Biotechnology-Derived Nutritious Foods for Developing Countries: Needs, Opportunities, and Barriers

Discussion summary and expanded abstracts from a workshop organized by ILSI's Human Nutrition Institute and International Food Biotechnology Committee, the International Food Policy Research Institute, and the Joint Institute for Food Safety and Applied Nutrition

Editors
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Biotechnology-derived nutritious foods for developing countries: Preface

On January 15–17, 2002, a distinguished group of international experts convened to review current scientific information on nutrition needs in developing countries and food-based approaches, including modern biotechnology, that could be used to address these problems. This workshop, "Biotechnology-Derived Nutritious Foods for Developing Countries: Needs, Opportunities, and Barriers," was organized by the International Life Sciences Institute (ILSI) through its Human Nutrition Institute and its International Food Biotechnology Committee, the International Food Policy Research Institute, and the Joint Institute for Food Safety and Applied Nutrition (a multidisciplinary research and education program established in 1996 by the US Food and Drug Administration and the University of Maryland).

Thirty-two individuals with expertise in modern biotechnology, nutrition, or both participated in the discussions. There were representatives from 16 developing countries in Africa, Asia, and Latin America. Other participants included United States–based experts and representatives from industry and academia and representatives from the Food and Agriculture Organization of the United Nations.

The first day of the workshop was devoted to nutrition issues facing developing countries, and to which strategies have worked in the past and why others did not. The second day focused on the potential for modern biotechnology to solve nutrition problems, specific projects that are under way, the barriers these efforts have encountered, and whether the nutrition community is involved in guiding these projects.

The proceedings of this workshop include the expanded abstracts from the plenary sessions as well as a summary developed from small-group discussions, which were then summarized and prioritized by the whole group. The expanded abstracts are those of the authors and do not necessarily represent the views of the sponsoring organizations. The summary was reviewed by all participants.

Funding for the workshop was provided by the ILSI Human Nutrition Institute, the ILSI International Food Biotechnology Committee, and the Joint Institute for Food Safety and Applied Nutrition. For further information about ILSI, please phone ILSI at 202-659-0074, e-mail at ilsi@ilsi.org, or visit the ILSI website at www.ilsi.org.

The organizers are especially grateful to the keynote speakers, Dr. Cutberto Garza and Dr. Gurdev Khush, for providing overviews to set the stage for the small-group discussions. The respondents from developing countries provided invaluable practical experience that was essential to the development of a useful summary. Dr. Barbara Schneeman masterfully handled the difficult task of drawing all of the discussion points together during the final plenary session. Mr. David Schmidt and Ms. Julia Tagwireyi served as the rapporteurs. Each participant contributed to the overall understanding of the issue and helped generate a genuine enthusiasm for the prospects for developing working relationships between the nutrition communities and the agriculture and plant-breeding communities in developing countries. All left the workshop excited about the prospects for improving the nutritional quality and quantity of foods available in developing countries.

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The nutrition situation: An overview

Cutberto Garza

Abstract

Malnutrition remains a major problem in both developing and industrialized countries and is getting worse in selected settings. However, progress has been made in alleviating malnutrition, and the motivation and tools for tackling malnutrition and its consequences have never been more favorable than they are now. Indeed, the genomic developments spawned by the ongoing biological revolution are increasing the pressure to solve problems that lead to low birthweight, stunting, disorders stemming from micronutrient deficiencies, and other manifestations of undernutrition.

Key words: Nutrition, malnutrition, phenotypic engineering

The world's nutrition situation can be characterized most succinctly by the "bad news/good news" cliché. The bad news is that malnutrition remains a major problem in both developing and industrialized countries and appears to be worsening in selected settings. The good news is that progress has been made and that the motivation and tools for tackling malnutrition and its consequences have never been greater and better, respectively. The motivation comes primarily from an ever-increasing understanding of the sustained relevance of nutrition throughout the life cycle and the fundamental roles nutrition plays in developing and sustaining human capital. The enhanced "tool set" is the benefit of unprecedented technological advances and a more functional understanding of the social, economic, and political dynamic that fosters malnutrition.

Focusing on undernutrition, one finds that the incidence of low birthweight in the developing world remains unacceptably high. It ranges widely among regions, from highs of approximately 30% to levels that are as low as those found in industrialized countries. Approximately 17.5 million people are affected in developing countries. Given the long-term consequences of this birth history and increasing survival, the cumulative population that is and will be affected is staggering. The estimated prevalence and number of stunted children is similarly alarming. The approximate prevalence for all developing countries is 29% of all children, or 165 million children. Yet more alarming is the high likelihood that these are underestimates. The urgency that this situation presents is exacerbated when one considers the additional numbers of individuals affected by or at risk for vitamin A, iron, and iodine deficiencies and the likely high numbers of individuals affected by other micronutrient deficiencies that have received less attention, e.g., zinc, folate, vitamin B_{12}, and riboflavin. It also is important to consider that focusing only on classic nutrients is an implicit recognition of our ignorance of other food constituents that account for the health benefits associated with eating patterns that are reflected in current food-based dietary guidelines [1].

The ongoing biological revolution, best illustrated by the unprecedented developments in genomics, steadily increases the pressure to solve problems that lead to low birthweight, stunting, micronutrient deficiencies, and other manifestations of undernutrition. The source of this increasing pressure is our steadily improving understanding of the biological bases of the functional consequences of those conditions. Increased knowledge is uncovering the basis for the intragenerational and, perhaps more disturbing, intergenerational effects of malnutrition, and thus the growing significance of the role of nutrition in "phenotypic engineering." Progressively, the insidious effects of undernutrition on human capital, their high financial and other costs, and the underlying reasons for those costs are becoming clearer.

As is true for poverty, which is the principal root cause of undernutrition, undernutrition is the consequence of an economic, political, and social dynamic

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whose interrelationships are salient and whose consequences often also are easily recognizable. As is true of other consequences of this dynamic, undernutrition concomitantly exacerbates, in an adversely synergistic fashion, both the dynamic itself and the undernutrition that is spawned by it. Yet despite this dynamic's overt nature and the salience of its consequences, sustainable interventions for their control are not as obvious as the dynamic itself, its consequences, or explanations for them.

The nutritional status of populations is one of the most easily recognized constituents and outcomes of this dynamic. Its centrality is demonstrated easily by considering the developmental goals adopted by the international community and summarized in the most recent World Development Report 2000/2001 [2]. Seven goals are articulated by that report on behalf of the international community:

- Reduce the proportion of people living in extreme poverty by half between 1990 and 2015.
- Enroll all children in primary school by 2015.
- Make progress toward gender equality and empowering women by eliminating gender disparities in primary and secondary education by 2005.
- Reduce infant and child mortality rates by two-thirds between 1990 and 2015.
- Reduce maternal mortality ratios by three-quarters between 1990 and 2015.
- Provide access for all who need reproductive health services by 2015.
- Implement national strategies for sustainable development by 2005 so as to reverse the loss of environmental resources by 2015.

The biological bases for the assertion that improved nutrition both is a prerequisite for meeting goals such as these and is one of the dividends of achieving them merit exploration. The intra- and intergenerational dimensions of these relationships and the biology that may underpin them will be considered in the context of the present and projected nutrition situation, population pressures, food access, nutrient gaps, and demographic changes.

