres, in developing and developed countries, be arranged?
3. In breeding for nutritionally improved crops, is collaboration with university researchers crucial in this endeavour?
4. Is there a collaborative role with the private sector in developing and disseminating staple food crops with improved nutritional content?

Excerpts from invited comments during plenary session before break-out groups

Milla McLachlan, World Bank

On first reading, I was dismayed that the questions posed for the break-out groups were extremely cautious and very tentative. These were asking us again to consider *whether* we should be incorporating agriculture into strategies for nutritional improvement, and not *how* to do this. Fifteen years after the first CGIAR-wide meeting on human nutrition, we should be asking bolder questions. Upon further reflection, I thought that this may be due to the admirable caution of a scientist, or a sober response to the experience that they, as agriculturalists, have had with us, as nutritionists.

Before directly addressing some of the break-out group questions, I will start with two brief "don'ts." First, please don't ask permission of the nutrition community, or wait for the nutrition community to welcome you to do something to improve nutrition. Rather do what needs to be done. We have seen a retreat away from food-based approaches over the last couple of years. The medical model has become very strong in nutrition and in the training of nutritionists. There has been a fair and legitimate disillusionment with food-production programmes that have nutritional improvement as a stated goal at the outset, but then never again think about nutrition or measure nutrition, so that there is never any impact on nutrition. Many food-related nutrition projects and nutrition education programmes have been too diffuse and have not focused on the improvement of the nutritional status of particular vulnerable groups, such as women and children. Therefore, there has been a quest for projects that directly address the nutritional problems of these groups.

Second, don't tinker at the margins. It is not good enough for the CGIAR system and agriculturalists just to spend what little money is available to see what can be done. Either take incorporation of nutritional concerns seriously and spend the resources that are required, or state publicly that the resources and/or the inclination to improve nutrition are not there, and that you will stick to the narrower objective of increasing production, or other objectives. It seems to me that the commitment of the CGIAR and agriculturalists to fighting food insecurity should be comprehensive—it should address food availability, access to food, and utilization. Food security without nutrition security seems to me to be a hollow victory.

I would like to challenge the CGIAR to pursue a bold, visionary "Agriculture for Human Nutrition Initiative." This may be undertaken at the regional level, or throughout the CGIAR system, or by key CGIAR centres linking with national nutrition and agricultural research partners; this is for future discussion.

However, such an initiative would involve four essential elements:

1. Agreement on a conceptual framework so that we are all working from the same understanding of the causes and consequences of malnutrition and the several pathways through which agriculture influences nutrition; we need to spend some time identifying priority pathways and, before that, agreeing on the criteria for selection of priority pathways.
2. Development of indicators to measure the impact of agricultural strategies on nutrition, not just outcome indicators but intermediate indicators as well.
3. Links between policies or programmes, agricultural research, and nutritional outcomes need to be made explicit from the beginning; partnerships must be an integral part of this initiative; development of methodologies and institutional arrangements for doing this can draw on CGIAR experience with other cross-cutting issues, such as gender and the environment.
4. This initiative must be sold to nontraditional funders that have a primary focus on poverty and health; it must be exciting, it must be new, and it will require an investment in communication, marketing, and fund-raising.

Mahiul Haque, Bangladesh Rice Research Institute

The Bangladesh Rice Research Institute (BRRI) has now released a total of 38 improved rice varieties. This year total production is about 30 million tons of rice, which is enough to also feed the poor. I have selected particular questions to answer that are relevant to BRRI's institutional mandate:

1. Do breeders have enough breeding objectives already without having to worry about nutrition objectives? Will working on nutrition objectives slow down reaching other breeding objectives? Over the past 30 years, we have had much success

in Bangladesh in increasing the supply of rice by introducing and continuously improving modern varieties of rice. It is now time to look into the nutritional quality of grains. From our institutional point of view, we are ready to include nutritional quality as one of our breeding objectives.

2. Who should pay for plant-breeding with a nutrition objective? This is a difficult question. Since the output can be directed towards different regions of the globe, this should be shared by the CGIAR, by national agricultural research institutes, and organizations that fund nutritional interventions.
3. In breeding for nutritionally improved food crops, how should collaboration between the CGIAR, national agricultural research centres, and universities be organized? As far as BRRI is concerned, the existing system of collaboration between national agricultural research centres and international centres can be used. Universities may be included in the collaboration to evaluate what has been accomplished.
4. What is the scope for developing consumer demand for crops that are more nutritious but that may be more expensive to market or that initially may be less desirable because of their colour? When the rice endosperm will be yellow because of vitamin A, we will have to wait and see, but I don't think that it will be a problem in our society.

Finally, I have some personal observations to make. The germplasm collection in our research institute consists of 7,500 lines, including local landraces. Using the genetic variation in this collection, we have been very successful in increasing production. If we had we been motivated before, we could have made progress in achieving the objectives of more iron, zinc, or vitamin A in rice. It is better late than never.

Gerald Combs, Cornell University, United States

Food plays important social, cultural, and economic roles in every society; but always it remains the (usually sole) source of nutrients. Therefore, nutritional status and, to a great extent, health, depend on access to, quality of, and diversity in food supplies. Perhaps it is the very personal nature of food use that allows these issues often to be overlooked amid efforts to enhance economies, alleviate poverty, and improve public health; but, in fact, these are the very issues that connect food to health outcomes.

Efforts to alleviate malnutrition in the developing countries have been targeted toward increasing supplies of macronutrients (in particular, energy and protein) and a few micronutrients (vitamin A, iron, and iodine), because deficiencies of these nutrients have been or are responsible for the ill-health of millions of people, a fact that has been well documented. That notwithstanding, it is true that millions of people in poor countries are also malnourished with respect to other vitamins (riboflavin, folate, and vitamin B_{12}) and minerals (selenium, calcium, copper, and probably chromium and boron). Although few programmes have addressed these latter deficiencies, none have undertaken to implement recent findings of great public health relevance in poor countries: the cancer-preventive effect of selenium; the heart-protective effects of folate, vitamin E, and perhaps copper; the antidiabetic effect of chromium; and the reduction of bone loss by boron. Somehow, contemporary nutrition knowledge is not being translated into programmes in the developing world.

The need for a new approach. Trans-disciplinary and trans-sectoral efforts are called for that address food systems in holistic ways, i.e., from the production, acquisition, and utilization of foods to the biophysical, economic, social, public health, and policy environments in which those activities are carried out. Whereas agricultural success has historically been measured in terms of yields and costs, food-systems approaches would also include measures of impacts on human nutritional status and health, as well as environmental, economic, and social sustainability.

Implications for the CGIAR. The improvement of diets (and, thus, health) is implicit in any effort to increase food production and/or decrease food production costs. If that is, indeed, the case for the CGIAR, then the relevant question is *not* whether the CGIAR should undertake the improvement of human nutrition as part of its agenda but, rather, whether it should make that goal explicit. In other words, should the CGIAR adopt what I have called the "new paradigm" for agriculture? Who is better positioned than the CGIAR, with its resident multidisciplinary expertise and its existing and potential network of collaborating researchers in various national agricultural research centres and research universities, to lead such an effort productively?

Making the new paradigm an institutional value would not mean creating a new programme; instead, it would mean using that paradigm to rethink and to link existing programmes. It would mean that CGIAR efforts would need to go beyond those that would target mainly crop yields and production costs, to link those outcomes with consumer accessibility and nutrient content and bioavailability. Such food-systems-based approaches would not be focused *only* on major crops; instead, they would consider *cropping systems* (including livestock) and their abilities to support balanced human nutrition in sustainable ways. The core strategies for doing this were laid out by an international expert consensus conference in 1995 and include items already on the CGIAR agenda: increasing the diversity of cropping systems, particularly with respect to indigenous fruits and vegetables and to pulses; developing "micronutrient-efficient" cultivars of major staple crops; improving the use of micronutrient- (iron and zinc) rich cereal brans; reducing phytates in staple grains and developing heat-stable phytases for use as food ingredients; improving means of measuring micronutrient bioavailability; standardizing data on food nutrient and phytochemical compositions; and developing models for integrated, small-scale farming systems.

If the global goal is to find ways to make the food systems of the world provide the nutrient needs of healthy human populations, then it is a highly relevant question to ask, "If not the CGIAR, then who will do this?"

Xioae Yang, Zhejiang University, China

Agricultural strategies are low cost and of great benefit to the poor. Since micronutrient malnutrition mainly occurs in the developing countries, we should find cheaper and economically acceptable ways to solve this problem. Although there have been some programmes for improving grain quality in China, no breeding programmes have been conducted to increase micronutrient concentrations and trace mineral availability related to human nutrition.

Micronutrient supplements are available in markets in China. Supplementation or fortification has a narrow objective, most often supplying only one micronutrient. These products are unavailable to the majority of the population, especially the poor population in rural areas. In contrast, agricultural approaches address a broad range of nutrients and may reach a broader population. Therefore, it is increasingly important and critical to link agricultural practices to improving human micronutrient nutrition. Since 25% of the world population resides in China, where there is widespread micronutrient malnutrition, it would be important to give China high priority in this effort.

Joseph Hunt, Asian Development Bank

Agricultural research as a public investment. How does agricultural research make valid claims on public finance? Economists think of agricultural research as creating public goods. There are at least four ways in which this is done:

1. Plant-breeding produces better nutrition for all through increased food supplies and lower food prices. It also reduces poverty. When micronutrient enhancement is involved, plant-breeding performs both functions. Not only does it improve anthropometry, but it contributes to sustained development, and the capacity to apply learning throughout life.
2. Through dissemination of research, creation of new information affects behaviour and decisions. This affects policy dialogue. It provides evidence-based impacts that can be built into programmes that integrate agriculture, health, and nutrition.
3. New information also affects messages that go into training, public education, and all forms of media.
4. Quality assurance and food safety are integral to agricultural research.

Broadening the framework for economic analysis. We want to broaden the framework of economic analysis beyond cost-benefit analysis. These are topics for further discussion.

1. Better nutrition has direct and indirect effects on productivity. The direct effects are mainly through wages and increased capacity to work. The indirect effects are through cognition and capacity to learn.
2. We need to look closely at the way we measure losses and benefits from better nutrition, so that we have a common currency for discussing these effects at all levels and across disciplines. We have to be able to compare such diverse effects as deaths averted, effects on wages and household income, and impact on cognition. Measures such as currency and disability-adjusted life years (DALYs) are currently being used.
3. Use of marginal costing to compare plant-breeding with other types of nutrition interventions is persuasive. Plant-breeding and conventional fortification could become important means to broadly reduce the prevalences of micronutrient deficiencies. Other interventions can then target those who still suffer from deficiencies.

Windows of opportunity in the life cycle. There are critical vulnerability points that we might think of as windows of opportunity in the life cycle, where agriculture might make a critical contribution. Eventually we want to link CGIAR objectives to sustained health over the life cycle, whereby public nutrition becomes an objective of the CGIAR, and in which generational and intergenerational effects are recognized.

1. Nutritional interventions and nutrition education for good practices at the birth of their first children targeted at adolescent girls can have a real effect on their probability of surviving in good health and of having better-nourished children.
2. Links between low maternal body mass index and low birthweight are quite important. Not only are low-birthweight children more likely to die early, they have a higher susceptibility to chronic diseases later.
3. Complementary feeding or breastfeeding issues are quite important and could be addressed through plant-breeding.
4. Chronic undernutrition affects the quality of life and productivity of future generations.
5. Links between gender-sensitive approaches and food health care should be emphasized.

Investment partnerships. We should think of a regional investment-planning model that builds broad partnerships for regional investment to sustain both agriculture and health as interwoven parts of the same problem. This process will help to define, through a demand-driven process, the roles of both the CGIAR and of donors.

Group recommendations

Following are the recommendations reported in plenary session that came out of the six break-out discussions. A summary of these six sets of recommendations is attempted in the final section of this paper.

Group 1. Increasing the supply of foods rich in bioavailable nutrients. Rapporteur: Samson Tsou, AVRDC

1. Make better use of CGIAR germplasm banks by generating and disseminating information on nutritional characteristics, such as mineral and vitamin content and bioavailability of those minerals and vitamins. Bioavailability would be determined through simple but reliable methods that are either currently available from nutritionists or are to be developed by nutritionists.
2. Undertake a multicentre, integrated agricultural systems approach project, including impact assessment methodologies, targeted at improving the adequacy of several micronutrients. The strategy would include agricultural production, post-harvest processing, and application of nutritional, economic, and social sciences.
3. Breeding for higher micronutrient density and for consumer acceptance of staple and non-staple foods should be a high priority for the CGIAR centres.

Follow-up activity

Take steps to acquire capacity to implement the first recommendation.

Group 2. Consumer aspects of plant-breeding and consumer education. Rapporteur: Suttilak Smitasiri, Mahidol University, Thailand

1. Technologies developed by CGIAR centres should be developed in line with end-user perceptions of desired characteristics—those of farmers, traders, and consumers. This will facilitate consumer education later on.
2. Undertake comprehensive nutrition communication promotion programmes at two levels: at the public level and targeted at poor groups. Importantly, this requires an evaluation component to check that messages are being effective.
3. Undertake programmes to improve the public trust in agricultural innovations. These would include studies to assess the perceptions of several groups (e.g., the general public, professionals, policy makers, and the private sector). Public attitudes towards agricultural innovations are presently negative. Public relations activities should be undertaken to build trust.

Follow-up activity

IFPRI should form a multidisciplinary task force (including social scientists, nutritionists, agriculturalists, and other stakeholders) to implement these three steps. Issues related to agriculture–nutrition linkages should be discussed at future CGIAR-wide meetings

Group 3. Economic factors that influence nutritional outcomes. Rapporteur: Mahabub Hossain, IRRI

Information gaps

1. Much information is available on health and nutrition and on economic policies and agricultural development strategies, but there are few data sets and studies that link the two.
2. Existing cost-effectiveness studies of various nutritional interventions focus too much on short-run impacts. There is a need to incorporate sustainability issues and long-run impacts in these studies.

Recommendations for research

1. Assessment of the impact of international agricultural trade on agricultural programmes, price policies, and nutritional outcomes.
2. Studies linking nutritional outcomes with agricultural and infrastructural development programmes and policies.
3. Assessment of the impact of crisis situations on nutritional outcomes, including the development of indicators for surveillance systems.

Follow-up activity

To accomplish this, there is a need for multidisciplinary collaboration and research partnerships. Institutional mechanisms must be found to foster linkages with nutritionists in the planning process and then to link with extension services and NGOs to implement any technologies that are developed.

Group 4. Impact of the Green Revolution on nutrition. Rapporteur: Britta Ogle, Swedish University of Agricultural Sciences

1. The CGIAR needs to consider the ethics of *not* incorporating nutrition into its research agenda. Safety and quality are important elements of better nutrition. New and different agricultural technolo-

gies always change diets and thus change the nature of health and nutritional problems, even perceptions of what are good diets.

2. A common conceptual framework between disciplines is needed to come to agreement on research priorities. This cannot be done at the global level, but it has to go down at least to the country level. A key issue is: How bioavailable are the nutrients that we seeking to bring more of into the system?
3. Research is needed on the genetic diversity of wild varieties, landraces, and modern varieties. How have the changes in the nutritional content of modern varieties impacted nutrition?

Follow-up activity

The first two recommendations are overriding follow-up actions that have to set the scene. Developing the proposed framework can be the basis for beginning a process of interdisciplinary communication.

Group 5. Intra-CGIAR coordination of research. Rapporteur: Robert Bertram, USAID

Follow-up activities

1. Undertake a more comprehensive stock-taking of CGIAR research activities related to human nutrition.
2. Secure approval from the CGIAR Technical Advisory Committee of a system-wide initiative related to human nutrition. This would involve developing a conceptual framework. This should include partnerships outside of the CGIAR, especially with human nutritionist organizations. IFPRI should take the lead.
3. Secure approval of human nutrition as a theme for International Centres Week (held annually).
4. Report on CGIAR breeding activities related to improving nutritional quality at crop science society meetings.
5. Report on CGIAR human nutritional research activities at the Administrative Coordinating Committee/Sub-Committee on Nutrition (ACC/SCN) meetings.
6. Tap into nontraditional sources of funding for activities related to human nutrition. This includes newly formed foundations and funding windows of present CGIAR donors that are not usually utilized.

Group 6. CGIAR collaboration with external organizations. Rapporteur: Barbara Schneeman, US Department of Agriculture

Principles for successful collaboration between disciplines

1. A shared vision; identification of where there are overlapping objectives.
2. Recognition of comparative advantages and strengths; clearly defined roles for each partner.
3. Trust, understanding, and mutual respect are necessary.
4. Equal relationships; avoidance of tokenism.
5. Nutrition is an outcome in which all disciplines can have a stake.