References

1. United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition. 4th Report on the world nutrition situation: nutrition throughout the life cycle. Geneva: ACS/SCN/WHO, 2000.
2. International Bank for Reconstruction and Development/World Bank. World development report 2000/2001: attacking poverty. New York: Oxford University Press, 2001.

Priority nutritional concerns in Asia

E-Siong Tee

Abstract

The sustained economic growth and increasing economic stability in the Asian region over the last three decades have been accompanied by changing lifestyles leading to significant changes in the food and nutrition issues facing Asian countries. The chronic diseases associated with excessive consumption of nutrients, especially fat, are becoming increasingly apparent. At the same time, Asia has a disproportionate share of the malnutrition problem. Underweight and stunting remain significant problems in many Asian communities, and micronutrient deficiencies of iron, iodine, and vitamin A continue to afflict large population groups. Effective data collection and analysis are essential to formulate and implement intervention programs to address both sides of the changing nutrition scenario in Asia.

Key words: Nutrition, undernutrition, overnutrition, Asia

More than three decades of sustained economic growth in the Asian region and increasing political stability in many Asian countries have brought about rapid advances in socioeconomic status. Even the least-developed countries in the region have made significant progress. Some, for example, China, are recognized as economically stable despite global economic uncertainties. Such rapid developments have brought about marked lifestyle changes, including food purchasing and consumption patterns. Significant demographic changes have also occurred. As a result, there is a definite change in the food and nutrition issues facing communities in the countries of the region.

While nutritional deficiencies in many Asian countries are slowly decreasing in magnitude, significant proportions of Asian population are now facing the other facet of the malnutrition problem: diet-related chronic diseases such as hypertension, coronary heart disease, diabetes mellitus, and certain types of cancers. Because of the different stages of socioeconomic development, the extent of both malnutrition extremes varies considerably among the different countries in the region. Asia thus needs to address both extremes of the nutrition situation.

Changes in the Asian nutrition scenario

Dramatic socioeconomic developments over the past 30 years have brought about increased nutrient availability in many countries in the region as well as improved health facilities. These improvements have led to improvements in morbidity and mortality and a marked decrease in nutrient deficiencies. Nevertheless, the extent of the undernutrition problem is still large, and the magnitude varies markedly among the countries in the region.

In addition to changes in the amounts of available nutrients in Asian countries, there have been marked changes in the sources of nutrients and the composition of diets. Significant changes in consumption patterns in Asian countries occurred from 1960 to 1990. Cereal consumption decreased in most countries, except in the low-income countries, where average consumption has remained more or less stable. There also have been increases in the percentage of energy from fat, and there has been an increased consumption of added fats in most countries. The most affluent countries show an increase in vegetable and fruit consumption. Meat consumption (and thus the consumption of saturated animal fat) has increased markedly in some countries; for example, Japan, China, and South Korea recorded increases of 250% to 330%. Consumption of milk and dairy products has increased in only a few countries [1].

There have also been other changes in dietary behav-

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ior. More families eat out, and the consumption of fried foods is increasing. Overeating is a concern among some. The use of dietary supplements is also increasing, and some individuals have the mistaken belief that supplements can replace missed meals. Other significant lifestyle changes have also taken place, including decreased physical activity, even in rural areas. The high prevalence of smoking in the region, however, remains unchanged.

The combined effect of these lifestyle changes is causing a significant change in the food and nutrition issues facing Asian countries. Of growing concern are the significant proportions of the population now faced with the other facet of the malnutrition problem: the chronic diseases associated with excessive consumption of various nutrients (e.g., fat), on the one hand, and low levels of intake of other nutrients (e.g., complex carbohydrates and fiber) on the other. The increased prominence of these diseases is evident in the mortality and epidemiologic data, which vary markedly among countries in the region. On the one hand, for the most developed countries, such as Japan and South Korea, the problem of diet-related chronic diseases predominates. On the other hand, less-developed countries in South Asia and the Indo-Chinese countries are burdened with a greater share of the undernutrition problem. Between these two extremes, China and most countries in Southeast Asia are faced with a significant chronic disease problem while also struggling with the persistent nutrient deficiencies that persist to some extent. These new dimensions in the nutrition situation in developing countries pose great challenges to nutritionists and other health workers.

Undernutrition: a huge and persistent problem in Asia

In spite of the economic advances in the region, undernutrition, including underweight and stunting, remains a significant problem in many Asian communities. Micronutrient deficiencies, especially those that result in iron-deficiency anemia, iodine-deficiency disorders, and vitamin A–deficiency disorders, afflict large population groups, especially young children [2–7].

Indeed, Asia has a disproportionate share of the malnutrition problem, where the number of malnourished children is mind-boggling. In 1980 there were 174 million stunted preschool children in Asia, constituting more than three-quarters (78.3%) of the stunted children in all developing countries. In 2000, this total declined to 128 million, but Asia still had two-thirds (70%) of the developing countries' stunted preschool children. In 1980, 52% of Asian preschool children were stunted—the highest rate of any region in the world. This figure has steadily declined, and in 2000, 34% of Asian preschool children were stunted.

A similar picture is presented for underweight preschool children in Asia. In 1980, there were 146 million underweight preschool children in Asia, constituting 83% of the underweight preschool children in developing countries. In 2000, the number declined to 108 million, or 72% of the total of underweight preschool children in all developing countries. The prevalence of underweight preschool children in Asia, 44%, was the highest of any region of the world in 1980, although it declined to 29% in 2000.

Iron-deficiency anemia also affects large numbers of Asians. Among preschool children, the prevalence of anemia is reported to be the highest in Africa and Asia. In Asia, the most affected subregion is South Central Asia, where the prevalence can be as high as 60%. Among pregnant women, Africa and Asia again have the highest prevalence of anemia. Anemia prevalences are as high as 75% in South Central Asia. Among school-age children, the prevalence of anemia is highest in Southeast Asia, where as many as 60% of children may be affected.

Huge numbers are similarly affected by iodine-deficiency disorders in Asia. In the Southeast Asian region alone, nine countries have been recognized as having iodine-deficiency disorders as a public health problem. A total of 172 million people, or 12% of the population, are affected by goiter, and another 41% are at risk for the disorder.

Vitamin A deficiency also remains a problem of immense magnitude, although data are not available to make good estimates of the extent of the problem. It is clear, however, that subclinical vitamin A deficiency in Asia should not be ignored.

Because the extent of the undernutrition problem remains huge, it is vital that actions be undertaken to tackle undernutrition-related issues. More thought should be given to implementing programs and activities relevant to local communities. Food fortification, supplementation in some cases, and efforts to increase food availability have all been tried in Asia with varying success. Nutrition education efforts have been going on in the region for three decades. Other factors related to malnutrition should be tackled at the same time, specifically environmental sanitation. The importance of infection should not be neglected.

Overnutrition: a major problem on the horizon

Dramatic changes in socioeconomic conditions in the Asian region are expected to continue in the future. The associated increase in diet-related chronic diseases in developing countries in Asia should be a cause for real concern and for concerted interventions. For countries not yet afflicted with diet-related chronic diseases, it is important to avoid or reduce the onslaught of these diseases. It is hoped that these countries will be able to learn from the mistakes of others, and not follow the same path.