Preconditions that would facilitate outside collaboration

1. Development and acceptance of a framework for analysis and application of agriculture–nutrition linkages.
2. Statement by the Technical Advisory Committee that the CGIAR will take nutritional impacts into consideration in its decisions and research activities.
3. A shift from a commodity focus to a food-systems focus. Such a shift demands both internal and external collaboration.
4. A dialogue between CGIAR centres and national agricultural research centres is important to define what approach would be taken.

Follow-up activities

1. Improve outside awareness of CGIAR activities through participation of CGIAR in meetings of professional societies. This would also increase the awareness of CGIAR scientists about possibilities for outside collaboration.
2. Information about CGIAR activities should be included in university education and training programmes; nutrition focus at International Centers Week and other CGIAR meetings; linking CGIAR information to various Internet sites; field trips for cross-training (e.g., bringing plant scientists to a health clinic to observe clinical signs of micronutrient deficiencies).
3. A CGIAR steering committee on agriculture–nutrition linkages should be created to interface with the ACC/SCN.
4. Case studies of successful interdisciplinary programmes could be used to highlight the benefits of interdisciplinary research.

Plenary discussion

After the group recommendations for research were presented, the floor was opened for discussion. A number of diverse topics were raised. Comments could be categorized into two groups. The first group were those comments that followed up on the recommendations presented above with specific ideas for promoting agriculture–nutrition interventions in a broad sense, or the breeding strategy more narrowly. The other set of comments touched on gaps in the workshop discussions and recommendations, for example, not enough discussion on topics such as labour and gender issues, nutritional problems other than micronutrients, linkages with the health system, and persons with disabilities.

Post-conference activities: Summary of recommended CGIAR research and extension/outreach activities

During the relatively short time remaining for plenary discussion, no attempt was made to summarize the recommendations of the six working groups. This is attempted below.

Related to breeding for nutritionally improved crops

1. Characterize lines in germplasm banks for nutritional characteristics
2. Undertake the next steps for breeding for nutritionally improved varieties with acceptable consumer characteristics.

Related to evaluation of the impact of CGIAR activities

3. Assess the impact of agricultural programmes and policies, agricultural trade, and economic crises on nutritional outcomes, including development of appropriate indicators.
4. Further evaluate genetic diversity of wild varieties, landraces, and modern varieties; draw out implications for past nutritional impacts of modern varieties.

Related to extension/outreach

5. Implement nutrition communication and promotion programmes directed at the malnourished poor.
6. Implement public relations programmes directed at the general public to improve trust in agricultural innovations.

How research should be structured and organized

7. Develop a multidisciplinary, common conceptual framework.
8. Use agricultural systems approaches to identify and prioritize interventions.
9. Conduct participatory research to ensure that variety releases are consistent with end-user perceptions of desired characteristics, including consumers and traders (not only farmers).
10. Undertake outside collaboration with nutrition and communications institutions and other disciplinary perspectives, including NGOs and extension services, as required.

Recommended follow-up activities

11. Form an interdisciplinary task force organized by the IFPRI, composed of members from inside and outside of the CGIAR, which would:
    - » identify and implement a process for development of a multidisciplinary, common conceptual framework describing agriculture–nutrition linkage, which could be then used for evaluating integrated approaches to nutrition improvement;
    - » evaluate the feasibility of implementing a strategy for nutrition promotion and communication, including consideration of the ethics of not incorporating nutrition explicitly into its research agenda;
    - » undertake a more comprehensive stock-taking of CGIAR research activities related to human nutrition;
    - » secure approval of human nutrition as a theme for International Centres Week;
    - » seek approval from the CGIAR Technical Advisory Committee for a system-wide initiative on human nutrition which would include partners from outside the CGIAR;
    - » interface with the ACC/SCN and report on CGIAR activities at the annual meetings of the ACC/SCN;
    - » seek ways to have CGIAR research related to human nutrition incorporated into university training programmes (case studies of successful interdisciplinary programmes could be used to highlight the benefits of interdisciplinary research); link information about CGIAR activities to various Internet sites; facilitate field trips for disciplinary cross-training (e.g., visits of agriculturalists to health clinics to observe clinical manifestations of malnutrition; visits of nutritionists to agricultural research stations).
12. CGIAR scientists should seek opportunities to report on CGIAR research activities related to human nutrition at professional meetings of various disciplines. This would improve awareness of CGIAR activities, and CGIAR scientists would become more informed about the possibilities for outside collaboration.
13. Seek to tap new donors and sources of funding for activities related to human nutrition. This would includes newly formed foundations and funding windows not presently utilized of present CGIAR donors.

Final reflections

Given the large number of diverse linkages between agriculture and nutrition, in some sense a disproportionate number of presentations focused on breeding for nutritionally improved crops. Indeed, it is revealing that every one of the six break-out groups recommended some variation on an activity that involved a broad overview of agriculture–nutrition linkages: developing a common conceptual framework, taking an integrated agricultural systems approach, and the need for multidisciplinary collaboration and research partnerships. The presentations might have been more evenly distributed across various linkages. Certain specific linkages were only mentioned.

In part, the skewed distribution of presentations reflected the stock-taking objective of the conference. To some degree, it represents what the CGIAR has been doing. More importantly, perhaps, this also reflects the tension between initiating research and planning research. Taking a systems approach and attempting to carefully evaluate a number of alternatives has clear potential benefits and inherent appeal to those engaged in research, but it is not without risks: (1) the risk of never reaching interdisciplinary consensus as to the optimal strategy, either because of the complexity of the system or because the principles of successful interdisciplinary collaboration developed by break-out group 6 are not followed; (2) the risk of coming to a consensus but not being able to manage the institutional coordination required by recommended actions; and (3) the risk that the final recommended actions, when implemented, will turn out to be themselves flawed. With these risks fully in mind, the first steps have been taken to initiate the proposed planning exercise, as described above.

The CGIAR Micronutrients Project has made it through the first two types of risk. It is on the verge of facing the third type of risk—finding out if it really works after all in feeding trials planned to begin shortly after this volume is published. If the breeding strategy is successful, then it will give impetus to other efforts to link agriculture to nutrition that may have little to do with plant-breeding per se, but that may have payoffs that are equally high.

References

1. Schneeman BO, Kennedy E. Agriculture–nutrition linkages and the US Department of Agriculture: a global view. Food Nutr Bull 2000;21:546–8.
2. Pinstrup-Andersen P. Improving human nutrition through agricultural research: overview and objectives. Food Nutr Bull 2000;21:352–5.
3. Underwood BA. Overcoming micronutrient deficiencies in developing countries: Is there a role for agriculture? Food Nutr Bull 2000;21:356–60.
4. Welch, RM, Graham RD. A new paradigm for world agriculture: productive, sustainable, nutritious, healthful food systems. Food Nutr Bull 2000;21:361–6
5. Haddad L. A conceptual framework for assessing agriculture–nutrition linkages. Food Nutr Bull 2000; 21:367–73.
6. Bouis HE, Graham RD, Welch RM. The Consultative Group on International Agricultural Research (CGIAR) Micronutrients Project: Justification and objectives. Food Nutr Bull 2000;21:374–81.
7. Gregorio GB, Senadhira D, Htut H, Graham RD. Breeding for trace mineral density in rice. Food Nutr Bull 2000;21:382–6.
8. Monasterio I, Graham RD. Breeding for trace minerals in wheat. Food Nutr Bull 2000;21:392–6.
9. Beebe S, Gonzalez AV, Rengifo J. Research on trace minerals in the common bean. Food Nutr Bull 2000;21:387–91.
10. Bänziger M, Long J. The potential for increasing the iron and zinc density of maize through plant-breeding. Food Nutr Bull 2000;21:397–400.
11. Cakmak I, Ozkan H, Braun HJ, Welch RM, Romheld V. Zinc and iron concentrations in seeds of wild, primitive, and modern wheats. Food Nutr Bull 2000;21:401–3.
12. Graham RD, Rosser JM. Carotenoids in staple foods: their potential to improve human nutrition. Food Nutr Bull 2000;21:404–9.
13. Chavez AL, Bedoya JM, Sánchez T, Iglesias C, Ceballos H, Roca W. Iron, carotene, and ascorbic acid in cassava roots and leaves. Food Nutr Bull 2000;21:410–3.
14. Maziya-Dizon B, Kling JG, Menkir A, Dixon A. Genetic variation in total carotene, iron, and zinc contents of maize and cassava genotypes. Food Nutr Bull 2000; 21:419–22.
15. Welch RM, House WA, Beebe S, Senadhira D, Gregorio G, Cheng Z. Testing iron and zinc bioavailability in genetically enriched beans (*Phaseolus vulgaris* L.) and rice (*Oryza sativa* L.) in a rat model. Food Nutr Bull 2000;21:428–33.
16. King JC, Donangelo CM, Woodhouse LR, Mertz SD, Shames DM, Viteri FE, Cheng Z, Welch RM. Measuring iron and zinc bioavailability in humans. Food Nutr Bull 2000;21:434–9.
17. Haas JD, del Mundo AM, Beard JL. A human feeding trial of iron-enhanced rice. Food Nutr Bull 2000;21:440–4.
18. Raboy V. Low-phytic-acid grains. Food Nutr Bull 2000;21:423–7.
19. Hagenimana V, Low J. Potential of orange-fleshed sweet potatoes for raising vitamin A intake in Africa. Food Nutr Bull 2000;21:414–8.
20. Vasal SK. The quality protein maize story. Food Nutr Bull 2000;21:445–50.
21. Datta S, Bouis HE. Application of biotechnology to improving the nutritional quality of rice. Food Nutr Bull 2000;21:451–6.
22. Phillips RL. Biotechnology and agriculture in today's world. Food Nutr Bull 2000;21:457–9.
23. Ali M, Tsou S. The integrated research approach of the Asian Vegetable Research and Development Center (AVRDC) to enhance micronutrient availability. Food Nutr Bull 2000;21:471–80.
24. Fassil H, Guarino L, Sharrock S, BhagMal, Hodgkin T, Iwanaga M. Diversity for food security: improving human nutrition through better evaluation, management, and use of plant genetic resources. Food Nutr Bull 2000;21:496–501.
25. Cardwell KF. Mycotoxin contamination of foods in Africa: antinutritional factors. Food Nutr Bull 2000;21:487–91.

26. Abd El-Moneim AM, van Dorrestein B, Baum M, Mulugeta W. Improving the nutritional quality and yield potential of grasspea (*Lathyrus sativus* L.). Food Nutr Bull 2000;21:492–5.
27. Ahmed MM, Mohammed J, Ehui S. Household-level economic and nutritional impacts of market-oriented dairy production in the Ethiopian highlands. Food Nutr Bull 2000;21:460–5.
28. Prein M, Ahmed M. Integration of aquaculture into smallholder farming systems for improved food security and household nutrition. Food Nutr Bull 2000;21:466–70.
29. Bouis HE. Commercial vegetable and polyculture fish production in Bangladesh: their impacts on household income and dietary quality. Food Nutr Bull 2000; 21:481–6.
30. Smitasiri S. A comment on how the nutritional impact of agricultural innovations can be enhanced. Food Nutr Bull 2000;21:502–5.
31. Barba C. The Philippine Plan of Action for Nutrition: an overview. Food Nutr Bull 2000;21:506–10.
32. dela Cuadra AC. The Philippine micronutrient supplementation programme. Food Nutr Bull 2000;21:511–3.
33. Solon FS. Food fortification in the Philippines: policies, programmes, issues, and prospects. Food Nutr Bull 2000;21:514–9.
34. Bayani EM. Reducing micronutrient malnutrition: policies, programmes, issues, and prospects—dietary diversification through food production and nutrition education. Food Nutr Bull 2000;21:520–5.
35. Juliano B. Comments on possible contributions of the Philippine agricultural research system to improving human nutrition. Food Nutr Bull 2000;21:528–30.
36. Castillo GT. Possible contributions of the Philippine agricultural research system to improving human nutrition. Food Nutr Bull 2000;21:526–7.
37. Smith IF. Micronutrient interventions: options for Africa. Food Nutr Bull 2000;21:531–6.
38. Bressani R. Micronutrient policies in Latin America. Food Nutr Bull 2000;21:537–40.
39. Eide WB. Agriculture for consumers: experiences from Norway. Food Nutr Bull 2000;21:541–5.

Erratum

In the article “Red palm oil in the maternal diet improves the vitamin A status of lactating mothers and their infants” by L. M. Canfield and R. G. Kaminsky (Food Nutr Bull 2000;21(2):144-8), please substitute the following for reference 17 on page 148:

17. Canfield LM, Liu Y, Kaminsky RG, Castillo C, Zavala G, Garner C, White K, Pagoaga E. Supplementation of mothers with red palm oil increases serum vitamin A of the breastfed infant. FASEB J 1997;7:2280.

Books received

TO COME

News and notes

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Annex

The Consultative Group on International Agricultural Research (CGIAR)

The CGIAR, established in 1971, is an informal association of 58 public- and private-sector members that supports a network of 16 International Agricultural Research Centres. The CGIAR's mission is to contribute to food security and poverty eradication in developing countries through research, partnership, capacity-building, and policy support. The CGIAR promotes sustainable agricultural development based on the environmentally sound management of natural resources. CGIAR centres conduct research programmes in collaboration with a full range of partners in an emerging global agricultural research system

Challenges posed by the interrelated global issues of poverty, hunger, population growth, and environmental degradation confront the world as it enters the twenty-first century. Agricultural research, conducted to help the world's poorest people make lasting improvements in their lives and in the lives of their children, is, therefore, critical to human progress.

The CGIAR focuses on five major research thrusts:

Increasing productivity. The CGIAR strives to make developing-country agriculture more productive through genetic improvements in plants, livestock, fish, and trees, and through better management practices. One important feature of the CGIAR's research is its focus on building into plants greater resistance to insects and diseases that adversely affect productivity and the stability of production in the tropics. While protecting farmers from losses, these improved plants help the environment because they require little, if any, chemical inputs.

Protecting the environment. Conserving natural resources, especially soil and water, and reducing the impact of agriculture on the surrounding environment is an essential, and growing, part of the CGIAR's efforts. The CGIAR plays a leading role in developing new research methods to identify long-term trends in major agricultural environments, and in developing solutions to pressing environmental problems.

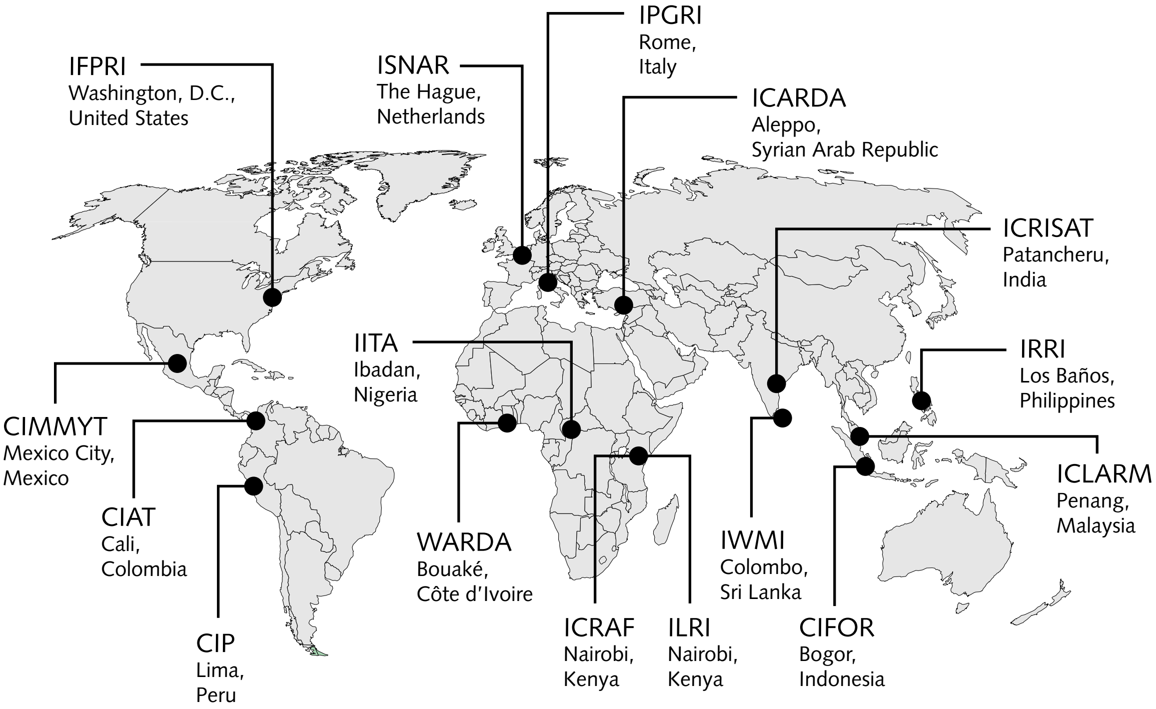
Saving biodiversity. The CGIAR holds one of the world's largest *ex situ* collections of plant genetic resources in trust for the world community. It contains over 500,000 accessions of more than 3,000 crop, forage, and agroforestry species. The collection includes farmers' varieties and improved varieties and, in substantial measure, the wild species from which those varieties were created.