The emerging problem of overweight in children cannot be ignored. The current proportion of overweight preschool children in developing countries is low, estimated to be 3.3% in 1995. There is, of course, considerable variation in this prevalence. The estimate for Asia was 2.9%, with a higher prevalence of 4.3% in Eastern Asia and 2.4% in Southeast Asia [8]. Data from individual Asian countries show higher proportions in Brunei Darussalam (9%), in Thailand (5.4%), among urban children in Kuala Lumpur (8%), and among urban children in China (6.5%). A total of 17.6 million preschool children in all developing countries were considered overweight. Of this total, 61%, or 10.6 million, were in Asia. The region therefore has the double burden of the highest number of stunted preschool children and the highest number of overweight children.

The problem of increasing overweight and obesity in Asian adults has been highlighted for more than a decade. The database on the extent of the problem is far from comprehensive, but various studies point to the severity of the problem. In Malaysia, the available data indicate that in urban communities the overall prevalence of overweight is probably about 29% and that of obesity about 12%. The combined prevalence of overweight and obesity (body mass index [BMI, expressed in kg/m^2] > 25) in Malaysia ranged from 26% to 53%, with an overall mean of 39%. The problem also appears to be prevalent in lower-income urban adults and in rural communities [7]. In a study of a small number of urban subjects in 12 Asian cities, the prevalence of overweight and obesity (BMI > 25) was found to be high (more than 23%) in 5 cities: Beijing, Hong Kong, Kuala Lumpur, Manila, and Bangkok. It was also noted that the most affluent societies in the study, for example, Seoul and Tokyo, did not have the highest prevalence of overweight.* In China, national nutrition surveys conducted in 1982 and 1992 showed that the prevalence of overweight and obesity in young adults increased from 9.7% to 14.9% in urban areas and from 6.2% to 8.4% in rural areas during the 10-year period [5].

Much of the overweight and obesity problem described occurs in urban areas. For example, in a study of more than 5,000 primary schoolchildren in Kuala Lumpur, the prevalence of overweight was 8%, much higher than that in a similarly large study in rural areas in the other parts of Malaysia, which reported a prevalence of 2% [7]. However, several reports in recent years have also highlighted the increasing prevalence of the problem in rural areas.

The high prevalence of overweight and obesity is associated with increases in a whole host of diet-related chronic diseases in many communities in the Asian region. Coronary heart disease has been reported to be a main cause of death in many countries, and the prevalence of hypertension and diabetes has reached worrying proportions.

It is imperative that the problems associated with diet-related chronic diseases be identified and recognized early enough for firm actions to be taken immediately. It is indeed a challenge for governments to formulate intervention programs to tackle both facets of the malnutrition problem. Several governments in Asia have carried out interventions focusing on healthier lifestyles, including healthy eating. Some communities are earnestly seeking ways to achieve healthy eating, including healthier food alternatives and health supplements, whereas others are not. The extent of the diseases is certainly not decreasing. Thus, what works and what does not, and what works where, are going to be important questions to answer.

Other nutritional concerns

Other nutritional concerns are the continued high prevalence of low birthweight, adolescent nutrition issues, and interactions between nutrition and infection. As the aging population of Asia increases markedly in the coming years, the nutritional needs of the elderly will be important issues to address.

Economic progress in the countries of the region will continue to be accompanied by lifestyle changes. It is therefore of the utmost importance to continue to monitor nutritional status. Systems to periodically collect data on nutritional status and dietary intakes should be in place in all countries. Indeed, comprehensive data specific to the communities concerned should be made available through systematic research programs to permit the formulation and effective implementation of intervention programs in developing countries. All countries in the region need to develop a national plan of action for nutrition, jointly formulated and implemented by all of the relevant sectors, including food, health, and education. Such plans should be periodically reviewed.

* Sakamoto M, Ishii S, Kashiwazaki H, Chiu PC, Chen CM, Chang NS, Leung SF, Rabuco LB, Tee ES, Winarno FG, Tontisirin K, Howden J, Saldanha LG. A collaborative study of nutritional knowledge, attitude and food practices among urban adults in the Asian region. Presented at the 2nd International Workshop on Nutritional Problems and Strategies in the Asian Region, 29–30 September 1997, Kuala Lumpur.

References

1. World Cancer Research Fund/American Institute for Cancer Research. Patterns of diet and cancer. In: Food, nutrition and the prevention of cancer: a global perspective. Menasha, Wisc, USA: Banta Book Group, 1997: 20–52.
2. World Health Organization. WHO global database on child growth and malnutrition. Geneva: WHO Programme on Nutrition, 2000.
3. de Onis M, Frongillo EA, Blossner M. Is malnutrition declining? An analysis of changes in levels of child malnutrition since 1980. Bull WHO 2000;78:1222–33.
4. United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition. 4th report on the world nutrition situation: nutrition throughout the life cycle. Geneva: ACC/SCN, 2000.
5. Ge KY, Fu DW. The magnitude and trends of under- and over-nutrition in Asian countries. Biomed Environ Sci 2001;14:53–60.
6. Krishnaswamy K. Perspectives on nutrition needs for the new millennium for South Asian regions. Biomed Environ Sci 2001;14:66–74.
7. Tee ES. Nutrition of Malaysians: Where are we heading? Malays J Nutr 1999;5(1/2):87-109.
8. de Onis M, Blossner M. Prevalence and trends of overweight among preschool children in developing countries. Am J Clin Nutr 2000;72:1032–9.

Food security in Latin America

Adolfo Chávez and Miriam Muñoz

Abstract

Although the nutrition situation in most Latin American countries is improving and malnutrition is easing, worrisome factors are emerging. Huge rural-to-urban migrations have been accompanied by a worsening nutrition situation in rural populations, especially in Mexico, Colombia, and Brazil, a phenomenon not readily apparent from average food availability and malnutrition data. Average figures can also mask the severe nutrition problems that persist in four densely populated areas: the Caribbean Islands, Central America, the Andean region, and parts of Brazil. Although globalization is improving the nutritional status of many population groups in Latin America, it is also creating new pressures. Latin American countries dependent on agriculture are especially vulnerable.

Key words: Nutrition, food security, Latin America

The recent food balance sheets from the Food and Agriculture Organization of the United Nations (FAO) show that food availability has increased in most Latin American countries. The average intake of calories per person per day for the region as a whole increased from 2,285 in 1980 to 2,700 in 2001 [1]. Similar improvement has been reported for malnutrition by the Pan American Health Organization, with weight-for-age in preschoolers as the indicator [2]. Some countries, such as Brazil, Colombia, and Mexico, have almost halved their proportions of malnourished people over the past 20 years. In an even shorter period, 11 years (1985–1993), the official figures dropped from 16.2% to 9.0% [3]. The same types of improvements are also being reported for some specific micronutrient deficiencies, mainly those of iodine and vitamin A.

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Regardless of the improvements, there are some worrisome data and other concerns about food security because of the agricultural and economic situation in the region. It is unclear whether the optimistic figures published by the United Nations agencies [1, 2] reflect what is actually occurring in Latin America. The huge migrations from rural to urban areas and some of the survival strategies of the poor are important factors in the region. For example, in Mexico unofficial surveys done by our research group show overall national improvement, but not as great as reported above [4, 5]. The improvement is explained by the change in the proportions of the rural and urban populations. The prevalence of malnutrition in rural areas actually worsened, increasing from 16% in 1980 to 19.8% in 2001, but its impact on the national figures was low because only 24% of the population is rural. The situation is similar in Brazil and Colombia, two of the largest countries in South America.

In two conferences held in 2001, the change in food security in Latin America was emphasized, and natural and socioeconomic factors were discussed [6, 7]. Of the natural factors, the contamination of surface and underground water, land erosion, and the high frequency of disasters were emphasized. However, more importance was given to the lack of agricultural financing, cuts in subsidies, the low prices of most commodities, competitive factors caused by the globalization of the marketplace, the low purchasing power of much of the population, and other socioeconomic factors. Together they constitute a pending crisis for Latin American agriculture and rural development.

Many Latin American experts concur on the major role of international globalization in creating competitive large companies, with their sophisticated technology, management, and financial systems, as compared with the less sophisticated production systems of Latin America. There is a preference in local markets for imported products from these large suppliers, which accounts for the increasing globalization of local commercial organizations.

The lack of agreement on Latin American figures for food availability and malnutrition can be explained in part by the probability that the average figures are hiding a phenomenon common to most countries: the contrasting situation in different regions and population groups. Severe problems persist in four densely populated areas [7]: the Caribbean Islands (Haiti, the Dominican Republic, and Cuba), Central America (southeastern Mexico, Guatemala, Honduras, El Salvador, and Nicaragua), the Andean region (Ecuador, Bolivia, and Peru), and the northern, northeastern, and western regions of Brazil. The rest of Latin America has local or regional problems, but the high demand for food elsewhere and the capacity to import food explain the high food availability figures published by the FAO.

Another nutritional problem in all of Latin America is, with few exceptions, as widespread as malnutrition: the tendency of the population to suffer from obesity, insulin resistance, and the chronic clinical syndromes linked to them—diabetes, hypertension, and cardiovascular problems. It is now known that populations of Indo-American ancestry tend to have the so-called thrifty gene, and that early malnutrition, from the womb to three years of age, predisposes them later to these chronic syndromes. Thus, in some communities or families, the children are at risk for malnutrition, while the adults are at risk for these chronic diseases.

The reality over the past 20 years of economic change and globalization is that most Latin American countries, and some regions especially, are struggling to cope with the new socioeconomic conditions, and that the situation must not be allowed to worsen. It is also true that Latin American agriculture is suffering and that the countries and regions that depend on agriculture are on the brink of crisis, with the near future difficult to predict.

International economic pressures surely will continue, and the new global market will be progressively more dominant. In the absence of other solutions, the ability of Latin American societies to adapt to and to adopt the new economic and technological conditions will be the key not only to their progress in the new globalized world but also to their very survival.

References

1. Food and Agriculture Organization of the United Nations. Food balance sheets for Latin America. Available at: http://apps.fao.org/lim500/wrap.pl?FoodBalanceSheet&Domain=FoodBalanceSheet&Language=english. Accessed on January 2, 2002.
2. UNICEF. Estado Mundial de la Infancia 2001. New York: UNICEF, 2001.
3. Secretaría de Salud—Instituto Nacional de Salud Pública, Instituto Nacional de Estadística, Geografía e Informática. Encuesta nacional de salud. Vol. I, Resultados: Niños menores de 5 años. Mexico, D.F, Mexico: Instituto Nacional de Salud Pública, 1999.
4. Avila Curiel A, Shamah Levy T, Chávez A. Encuesta Nacional de Alimentación y Nutrición del medio rural. Vol. 1. Resultados por entidad. Encuesta Nacional de Alimentación y Nutrición 1996. Cuernavaca, Morelos, Mexico: Instituto Nacional de Nutrición, 1997.
5. Avila Curiel A, Chávez A, Shamah Levy T. Encuesta Urbana de Alimentación y Nutrición en la zona metropolitana de la Ciudad de Mexico. Encuesta Nacional Urbana de Alimentación 95. Cuernavaca, Morelos, Mexico: Instituto Nacional de Nutrición, 1996.
6. Chávez A, Muñoz de Chávez M. La seguridad alimentaria y nutricional como estrategia de combate a la pobreza. INCAP Reunión Científica LII Aniversario "Aunando esfuerzos, medio ambiente y seguridad alimentaria para el logro de desarrollo sostenible." Mimeo. Guatemala City, Guatemala: Institute of Nutrition of Central American and Panama (INCAP), 2001.
7. Instituto de Nutrición de Centro América y Panamá and US Agency for International Development. Hemispheric Conference on Disaster Risk Reduction. San José, Costa Rica, December 4–6, 2001. Mimeo. Guatemala City, Guatemala: Institute of Nutrition of Central American and Panama (INCAP), 2001.

Three criteria for establishing the usefulness of biotechnology for reducing micronutrient malnutrition

Howarth E. Bouis

Abstract

The fundamental reason that plant breeding using either conventional breeding or biotechnology is so cost-effective is that the benefits of a one-time investment at a central research location can be multiplied over time across nations all over the world. Supplementation and fortification incur the same recurrent costs year after year in country after country. However, each intervention has its own comparative advantages, such that a combination of several interventions is required to substantially reduce micronutrient malnutrition. Improving the density of trace minerals in plants also reduces input requirements and raises crop yields. A simulation model for India and Bangladesh demonstrated that $42 million invested in conventional breeding in developing and planting iron- and zinc-dense varieties of rice and wheat on only 10% of the acreage used for these crops would return $4.9 billion in improved nutrition (including a total of 44 million prevented cases of anemia over 10 years) and higher agricultural productivity.

Key words: Biotechnology, nutrition, micronutrient malnutrition

The potential usefulness of biotechnology in providing more nutritious food staples in developing countries depends on meeting three general criteria.

First, 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.

Second, there must be aspects of the breeding strategy for which biotechnology is superior to traditional breeding techniques. For example, this is the case for adding β-carotene-related and heat-stable phytase genes to rice. In the long run, as more is understood about the factors driving the translocation of minerals in plants, it may also be the case for increasing trace mineral density.

Third, 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;
» consumers will accept any noticeable changes in the color, taste, texture, cooking qualities, and other features associated with the characteristic being added;
» the characteristic being added will result in a measurable improvement in the nutritional status of the malnourished target population; and
» biofortified transgenic crops are safe to eat.

The conditions for the third criterion, in particular, have yet to be firmly established. However, it is important not to be overly cautious. The potentially enormous benefits of biotechnology to the poor in developing countries in relation to costs are so high that research in this area should be vigorously pursued [1].

The comparative advantages of a plant-breeding approach

The fundamental underlying cause of micronutrient malnutrition is that agricultural systems are not producing sufficient vitamin- and mineral-rich foods such as fruits, meat, fish, legumes, and vegetables that the poor want to eat but simply cannot afford to purchase. It is essential that some activities with longer-term payoffs and lower costs address the root cause at the same

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time that shorter-term measures are taken to relieve suffering and improve lives as quickly as possible. This dual approach is highly complementary.

We all envision a future when nutrition education and increased incomes of the poor will be combined with greater availability and lower food prices to improve dietary quality. However, this will require the eventual investment of many billions of dollars by small farmers, the business sector, and governments over several decades to increase the production and availability of these nutrient-rich, nonstaple foods. In the meantime, specific agricultural strategies can be implemented to improve nutritional status. One of these is "biofortification"—breeding for micronutrient-dense staple food crops, a strategy of getting plants to fortify themselves.