Improving policies. Agricultural producers are heavily influenced by public policy. The CGIAR's policy research aims to help streamline and improve policies that strongly influence the spread of new technologies and the management and use of natural resources.

Strengthening national research. The CGIAR is committed to strengthening national agricultural research in developing countries through side-by-side working relationships with colleagues in national programmes, strengthening skills in research administration and management, and formal training programmes for research staff.

CGIAR Centres

The map shows the locations of the 16 CGIAR agricultural research centres: CIAT, Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture); CIFOR, Center for International Forestry Research; CIMMYT, Centro Internacional de Mejoramiento de Maiz y Trigo (International Center for Maize and Wheat Improvement); CIP, Centro Internacional de la Papa (International Potato Center); ICARDA, International Center for Agricultural Research in the Dry Areas; ICLARM, International Center for Living Aquatic Resources Management; ICRAF, International Centre for Research in Agroforestry; ICRISAT, International Crops Research Institute for the Semi-Arid Tropics; IFPRI, International Food Policy Research Institute; IITA, International Institute of Tropical Agriculture; ILRI, International Livestock Research Institute; IPGRI, International Plant Genetic Resources Institute; IRRI, International Rice Research Institute; ISNAR, International Service for National Agricultural Research; IWMI, International Water Management Institute; and WARDA, West Africa Rice Development Association.


IFPRI
Washington, D.C.,
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ISNAR
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IPGRI
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ICARDA
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In Memoriam

Abraham Horwitz, 1910–2000

Editorial Introduction to the Obituary

With the death of Abraham Horwitz on July 10, 2000 nutrition lost a uniquely effective advocate who cannot be replaced. In the obituary which follows, John Mason, who served as the Technical Secretary of the UN ACC-Subcommittee on Nutrition (SCN) during all of Dr. Horwitz long tenure as its Chair captures well his contributions to nutrition and health after leaving as Director of the Pan-American Health Organization (PAHO). Much more could be said of his important contributions to the development of the public health delivery system of Chile which led to vital statistics comparable to those of North America and Europe at a time when they were poor in the other countries of the region. The history of this development in which Dr. Horwitz played a major role was well described in his article "Comparative public health: Costa Rica, Cuba, and Chile" in the Volume 9, Number 3, 1987 issue of the Food and Nutrition Bulletin [1]. In an earlier article he reported on increasing the capacity of the international agencies for policy formulation and programme or project preparation in nutrition [2].

In 1958 he succeeded a strong, successful, and aggressive long-term Director of PAHO, Dr. Fred Soper, and his own unique style and vision soon became evident. Although Soper had an infectious disease background, he found himself committed to set up an Institute of Nutrition of Central America and Panama (INCAP). It was established in 1949, and I was appointed its founding director. When Dr. Horwitz became the director of PAHO in 1958, his appreciation of nutrition was important for INCAP. Equally significant was his understanding of the importance of identifying problems accurately through research to find practical solutions before recommending policies and training staff to help countries implement them. He also stressed the importance of INCAP within the PAHO system for training at all levels and institution building within its member countries and throughout the region. It is no coincidence that the period of Dr. Horwitz's guidance of PAHO was also the period of the greatest productivity and effectiveness of INCAP under three directors.

He will be sorely missed by colleagues at each of the institutions to which he has contributed so much, especially the School of Public Health and Ministry of Health of Chile, the Pan-American Health Organization and the Institute of Nutrition of Central America and Panama, the ACC Subcommittee on Nutrition and its Advisory Group on Nutrition, the Committee on International Nutrition of the Food and Nutrition Board and other NAS and IOM committees that he has chaired, the International Vitamin A Consultative Group, and the nutrition staffs of all of the international and bilateral agencies concerned with nutrition. We will all remember the gentle, courteous, and quiet manner in which he brought us to understand his vision and follow his leadership. However, behind these self-effacing qualities was a very strong and proud man absolutely dedicated to the health and welfare of human kind. He was also a passionate devotee and supporter of classical music, and this is another domain in which he will be remembered by many.

Nevin Scrimshaw, Editor

References

1. Horwitz A. Comparative public health: Costa Rica, Cuba, and Chile. Food Nutr Bull 1987;9(3):19-29.
2. Horwitz A. Increasing the capacity of the international agencies for policy formulation and programme or project preparation in nutrition. Food Nutr Bull 1979; 1(4):11–14.

Abraham Horwitz, Director Emeritus of the Pan-American Health Organization (PAHO) and from 1986 to 1995, Chairman of the UN Sub-Committee on Nutrition, died at home in Washington, D.C. on July 10. He had been active in serving the disadvantaged in health and nutrition for more than 60 years.

Dr. Horwitz, as he was always known to his colleagues and friends out of respect to his stature and dignity, was born in 1910. He qualified in medicine in his native Chile in 1936, one of three brothers of a family of five to do so. He was quietly proud of Chile in many ways, not least that as a secular physician from a Jewish family, originating in Central Europe, he was encouraged and could thrive in its Catholic society. He was always conscious of the cultural excellence and tradition of his country, and was outraged and saddened by the Pinochet years.

He first went to the United States in 1942 as a Rockefeller Foundation fellow in infectious diseases, to the Herman Kiefer Hospital in Detroit. He then obtained a Master of Public Health degree at Johns Hopkins University School of Public Health in 1944. Upon returning home, he served as professor of infectious diseases, bacteriology, and immunology at the University of Chile, and became Director of its School of Public Health until 1950.

In 1950, he joined PAHO for a brief period, but soon returned to Chile to help organize the new Chilean National Health Service (NHS). As its Assistant Director from 1953 to 1959, he made a major contribution to the improvement of public health in Chile. In Dr. Horwitz's words "Actions for the protection of health and the prevention and treatment of disease were developed, with particular attention to an information system to register, analyze, and publish how health problems were evolving. The NHS "integrated a number of dispersed and uncoordinated institutions of medical care and public health into one Service to cover progressively the whole population of the country. Bringing institutions together for broader effectiveness in promoting improved health and nutrition was a theme in most of his endeavours.

His understanding, in the 1950s, of the importance of information itself in furthering and sustaining change was prescient, and he returned to it many times. He recognized that monitoring and open accountability could nudge institutions, large and small, in the right direction. The achievements of the NHS of Chile became widely recognized, and many aspects have provided models for other nations, up to the present day. Nutrition was an important component of the NHS, which provided access to free milk to much of the child population. Even in the depths of the Pinochet years, there was enough public support, much of it by the scientific community in Chile, to actually prevent a proposed curtailment of this useful social welfare and public health programme.

As a result of such support, Chile's rapid and steady health progress, over many decades, in reducing infant child mortality, was remarkably resilient to changing politics. Dr. Horwitz would often note, with satisfaction, that the infant mortality rate in Chile fell from a reported 126/1000 live births in 1953 at the start of the NHS (an underestimate, in his view, due to under-registration), to 12/1000 in the mid-1990s; and that malnutrition, particularly moderate to severe malnutrition, had virtually disappeared. Later, from PAHO he was to sponsor a ground-breaking study which showed that in more than half the child deaths in Latin America malnutrition was an associated or underlying cause.

In 1958 he was the first Latin American to be elected Director of PAHO, and with four terms from 1959 to 1975, was the longest-serving. He directed PAHO with great dynamism and strength. He was a pioneer in placing health in the context of human development. He insisted that good health was not only good in itself, but a necessary condition for economic progress, and that therefore funds for health were an investment in the future prosperity of countries. Donors were persuaded, and investment funds were secured and used in many countries to build up sustainable health systems. Dr. Horwitz believed in institutional development, in what is now being called 'capacity-building.' He sought to avoid the unidimensional quick fixes that international assistance often favours. The InterAmerican Development Bank, then the World bank, USAID, and other donors accepted his approaches. An achievement, nearer home, was that the Kellogg Foundation 'loaned' funds for constructing the PAHO building in Washington D.C., agreeing that these would not be paid back directly, but rather in the form of additional health programmes in Latin American countries. Not many arrangements are negotiated on as imaginative and publicly beneficial terms.