The fundamental reason that plant breeding is so cost-effective is that the benefits of a one-time investment at a central research location can be multiplied over time across nations all over the world. Other interventions incur the same recurrent costs year after year in country after country. Table 1 provides a comparison of the nutritional benefits that $80 million can purchase through programs of supplementation, fortification, and plant breeding and biofortification [2].

Moreover, recent research has demonstrated that improving the density of trace minerals in plants is beneficial for crop nutrition as well, reducing input requirements and raising crop yields. Thus, biofortification has a dual benefit for public health and for farm productivity, so that investments in this area have a particularly high payoff. For example, seeds of lines of wheat and rice bred to be high in zinc content have a higher survival rate, and initial growth is more rapid. Ultimately, yields are higher, particularly in poor soils in arid regions. Crop lines with roots that are efficient in taking up trace minerals from soils resist disease better, and the roots extend more deeply into the soil and can thus tap more subsoil moisture and nutrients. Consequently, these lines are more drought resistant and require less irrigation. Because of their more efficient uptake of existing trace minerals, these varieties also require fewer chemical inputs. Thus the new seeds can be expected to be environmentally beneficial as well. The benefits for agricultural productivity and environmental sustainability are a highly desirable complementary aspect of breeding for trace mineral density, which further enhances the cost-effectiveness of biofortification [3, 4].

A further comparative strength of biofortification is that it can reach the malnourished in relatively remote rural areas where commercial markets are least developed. Biofortification is therefore highly complementary with conventional fortification, which works best in urban settings where markets are better developed.

Biofortification seeks to take advantage of existing consumer and farmer behavior. Increasing the iron and zinc density of the most widely grown and consumed crop lines would not change the color and taste of staple foods, which poor women and children already eat in large amounts day after day. Farmers would choose to grow these nutritionally enhanced lines because of their high profitability.

Benefit-cost analysis

A simulation model has been developed for India and Bangladesh to demonstrate the enormous economic benefits of the biofortification strategy. This model assumes that iron- and zinc-dense varieties of rice and wheat developed under a proposed project are adopted on only 10% of approximately 83 million hectares planted with rice and wheat. The somewhat conservative assumptions suggest that the returns that come during the second decade of research and development (years 11–20 of the simulation model) would be about $4.9 billion on a total investment of $42 million: $1.2 billion in benefits from better nutrition and $3.7 billion in benefits from higher agricultural productivity.

A more formal benefit-cost analysis, using a 3% discount rate (commonly used for analysis of social benefits), gives a benefit-cost ratio (present value of benefits divided by present value of costs) of 19 for returns to better iron nutrition. This ratio rises to 79 if benefits to higher agricultural productivity are included. A different way of expressing the concept of discounting over time is the internal rate of return, the interest rate

TABLE 1. Comparison of an investment of $80 million across interventions

Supplementation	Fortification	Plant breeding/biofortification
Provide vitamin A supplementation to 80 million women and children in South Asia (1/15 of the total population) for 2 years, at a cost of 50 cents for 2 pills, each effective for 6 months	Provide iron fortification to 33% of the population in South Asia for 2 years. Costs of fortification estimated as 10 cents per person per year	Develop 6 nutrient-dense staple crops for dissemination to all the world's people for consumption year after year. This includes dissemination and evaluation of nutritional impact in selected countries Establish prebreeding knowledge base for 9 additional staple crops important in the diets of the poor

at which the benefits would equal the direct costs plus interest if the funds were borrowed to make the investment. In this case, the annual internal rate of return is 29% if only benefits to human nutrition are considered, and 44% if both benefits to human nutrition and higher agricultural productivity are considered.

In the longer term (years 11–25 of the simulation), it is estimated that a total of 44 million cases of anemia will be prevented annually. This is based on a conservative assumption of only a 3% reduction in anemia among those consuming the high-iron rice. This works out to cost of about US$1 per annual case of anemia prevented and an annual cost of 3 cents per person reached, whose iron (and zinc) intakes increase by 50% through consumption of the biofortified rice and wheat [5].

References

1. Bouis H. The role of biotechnology for food consumers in developing countries. In: Qaim M, von Braun J, Krattiger J, eds. Agricultural biotechnology in developing countries: toward optimizing the benefits for the poor. Dordrecht, Netherlands: Kluwer Academic Publishers, 2000:189-213.
2. Bouis H. Plant breeding: a new tool for fighting micronutrient malnutrition. J Nutr 2002;132:491-4.
3. Graham R, Welch R. Breeding for staple food crops with high micronutrient density. Agricultural Strategies for Micronutrients Working Paper 3. Washington, DC: International Food Policy Research Institute, 1996.
4. Welch R. Breeding strategies for biofortified staple plant foods to reduce micronutrient malnutrition globally. J Nutr 2002;132:495–9.
5. Hunt JM. Reversing productivity losses from iron deficiency: the economic case. J Nutr 2002;132(4S): 794S–801S.

The promise of biotechnology in addressing current nutritional problems in developing countries

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Abstract

To meet the nutritional needs of a rapidly growing world population, which is likely to reach 8 billion by 2030, 50% more food grains with higher and more stable yields must be produced. Biofortification is considered the most effective way to increase micronutrient intakes. It is low cost and sustainable and does not require a change in eating habits or impose recurring costs. A research project to improve the iron and zinc content of rice was initiated at the International Rice Research Institute in 1992. Several experimental lines of rice with increased iron and zinc content have been produced. In another experiment rices with β-carotene have been produced. Other experimental efforts aim at raising the micronutrient content in wheat, maize, cassava, sweet potatoes, and beans. Maize with improved amino acid balance is being grown in several African countries.

Key words: Biotechnology, nutrition, biofortification, micronutrient malnutrition

Access to a healthy diet is a fundamental right of every human being, yet 800 million people, mostly in the developing world, go to bed hungry every night. Furthermore, micronutrient deficiencies, which affect 3 billion people, hinder the development of human potential and the social and economic development of nations.

Access to food depends on income. Currently, more than 1.3 billion people in the world are extremely poor, with incomes of less than US$1 per person per day, and another 2 billion are only marginally better off [1]. Thus, investments in employment generation are as important as investments in food production.

The malnutrition problem is further exacerbated by increases in the world population, which is likely to reach 8 billion by 2030. Most of this increase (93%) will take place in the developing world, whose share of the global population is projected to increase from 78% in 1995 to 83% in 2020. To meet the challenge of feeding an ever-increasing population and alleviating protein–energy malnutrition, we will have to produce 50% more food grains. To meet this challenge, we will need crop varieties with higher and more stable potential yields. Conventional plant-breeding as well as biotechnology techniques will be employed to develop crop varieties with higher yields and greater resistance to diseases and insects.

Tackling micronutrient malnutrition

In addition to protein–energy malnutrition, deficiencies of minerals and vitamins affect a high proportion of the world's poor. Deficiencies of iron, zinc, iodine, and vitamin A are most acute. An estimated 2 billion people in the world are iron deficient. At least 400 million are deficient in vitamin A, 100 million of whom are young children. As many as 3 million children die annually as a result of vitamin A deficiency [2]. One billion people live in iodine-deficient regions, and many of them suffer from iodine-deficiency disorders, including goiter, cretinism, lower intelligence, and increased prenatal mortality [3]. Zinc deficiency, which is thought to be widespread, can lead to retarded growth, depressed immune function, anorexia, dermatitis, skeletal abnormalities, and child mortality if prolonged [4]. Furthermore, zinc deficiency has been linked to underutilization of vitamin A. Even in developed countries, micronutrient deficiencies affect a significant number of people. Taken together, micronutrient deficiencies affect a far greater number of the world's population than does protein–energy malnutrition [5].

Intervention programs for alleviating micronutrient malnutrition include supplementation, food fortification, education, and biofortification. Fortification programs have been successful in reducing malnutrition

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in specific situations, for example, fortification with iodine through the use of iodated salt. However, for iron, zinc, and vitamin A, fortification and supplementation programs are expensive, incur ongoing costs, and are unlikely to reach all of those at risk. Moreover, such intervention programs have often been suspended for economic, political, or logistical reasons [6].

One approach to solving the problem of micronutrient deficiencies is to persuade people to make their diets more nutritious. However, attempts to change eating behavior are generally unsuccessful. It is often difficult for poor people to make dietary changes using local food. These attempts require a lot of input, constant follow-up, and education. When they are scaled up, they rarely work, so they tend not to be sustainable.

Under these limitations, biofortification is considered the most effective way to tackle micronutrient malnutrition. This strategy for supplying micronutrients to the poor in developing countries involves making staple foods eaten by the poor more nutritious by using conventional plant breeding and biotechnology. This strategy is low cost and sustainable, and it does not require a change in eating habits and does not impose the recurring costs that accompany food supplementation and fortification.

Increasing the mineral and vitamin concentration of staple crops

The main concern about the potential benefits of using mineral- or vitamin-dense staple crops is whether the increased concentrations will in fact result in significant increases in bioavailable minerals and vitamins and, consequently, improve the nutritional status of malnourished populations. For this to happen, vulnerable groups have to consume the improved varieties of staple crops in sufficient quantities.

Even more important, the net amounts of bioavailable nutrients they ingest must be greater than those in traditional crops. For example, the main sources of iron for impoverished populations are staple cereals and starchy roots, tubers, and legumes, but most of the iron ingested from these sources has low bioavailability. It is estimated that cereals contribute up to 50% of iron intake in households from lower socioeconomic groups [7]. For zinc, the contribution from plant sources can be as high as 80%. This means that doubling the iron and zinc density of food staples could increase the total intake by at least 50%. The main problem, however, is that diets based on plant staples usually contain large amounts of phytic acid [6], which inhibits iron and zinc absorption. Thus, crop-improvement strategies should aim at increasing the level of micronutrients, on the one hand, and reducing the amount of phytic acid, on the other.

Improving the amount and bioavailability of iron and zinc

A research project to develop improved rice varieties with high iron and zinc content was initiated at the International Rice Research Institute (IRRI) in 1992. Considerable variation in both iron and zinc was observed in the rice germplasm. Iron concentrations ranged from 6.3 to 24.4 mg/kg, with a mean value of 12.2 mg/kg. For zinc, the range was 15.3 to 58.4 mg/kg [8].

Efforts are under way to develop improved rice germplasm with elevated levels of iron and zinc. Crosses between traditional varieties and high-yielding varieties have produced progenies with both high yield and high micronutrient levels. For example, an improved breeding line, IR68144, has both a high concentration of iron in grain (about 21 mg/kg) and a high yield potential. Milled rice of this variety is being used in human feeding trials to determine the bioavailability of the iron [8].

A genetic engineering approach has been successfully applied to raise the iron content of rice. Goto et al. transferred the soybean ferritin gene into the Kita-ake rice variety through transformation [9]. The iron content of the transgenic seeds was as much as threefold greater than that of untransformed seeds. Similarly, Lucca et al. introduced the ferritin gene from the common bean into rice, and the transgenic lines had twice as much iron as controls [10]. To increase the bioavailability of iron, Lucca et al. introduced the thermotolerant phytase gene from a fungus into the rice endosperm to break down phytic acid, thus improving the bioavailability of the iron in rice [10]. Mutants of barley, maize, and wheat with low amounts of phytate are available and may be employed to develop varieties of these crops with improved iron bioavailability.

Ortiz-Monasterio found a fourfold variation between the lowest and highest concentrations of iron and zinc in the grains of several hundred wheat accessions [11]. Studies at the International Center for Tropical Agriculture showed that certain varieties of common bean had 60% to 80% more zinc than other widely grown varieties. Breeding efforts are under way to incorporate high levels of zinc into improved varieties [12].

Improving the vitamin A content of crops

β-Carotene, a precursor of vitamin A, does not occur naturally in the endosperm of rice. Therefore, populations that derive most of their calories from rice suffer from vitamin A deficiency. The poor people in many Asian countries (Vietnam, Laos, Cambodia, Myanmar, Bangladesh, and India) derive more than 60% of their calories from rice.

Ye et al. introduced two genes from daffodil (*Narcissus pseudonarcissus*) and one gene from a bacterium (*Ervinia uredovora*) into rice variety Taipei 309 through genetic engineering [13]. Ten plants had a yellow endosperm (because of the presence of β-carotene), had a normal vegetative phenotype, and were fully fertile. Taipei 309 was used to introduce the β-carotene biosynthetic pathway, which is easy to transform. However, Taipei 309 is no longer cultivated. IRRI has started a project with the aim of introducing the genes for β-carotene production into widely grown improved varieties through transformation as well as through conventional hybridization techniques. It is anticipated that improved rice varieties containing β-carotene will become available during the next two to three years.

Strong carotenoid pigmentation was present in older wheat varieties used for bread. However, during the twentieth century, market demand drove wheat breeding to focus on the production of wheat varieties for white flour. The pigmented-type wheat varieties can be brought back into breeding programs if desired. There also are high-β-carotene maize types (yellow maize) that are high yielding. However, in many cultures, consumers prefer white maize, which lacks carotenoids and is nutritionally inferior. Education programs should be undertaken to popularize the use of yellow maize.

Cassava is an important staple food for 50 million poor people. Genetic variation in cassava roots for β-carotene content is high. Orange-colored roots have 9 to 10 times more β-carotene than white roots. There is thus an obvious advantage in popularizing the use of orange-colored varieties of cassava.

An action research project was recently implemented by the Kenya Agricultural Research Institute in Nairobi in collaboration with the International Potato Center in Lima, Peru. Orange-fleshed varieties of sweet potatoes that were both high yielding and rich in β-carotene were introduced to women farmers. The orange-fleshed sweet potatoes, both when eaten alone and when consumed as ingredients in processed foods, were highly acceptable to both producers and consumers. Using standard methods of analysis, it was demonstrated that their increased consumption contributed to the alleviation of vitamin A deficiency in case study households [14]. In sub-Saharan Africa, sweet potatoes are an important source of calories for poor people, but most of the sweet potato varieties grown there have white flesh and therefore lack β-carotene. The introduction of orange-fleshed sweet potatoes should receive priority.