Regional institutions for promoting nutrition were strongly supported during Dr Horwitz's tenure at PAHO. He took pride in strengthening the Institute of Nutrition of Central America and Panama (INCAP) that had been founded by PAHO, Member Countries, and the Kellogg Foundation in 1949. He recognized that health interventions need to be knowledge based and strongly supported INCAP's applied research and training programmes. The Caribbean Food and Nutrition Institute also benefited from his influence.

The eradication of smallpox from the Americas in 1971 was declared by the PAHO Directing Council in 1973, many years before its global eradication. This was largely because Dr. Horwitz had focused on this goal early in his time at PAHO, supporting and strengthening vaccination programmes. Polio too was first declared eradicated in the Americas in 1994, another Horwitz legacy. Reminiscing in 1995 on his PAHO days, Dr. Horwitz singled out, as achievements of which he was proud, the moving of health investments on a broad front that included “health infrastructure, water and sanitation, university education in health sciences and technology, food and nutrition, veterinary public health, and other programmes.” Others were his setting up regular reporting on the progress of health interventions; the recognition of health as of value in itself, in today’s terms “health as a human right,” and smallpox eradication.

In 1975 Dr. Horwitz left the directorship of PAHO with the lifelong appointment of Director Emeritus voted him by the PAHO Council and announced that he would devote the rest of his professional life to promoting better nutrition in developing countries in the context of health programmes. The National Library of Medicine provided him with an office and he was soon called on to play a leadership role in a variety of nutrition related activities. In 1978 he became Chair of the Committee on International Nutrition Programs of the National Academy of Sciences, a position in which he continued until 1986. In this and similar roles he adopted an approach of bringing together the best experts he could find, and persuading them (a task in which he never failed) to address crucial and emerging issues in nutrition and health. He was soon appointed to the Advisory Group on Nutrition (AGN) to the UN system, becoming its Chair in 1984. In 1975 he established the Pan-American Health and Education Foundation (PAHEF), of which he soon became the Chair, a position which he still held at the time of his death. In 1988 he became Chair of the International Vitamin A Consultative Group (IVACG).

In all of these roles he shifted his emphasis from executive action to advocacy and coordination. Throughout his 70s and well into his 80s, he traveled tirelessly to give speeches, chair meetings, and promote policies and programmes for the betterment of the disadvantaged. With elegance of presentation, clear articulation, and gentle voice he enjoined us: “Please do contribute your thinking, but, never try to change my Spanish-English—it serves me very well.” He could blithely violate rules of grammar yet produce a much better construction. Sometimes he could do the same with institutions. He was patient but unimpressed with analysis; he would usually get to a better answer quicker by his brilliant intuition linked with careful and patient inquiries than the rigourous analyst. “We must think about this” was an invitation to explore intriguing possibilities to arrive at a clear view of the issue and how to tackle it. The intellectual journey was always fulfilling.

As Chair of PAHEF and IVACG he guided them through productive times. PAHEF, as a non-profit organization, succeeded in channeling very significant funds to health education, notably as textbooks and instruments to medical students in Latin America. The recognition of the importance of vitamin A in child survival, and the subsequent huge expansion of deficiency control programmes, owe much to his perceptiveness, advocacy, and intervention at critical moments.

Dr. Horwitz was elected Chair of the United Nations system’s Sub-Committee on Nutrition in 1986. Since it is a sub-committee of the UN’s Administrative Committee on Coordination, it has the acronym ACC/SCN. Characteristically, he insisted on an informal meeting of the concerned agencies before accepting, at which he suggested the ways in which he would approach this task, indicating that he would be proactive and not just reactive. They agreed to this and he set about moulding the agenda of the group, establishing processes based on the best available information, and, perhaps like a polite and deferential sheepdog, rounding up the agencies and trying to guide them in something like the same direction. Above all, he believed that “good nutrition is essential for human development and well-being, and that available resources, better invested and managed, could reduce significantly malnutrition in the world.” And he used all of his strength and skills to make that happen, for as long as he was able.

His Chairmanship of the ACC/SCN lasted almost 10 years, from 1986 to 1995. Dr. Horwitz pushed ahead on a wide front of issues, at the same time striving to broaden the participation in the work of the committee. He formalized the participation of bilateral aid agencies, and opened the meeting to representatives of NGOs. He also co-opted the advice and attendance of a range of scientists and policy makers. The first session of the SCN that he chaired took on the question of structural adjustment and its effects on the poor, bolstering attention to this emerging policy concern. Micronutrient deficiencies, especially of vitamin A, were given priority, initially as 10-year UN plans pushed through by the SCN; and its impact on child mortality was documented and publicized under SCN auspices. Women’s status, and their role in nutrition and health, were given priority. He worked his staff and advisers hard, but his vision was far-sighted and timely. His annual instructions to the AGN were legendary because he wanted them to deal with such a wide range of issues.

Underlying all of this activity was the firm belief that sound science and good information were the basis for steady progress. Dr. Horwitz promoted a process of regular reporting on trends in global nutrition and resource allocations, and for addressing key policy questions, through a variety of methods such as annual symposia, and promulgating the conclusions. He brokered an agreement between the agencies for assembling and, for the first time, publishing periodically multisectoral information on this topic. Under his leadership the SCN meetings became an annual forum to learn what was happening in nutrition.

At the beginning of the 1990s nutrition needed more attention. Most of the policy debates were becoming resolved and more than ever action was feasible. The World Summit for Children of 1990 set a number of highly specific nutritional goals. In preparing for the annual SCN meeting, held at UNICEF in 1989, the question was how to now raise the profile of nutrition. The SCN proposed an International Conference on Nutrition. This led to the ICN, convened by FAO and WHO, in Rome in December 1992. Although denied the floor at the Plenary of the ICN because he did not represent a government or agency—to most an astounding and gratuitous slight—Dr. Horwitz, as always, focussed on the positive. He stressed the success of the ICN in drawing attention to the needs of the poor, and the feasibility of and obligation for renewed and expanded efforts to combat malnutrition.

With Dr. Horwitz's leadership, the SCN continued to promote these topics, in an ever-increasing forum of participants. He introduced new initiatives on refugee feeding, on updates on the world nutrition situation, and on the emerging problems of nutrition related to chronic diseases increasingly affecting developing countries. He also promoted the role of caring practices and maternal behaviour for the nutritional improvement of children. In the aftermath of the ICN, there was an increasing struggle for survival of the SCN itself. After re-election to a two-year term as Chair in 1992, Dr. Horwitz accepted a further year's extension until 1995. In an epic meeting to determine his succession, at which he shocked the representative of the UN Secretary-General by requesting a vote if consensus could not be achieved, he secured his choice, in Richard Jolly, then of UNDP.

SCN members had the moving experience of meeting Dr. Horwitz for the last time at the SCN session in Washington in April of this year when he attended the second annual presentation of the Abraham Horwitz lecture.

Dr. Horwitz will always be remembered for his personal integrity and achievements—and literally millions of people have reason to be grateful for his life. Those who knew him will remember his patience, unfailing courtesy, and deep kindness: as well as his humanity, sense of humour, and laughter. Asked in 1995 "What advice do you have for us all?" he said: "Keep faith that you are committed to a most noble cause, the well-being of people whom you do not know but whose needs you feel intensely. Redouble your efforts in whatever you do in nutrition while being bold and imaginative." He did just that.

John Mason, PhD
Professor, Department of International Health and Development,
Tulane School of Public Health and Tropical Medicine, New Orleans

Comments from Close Friends and Colleagues

Moises Behar, Former Director, INCAP and Nutrition Unit, WHO

As Director of the Institute of Nutrition of Central America and Panama (INCAP) for many years I was very lucky to have Dr. Horwitz as my immediate supervisor. At that time, INCAP was an energetic institution with a group of young, well-trained, and devoted professionals struggling to help in solving the serious nutritional problems of the population of the area. We were working under difficult conditions, with a limited and insecure budget, coming mostly from grants; and responsible to the governments of six small and unstable countries. Fortunately, Dr. Horwitz was the Director of the Pan-American Health Organization (PAHO), the office responsible for the administration of INCAP. He was always very understanding and supportive. PAHO, like most large, complex organizations, has cumbersome and strict regulations. I frequently had to ask him to overcome rules that obstructed our efficient operation. Everything we were able to accomplish, in the understanding and in the development of measures to control or ameliorate the major nutritional problems of the population of the area, and in the training in nutrition of large numbers of health professionals, was in large measure thanks to him. To me, he was like a father, a teacher, and a friend. Strict, but wise and understanding as a good father. A great teacher through advice and example; and supportive and cordial as a friend. A proof of his social sensitivity was how, after his experience as Director of PAHO, he became interested in nutrition and devoted to this discipline the rest of his active professional life.