Improving the amino acid balance

A human diet derived from cereal grains is deficient in some of the 10 essential amino acids, especially lysine, that are required for normal growth and development. Natural variation in the maize germplasm was exploited to develop quality protein maize (QPM) at the International Maize and Wheat Improvement Center (Mexico). The opaque 2 gene was incorporated into improved maize germplasm, and it doubled the amount of lysine and tryptophan. QPM maize varieties have been released in several countries and are now grown on almost 1 million hectares, and the area under QPM maize cultivation is also increasing.

Biotechnology approaches are also being used to enhance the lysine content of rapeseed (canola), corn, and soybean. The introduction of two bacterial genes for dihydrodipicolinic acid and aspartokinase enzymes encoded by the *dapA* gene from *Corynebacterium* and the *lysC* gene from *Escherichia coli* led to a fivefold increase in lysine in canola, corn, and soybean [15]. Similarly, the amino acid profile and total protein content of potato were improved through the introduction of the *AmA1* gene from *Amaranthus hypochondriacus* [16].

Conclusions

The use of biotechnology is proving to be important in improving germplasm to alleviate the malnutrition that affects almost half of the world's people. Linking agriculture and nutrition to promote dietary change and improve nutritional status can generate wide social as well as economic benefits.

References

1. World Bank. World development report 1997. New York: Oxford University Press, 1997.
2. Sommer A. Vitamin A status, resistance to infection and childhood mortality. Ann NY Acad Sci 1990;587: 17–23.
3. Hetzel BS. Iodine deficiency: an international public health problem. In: Brown ML, ed. Present knowledge in nutrition, 6th ed. Washington, DC: International Life Sciences Institute, 1990:308–13.
4. Cousins RJ, Hempe JM. Zinc. In: Brown ML, ed. Present knowledge in nutrition, 6th ed. Washington, DC: International Life Sciences Institute, 1990:251–60.
5. Chandra RK. Micronutrients and immune functions. Ann NY Acad Sci 1990;587:9–16.
6. Gibson RS. Zinc nutrition and public health in developing countries. Nutr Res Rev 1994;7:151–73.
7. Bouis H. Plant breeding: a new tool for fighting micronutrient malnutrition. J Nutr 2002;132:491-4.

8. Gregorio GB, Senadhira D, Htut H, Graham RD. Breeding for trace mineral density in rice. Food Nutr Bull 2000;21:382–6.
9. Goto F, Yoshihara T, Shigemoto N, Toki S, Takaiwa F. Iron fortification of rice seed by the soybean ferritin gene. Nature Biotechnol 1999;17:282–6.
10. Lucca P, Hurrell R, Potrykus I. Genetic engineering approaches to improve the bioavailability and level of iron in rice grains. Theor Appl Genet 2001;102:392–7.
11. Ortiz-Monasterio I. CGIAR micronutrient project. Update No. 3. Washington, DC: International Food Policy Research Institute, 1998.
12. Beebe S, Gonzalez AV, Rengifo J. Research on trace minerals in common bean. Food Nutr Bull 2000;21: 387–91.
13. Ye X, Al-Babili S, Kloti A, Zhang J, Lucca P, Beyer P, Potrykus I. Engineering the provitamin A (β-carotene) biosynthetic pathway into (carotenoid free) rice endosperm. Science 2000;287:303–5.
14. Hagenimana V, Low J. Potential of orange-fleshed sweet potatoes in raising vitamin A intake in Africa. Food Nutr Bull 2000;21:414-8.
15. 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.
16. Chakraborty S, Chakraborty N, Datta A. Increased nutritive value of transgenic potato by expressing a nonallergenic seed albumin gene from *Amaranthus hypochondriacus*. Proc Natl Acad Sci USA 2000;97: 3724–9.

Can biotechnology help meet the nutrition challenge in sub-Saharan Africa?

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Abstract

The successful efforts in the 1980s to redress nutrition problems in sub-Saharan Africa are being eroded. Countries in eastern and southern Africa are now facing serious food shortages because of recurrent droughts, floods, civil wars, and the concomitant growing poverty. The potential for biotechnology to alleviate hunger holds promise if the new technology can be adapted to the prevailing sociocultural context in Africa. Agronomists and biotechnologists need to work together to ensure that the biotechnology agenda for Africa is responsive to the food and nutrition needs of its people.

Key words: Biotechnology, nutrition, sub-Saharan Africa

The nutrition situation in sub-Saharan Africa is deteriorating, especially in the Greater Horn region (Somalia and Sudan). Countries in eastern and southern Africa are facing serious food shortages as a result of recurrent droughts, floods, civil wars, and the concomitant growing poverty. Thirty-three percent of children less than five years of age are undernourished, and 50% of all deaths in these children are due to mild to moderate malnutrition. These trends have been accelerating since the early 1990s and show no sign of improvement. From 11% to 30% of adults have a low body mass index as a result of inadequate seasonal food intake, intense physical activity, and parasitic infestation. The main micronutrient-related problems of concern in sub-Saharan Africa are iron-deficiency anemia and deficiencies of iodine, vitamin A, and niacin. Niacin is of concern in countries where a predominantly maize diet is consumed. Although some progress has been made with iodine deficiency, deficiencies of the other micronutrients remain a public health problem.

Diet-related chronic diseases are now also prevalent in sub-Saharan Africa. Africa thus has to deal with the double burden of diet-related chronic disorders as well as the traditional nutrition problems and infectious diseases.

Efforts to redress nutrition problems in sub-Saharan Africa were successful during the 1980s, when several countries managed to reduce the prevalence of protein–energy malnutrition. These gains were the result of multipronged strategies characterized by large-scale community-based nutrition programs that focused on growth promotion in children less than five years of age, an effective primary health-care strategy. Also implemented were food-based strategies that promoted appropriate household food security strategies as well as food distribution programs to vulnerable communities during droughts. Food fortification with micronutrients such as vitamin A and the B-complex vitamins was undertaken in the 1990s. The multisectoral dimensions of the nutrition problem were well recognized. Several countries developed national food and nutrition policies and strategies to harness the involvement of all relevant stakeholders in the fight against malnutrition.*

Sadly, the gains made in the 1980s have been largely eroded, for several reasons, including a decline in public sector investment, which has been a hallmark of economic reform programs in Africa. Nutrition improvement in sub-Saharan Africa faces many challenges, including poverty, the growing disease burden, especially that from HIV/AIDS, and deteriorating economies with concomitant reduced public sector expenditures affecting nutrition programming. Challenges to food production include the HIV/AIDS pandemic (which is reducing the numbers of productive members of communities and eroding the intellectual capital of most developing countries in sub-Saharan Africa) [1], climatic changes resulting in environmental

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* Food and Agriculture Organization /World Health Organization. Unpublished report of the Inter-country Workshop on Follow-up to the International Conference on Nutrition, 20–23 March 2001, Harare, Zimbabwe.

degradation, the high input costs of new seed varieties, and disruption from civil wars.

Can biotechnology provide some solutions to the growing nutrition problem in sub-Saharan Africa? The potential seems to be there if the technology can be adapted to the prevailing sociocultural context as well as the prevailing nutrition problems in the region. To be successful, biotechnology approaches should be implemented within the framework of existing national priorities and strategies for food security and nutrition.