Fernando Viteri, INCAP, PAHO, and Professor, University of California at Berkeley

As I evoke Dr. Abraham Horwitz's memory several outstanding features about this great man become dominant: Dr. Horwitz was, above all, a generous man, a true friend, a gentleman and a scholar who had a singular "grand vision," based on love for everyone, and on a unique capacity to generate enthusiasm for efforts aimed at promoting health, beauty, joy, and the common good beyond the limitations all of us have. He was a man who combined the rigourous demands of a scientific-humanistic leader with the openness of thought, with the humility to seek advice, and with the pragmatism of a practical and effective administrator.

I had the fortune of considering myself a disciple of Dr. Horwitz for over 50 years. I became his friend 20 years ago, when destiny brought me to Washington, D.C.. At that time he already was Director Emeritus of PAHO, the institution he built with the vision I tried to describe above. He was working then at the National Institutes of Health (NIH), and whenever possible we would go on long walks on Saturday mornings, which I found most inspiring. His loyal canine companion Sophos would come with us. Upon our move to California I missed his presence and I always looked forward eagerly to catch up with him anywhere in the world. I considered myself most fortunate to be able to visit with him, to receive encouragement and advice, based on his wisdom, which he was always very generous in sharing. After he received a very well deserved tribute at the 27th ACC/SCN session last April I had the pleasure of one last visit at his home. As always he was the epitome of the perfect gentleman and gracious mentor. He will be fondly remembered by me, as well as by all who had the privilege of being associated with him.

Kraisid Tontisirin, former Director Institute of Nutrition, Thailand, Director Food and Nutrition Division, FAO

The new millennium has brought along much promise and challenge ahead, but has also followed the dictates of nature and ageing outcomes in mankind. One of our pillars of strength, Dr. Abraham Horwitz is no more with us. He leaves behind a great legacy of achievement to all in the field of nutrition and development and in particular, vitamin A. All of us who knew him through his writings and who have met and worked with him would agree no more than I do, about the simplicity, yet greatness of this man.

To my mind, Dr. Horwitz was a symbol of dedication with a strong sense of integrity in scientific thought and action. He was a kind personality, pleasant in word, who guided us with his vision and clarity of thinking. Much of this also helped to promote a convergence in nutrition activities among UN agencies and encourage other fruitful partnerships. His single-minded commitment to give mankind his might to address the problem of malnutrition, is something that each of us could try to emulate in our own small way. In particular, his actions always moved towards the larger population, those who needed that >tap' to improve their lives. His efforts to steer the younger generation to fight malnutrition are again marks of a great human being with vision—we will cherish these ideals and do our best to live up to them.

Reynaldo Martorell, INCAP, and Professor, Emory University

I had the great pleasure of serving on several professional bodies that were chaired by Dr. Horwitz: the Committee on International Nutrition Programs of the Food and Nutrition Board of the U.S. National Academy of Sciences, the UN Subcommittee on Nutrition, and the Pan-American Health Education Foundation. He was a master chair: entertaining, imaginative, resourceful, subtle, principled, persuasive, and of course, highly effective. When I came to know him in the 1980s and 1990s, his age was often featured in self-deprecating remarks, which served a variety of purposes. Once, after hearing a long-winded, convoluted, overly technical explanation, he said "You know, I am getting very old and you need to explain things to me in simple English." On another occasion, the discussion seemed interminable and he said "You need to decide soon. At my age, if you don't hurry, I may not be around to hear your decision." When I became Chair of the SCN's Advisory Group on Nutrition I sought his advice on the art of chairing. I remember three things (said in his very cultured Spanish). "Talk just long enough and never too much" was one. Another bit of advice was never go into a meeting without a clear idea of the desired outcome for each agenda item. "The group may decide otherwise or you might change your mind but always begin with an idea of what you want," he told me. He also had a recommendation for moving the meeting forward. "Pick two or three people representing the contrasting views and ask them to meet to iron out the differences during lunch or in the evening and to report their consensus to the group," he advised. On more than one occasion, I saw this "unite and conquer A strategy work effectively.

Alfred Sommer, Dean, School of Public Health, Johns Hopkins University

Dr. Horwitz was a unique individual: a renaissance mind, that was both contemplative and greatly attracted to new ideas. Without even warning or an appointment, I "dropped in" to see him in 1985 when I happened to be in the vicinity of PAHO and was feeling beleaguered by colleagues who doubted that vitamin A deficiency could be responsible for significant childhood mortality. I clearly recall his greeting this unanticipated guest at the elevator, and warmly guiding me to his office with the words: "I've heard about some of your exciting work. Please share it with me and my colleagues." It's astounding to recall that he only discovered nutrition after formally retiring from a distinguished public health career. Those of us in IVACG, which he chaired, readily recall that gentle, lilting refrain that helped us evaluate abstracts or proposals: "This is very interesting, but personally I am somewhat doubtful." Regardless of our previous thoughts, we all quickly re-evaluated our positions! One of my greatest pleasures was to know and learn from this wise and gentle man. One of my greatest honors was to place around his shoulders the regalia of his Johns Hopkins "Doctorate of Humane Letters, honoris causa," 50 years after he'd earned his MPH degree from our School of Hygiene and Public Health.

Barbara Underwood, President, IUNS

Dr. Horwitz was an amazing, energetic leader and person. I was privileged to work with him in several capacities over the last three decades, perhaps the most significant being during his chairmanship of IVACG. After opening IVACG meetings, he sat in the front row of every session listening to capture relevant points from discussions and harmonize divergent views. His traditional summary remarks to end the meetings were always the highlight, as we all listened for his cogent remarks and pearls of wisdom. He was a true humanitarian and appalled that vitamin A deficiency continued to extract such a toll on human life and well-being. His concern, however, went beyond vitamin A deficiency to other forms of malnutrition and those conditions of deprivation that entrapped the poor and limited the quality of their lives. His compassionate leadership in humanitarian programmes globally applied will be his legacy in the history of nutrition. Dr. Horwitz was an inspiration to me as I know he was for many. He was a source of wisdom I often sought to provide a balanced view on controversial issues. I will miss his counsel.

Peter Greaves, UNICEF

I have warm memories of Dr. Horwitz as a wise and benign B but at the same time tough and shrewd B Chairman of the SCN, with a formidable intellect. His patience and persistence B sometimes to the point of obstinacy B were legendary, but he was always courteous, and almost always gracious. Everyone was encouraged to have their say, however inordinately long, or incoherently expressed. This often caused havoc to the timetable, requiring heroic adjustments by the secretariat, but in the end matters were resolved and proceedings concluded deftly. Dr. Horwitz's concern to promote action rather than argument sometimes led to tension between the orthodox view that action was the prerogative of the agencies and 'coordination' the role of the SCN, and a more contentious but imaginative view that some proactive initiatives were legitimate activities of the SCN B or its secretariat (a distinction repeatedly and somewhat tediously made by some members). Dr. Horwitz"s skills and dexterity, aided by his charm and charisma, in negotiating these hazards and projecting a positive vision for nutrition won him widespread respect, admiration, and affection.

Ricardo Uauy, Director, Institute of Nutrition and Food Technology, Chile

Dr. Horwitz is now gone but he leaves us a legacy of commitment for public service and scientific excellence with a human touch. His impressive career achievements spanned the Americas and eventually the world at large. Within a lifetime he developed a national career as a Professor of Microbiology in Chile, successfully facing an epidemic of meningococcal meningitis, later leading a public health advocacy effort that culminated in the setting up of the Chilean National Health Service. He went on to serve the Americas as a regional public health leader Directing PAHO for 16 years demonstrating energy and great capacity to organize and mobilize this complex institution in support of health and development projects. Perhaps his greatest achievement during this time was improving the water supply and sanitation of the region. The message given by Dr. Horwitz was very clear "Health has an intrinsic value for all human beings, i.e., it is an end in itself, but it is also an essential means for human and economic development." No PAHO Director, before or after Horwitz, has been reelected four times. Finally a global career in international nutrition as Chair of the UN ACC/SCN. His work presiding over the SCN included responsibility for reporting on the world nutrition situation, with special attention to the situation of refugees, definition of micronutrient deficiencies (iodine, iron, and vitamin A) as global problems, and proposing the International Conference in Nutrition organized by FAO/WHO in 1991 with the imperative to act to significantly reduce hunger and malnutrition before the end of the century. His vision on the importance to health and nutrition for human and social development can be summarized as follows: "health and nutrition should be placed at the centre of human and social development in all countries, but particularly in those where the malnutrition-infection complex is the major cause of death and disease of children and of mothers." As a point of personal interest, Dr. Horwitz's career influenced me directly, as my father who did his medical thesis under the promising professor Dr. Horwitz, frequently used his example to motivate me to strive for excellence. We will remember him as a source of inspiration for us who are here and for those that will come in the future.

John Kevany, PAHO and Professor, Trinity College, Ireland and Rosemary Kevany

By any measure, Abraham Horwitz was my principal guide and mentor over 30 years of international health work. To me, he was a person of immense vision, great humanity, and coruscating wit. I was privileged not only to work for and with such an exceptional person, but also to accompany him on occasions after work to concerts and theatres where his erudition in music and drama provided a wonderful finish to the day. His personal charm was no less remarkable, as evinced by a bouquet of roses sent to Rosemary when he needed me to work in PAHO one Sunday morning on a forthcoming presentation. As in all relationships we had our occasional differences of opinion, but he was always enormously generous in seeking to resolve these—a touch on the elbow, a wry smile, a chat in the corridor and he had me back on track. With so many others, I will miss him greatly and feel bereft of someone who gave real meaning to the words 'humanity' and 'compassion'.

Note for contributors

The editors of the *Food and Nutrition Bulletin* welcome contributions of relevance to its concerns (see the statement of editorial policy on the inside of the front cover). Submission of an article does not guarantee publication—which depends on the judgement of the editors and reviewers as to its relevance and quality. All potentially acceptable manuscripts are peer-reviewed. Contributors should examine recent issues of the *Bulletin* for content and style.

Language. Contributions may be in English, French, or Spanish. If French or Spanish is used, the author should submit an abstract in English if possible.

Format. Manuscripts should be typed or printed on a word processor, **double-spaced**, and with ample margins. Only an original typed copy or a photocopy of equivalent quality should be submitted; photocopies on thin or shiny paper are not acceptable.

When the manuscript has been prepared on a word processor, a diskette, either 3½- or 5¼-inch, should be included with the manuscript, with an indication of the disk format and the word-processing program used.

Length. Ordinarily contributions should not exceed 4,000 words.

Abstract. An abstract of not more that 150 words should be included with the manuscript, stating the purposes of the study or investigation, basic procedures (study subjects or experimental animals and observational and analytical methods), main findings (give specific data and their statistical significance if possible), and the principal conclusions. Emphasize new and important aspects of the study or observations. Do *not* include any information that is not given in the body of the article. Do not cite references or use abbreviations or acronyms in the abstract.

Tables and Figures. Tables and figures should be on separate pages. Tables should be typed or printed out double-spaced. Submit only original figures, original line drawings in India ink, or glossy photographs. Labels on the figures should be typed or professionally lettered or printed, not handwritten.

Photographs. Ideally photographic materials should be submitted in the form of black and white negatives or black and white glossy prints. Photographs will not be returned unless a specific request is made.

Units of measurement. Preferably all measurements should be expressed in metric units. If other units are used, their metric equivalents should be indicated.

Abbreviations. Please explain any abbreviations used unless they are immediately obvious.

References. References should be listed at the end of the article, also double-spaced. Unpublished papers should not be listed in references, nor should papers submitted for publication but not yet accepted.

Number references consecutively in the order in which they are first mentioned in the text. Identify references in the text and in tables and figure legends by arabic numerals enclosed in square brackets. References cited only in tables or figure legends should be numbered in accordance with the first mention of the relevant table or figure in the text. **Be sure references are complete.**

Reference citations should follow the format illustrated below.

Journal reference

—*standard journal article* (list all authors):

1. Alvarez ML, Mikasic D, Ottenberger A, Salazar ME. Caracteristicas de familias urbanas con lactante desnutrido: un análisis critico. Arch Latinoam Nutr 1979;29:220–30.

—*corporate author:*

2. Committee on Enzymes of the Scandinavian Society for Clinical Chemistry and Clinical Physiology. Recommended method for the determination of gammaglutamyltransferase in blood. Scand J Clin Lab Invest 1976;36:119–25.

Book or other monograph reference

—*personal author(s):*

3. Brozek J. Malnutrition and human behavior: experimental, clinical and community studies. New York: Van Nostrand Reinhold, 1985.

—*corporate author:*

4. American Medical Association, Department of Drugs. AMA drug evaluations. 3rd ed. Littleton, Mass, USA: Publishing Sciences Group, 1977.

—*editor, compiler, chairman as author:*

5. Medioni J, Boesinger E, eds. Mécanismes éthologiques de l'évolution. Paris: Masson, 1977.

—*chapter in book:*

6. Barnett HG. Compatibility and compartmentalization in cultural change. In: Desai AR, ed. Essays on modernization of underdeveloped societies. Bombay: Thacker, 1971:20–35.

Identification. Please give the full name and highest degree of all the authors, the name of departments and institutions to which the work should be attributed, the name, address, and fax number of the author responsible for correspondence about the manuscript, and sources of support for the work. If the material in the article has been previously presented or is planned to be published elsewhere—in the same or modified form—a note should be included giving the details.

Manuscript copies. The contributor should keep a duplicate copy of the manuscript. Manuscripts will not be returned unless specifically requested. Proofs will be sent to the authors only in exceptional circumstances.

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La rédaction du *Food and Nutrition Bulletin* recherche des articles traitant de sujets correspondant à ses thèmes (voir au vérso de la couverture la politique éditoriale de cette revue). La remise d'un manuscrit ne signifie pas sa publication, qui dépend de l'opinion de la rédaction et des réviseurs sur son intérêt et sa qualité. Tous les manuscrits susceptibles d'être acceptés sent révisés par des pairs. Les auteurs sent invités à se pencher sur les récents numéros du *Bulletin* pour prendre connaissance de son contenu et de son style.

Langues. Les manuscrits peuvent être rédigés en anglais, en français ou en espagnol, et dans ces deux derniers cas, l'auteur ajoutera, si possible, un résumé en anglais.

Format. Les manuscrits doivent être dactylographiés ou imprimés sur une machine de traitement de texte, **en double interligne**, avec une marge suffisante. Ne doit être présenté qu'un exemplaire original dactylographié ou une photocopie de qualité équivalente.

Lorsque le manuscrit a été préparé sur une machine de traitement de texte, une disquette de 3,50 ou de 5,25 pouces devrait dans toute la mesure possible y être jointe en précisant son format et le programme utilisé.

Longueur. Les manuscrits ne doivent pas, normalement, dépasser 4000 mots.

Résumé: Un résumé de 150 mots maximum doit accompagner le manuscrit. Il devra donner les buts de l'étude ou des recherches, les procédures de base (sujets de l'étude ou animaux expérimentaux et méthodes d'observation et d'analyse), les principaux résultats (fournir des données spécifiques et indiquer dans la mesure du possible leur importance statistique) ainsi que les principales conclusions. Veuillez mettre en relief les aspects nouveaux et importants de l'étude ou des observations. Prière de *ne pas* inclure des informations qui ne figurent pas dans le corps de l'article. Dans le résumé, ne citez aucun ouvrage de référence et n'utilisez ni abréviations ni sigles.

Tableaux et figures. Ils doivent être reportés sur des feuillets séparés. Les tableaux doivent être dactylographiés ou imprimés en double interligne. Veuillez soumettre uniquement des figures originales, des dessins à l'encre de Chine ou des photographies tirées sur papier glacé. Les labels qui apparaissent sur les figures doivent être dactylographiés ou gravé ou imprimés de manière professionnelle et non pas écrits à la main.

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Références. Les références doivent apparaître à la fin de l'article, en double interligne également. Les documents non publiés ne doivent pas figurer dans les références pas davantage que les documents présentés à des fins de publication mais qui n'ont pas encore été acceptés.

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—*article de journal type* (énumérer tous les auteurs):

1. Alvarez ML, Mikasic D, Ottenberger A, Salazar ME. Caracteristicas de familias urbanas con lactante desnutrido: un análisis critico. Arch Latinoam Nutr 1979;29:220–30.

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(E.-U.): Publishing Sciences Group, 1977.

—*éditeur, compilateur, président en tant qu'auteur:*

5. Medioni J, Boesinger E, éds. Mécanismes éthologiques de l'évolution. Paris: Masson, 1977.

—*chapitre d'un ouvrage:*

6. Barnett HG. Compatibility and compartmentalization in cultural change. Dans: Desai AR, éd. Essays on modernization of underdeveloped societies. Bombay: Thacker, 1971:20–35.

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