There are several barriers to the adoption of biotechnology in developing countries. Some of them are based on inadequate information on the benefits and risks associated with the technology. Fears of safety and unknown consequences to health are arising in developing countries as the developed countries themselves are questioning the technology.* Unfortunately, most African countries involved in biotechnology research and development are implementing an agenda that was created outside of Africa and that is not addressing the pressing nutrition needs of African countries [2]. The issue of patents and property rights often dictates what and how biotechnology research is conducted in developing countries. The products of such research are commercialized and become inaccessible to the subsistence farmer in rural Africa who needs it the most. The level of investment in biotechnology research is beyond the means of most developing countries, whose research budgets have been declining over the years. Most biotechnology research undertaken in developing countries has been donor funded and may not be responding to the pressing problems in these countries.

The Green Revolution was adopted by some African countries, such as Kenya and Zimbabwe, in the 1960s. It doubled the maize yield, which was good for the farmer who could afford the inputs. The downside of the Green Revolution was that it resulted in a reduced food basket, because farmers focused on maize as a cash crop and abandoned the indigenous open-pollinated seeds, which could be reused and had better storage properties. Hybrid seed and other inputs have to be purchased each season. The traditionally practiced mixed cropping also served to fertilize soils through the nitrogen-fixing properties of legumes, thus reducing the need for commercially produced fertilizers. Mixed cropping has now been largely abandoned in favor of monocropping with hybrid seed varieties. The adoption of a monocropping farming system has contributed to a reduced diversity of food crops grown by farmers in Africa. To what extent has this development led to more nutritional problems? Furthermore, hybrid maize seed is softer and therefore easier to process, but it is more vulnerable to pests and has poor keeping qualities for the rural farmer who needs to be able to keep grain until the next harvest.*

Although the economic benefits of genetically modified crops to the farmer who can afford to adopt them are well documented, their ramifications on nutritional quality, their toxic potential, and their allergenic potential have been less well studied, but need to be. It should be noted that substances introduced via biotechnology occur naturally in some foods and that communities over time have found ways to deal with them.

Biotechnology has the potential for introducing some negative properties into foods that previously did not have them, and this is cause for concern. Biosafety standards and policies also need to take into account the nutritional ramifications of these genetically modified food products and to ensure that the potential benefits and risk to nutritional outcome are assessed [3].

The nutrition community in Africa needs to work together with agronomists and biotechnologists to ensure that the biotechnology agenda for Africa is responsive to the food and nutrition needs of its people. The biotechnology agenda for Africa also must take into account the challenges posed by the worsening nutrition situation, HIV/AIDS and other diseases, poverty, recurrent droughts, and environmental degradation if it is to be responsive to Africa's food and nutrition problems.

* Unpublished report on genetically modified foods and rural agriculture. Harare: Consumer Council of Zimbabwe, December 2001.

* Tagwireyi J. The green revolution in Zimbabwe: introduction of hybrid maize to subsistence farmers: a blessing or a curse? Unpublished course assignment, Cornell University, Ithaca, NY, USA, 1994.

References

1. Administrative Committee on Coordination/Sub-Committee on Nutrition. Commission on the Nutrition Challenges of the 21st Century: an agenda for change in the millennium. Geneva: ACC/SCN, 2000.
2. Brenner C. Biotechnology policy for developing countries' agriculture. OECD Policy Brief No. 14. Paris: Organization for Economic Cooperation and Development, 1997:22–4.
3. Fogg-Johnson N, Merolli A. Food biotechnology: nutritional considerations. In: Bowman B, Russell R, eds. Present knowledge in nutrition, 8th ed. Washington, DC: ILSI Press, 2001:725–32.

Food biotechnology and nutrition in Africa: A case for Kenya

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Abstract

Household food consumption surveys indicate that the diet in Kenya is ill balanced and that many families cannot afford nutrient-rich foods such as meat and fruits. In this regard, rural populations—the majority of the Kenyan population—are much worse off than urban populations. Agriculture, the most important sector in the Kenyan economy, contributes 27% of the gross domestic product and generates 65% of the country's export earnings. Food-enhancing biotechnologies thus could increase national food yields and fill nutrition gaps by contributing to household and national food security and poverty reduction in Kenya. To overcome barriers to adopting biotechnology to improve food crops in Kenya and elsewhere in Africa, policy makers must create a receptive environment for, increase public understanding of, and stimulate investment in the new technology.

Key words: Biotechnology, nutrition, Africa, agricultural productivity

In Kenya, cereals are the main source of energy, providing almost 60% of needed calories. Other main sources are bananas and tubers. The consumption of sugar and of fats and oils is negligible from the point of view of calorie sources. Caloric need is met in approximately half of Kenyan families, with considerable variation according to the area and season of the year. The caloric supply is often poorest in eastern Kenya, and famine relief is commonly undertaken in the area. Pastoralists generally have a lower calorie intake than does the sedentary population. The quantity of animal and plant protein consumed varies according to household income. Where pulses grow, consumption is often adequate to meet the protein needs of households. The intake of animal protein also varies according to family income and usually contributes 0.5% to 10% of the total protein consumed. For the population around Lake Victoria, 25% to 33% of the protein supply often is from fish. The quality of protein, expressed as protein score, is generally below 65%.

The limiting amino acids are tryptophan and those containing sulfur. The sources of riboflavin and amino acids include cereals, legumes, and fruits, the intake of which is low in all areas. The main sources of vitamin A are green vegetables, pumpkin, tomato, yellow fruits, and milk in pastoral tribes. The intake of vitamin A is estimated to be insufficient (about 30% of the recommended amounts in all areas). Niacin is obtained mainly from maize, which provides an insufficient supply to some families. The sources of vitamin C are mainly fruits and vegetables, and intakes are low in many Kenyan families. Thiamine is obtained through the consumption of cereals and legumes, and intakes are above recommended allowances in all areas. Judging from the composition of the diet, the intake of cobalamin is probably below the daily recommended allowances. Food sources of iron include cereals, legumes, and leafy vegetables.

Data from household food consumption surveys carried out in seven locations in Kenya (three provinces), excluding pastoral areas, show that the Kenyan diet is insufficient in many respects: it does not supply nutrients in the required amounts and thus is ill balanced. There are also concerns with the nutritive value of diets, because many families cannot afford meat, fruits, and other nutrient-rich foods, particularly in rural areas; thus, a good number of these families, who constitute the majority of the population, are much worse off than those in urban populations. Dietary assessment reports show that Kenyan diets are lacking in adequate energy intakes for preschool-age children, school-age children, and adult women. Intakes of other nutrients are marginal or low for most age groups, except for ascorbic acid and thiamine.

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Nutrition-related diseases prevalent in Kenya

Because of these nutritional deficiencies, Kenyan children are affected by a number of nutrition-related disorders. Protein–energy malnutrition is largely responsible for the high rate of mortality and morbidity in poor children, and the problem is particularly severe in children between one and five years of age. Severe protein–energy malnutrition in children manifests as marasmus, often in newborns to one-year-olds, with marked emaciation as the striking feature. Severe protein malnutrition manifests as kwashiorkor, which may coexist with marasmus, but which usually appears at the time of weaning. Marked swelling (edema) from the lack of protein, especially of the face, abdomen, and feet, is the main feature of kwashiorkor. Both conditions—marasmus and kwashiorkor—are also characterized by stunting, diarrhea, discoloration and sparseness of the hair, discoloration and peeling of the skin, and anemia, although all of these symptoms may not be present in every case.

Vitamin A deficiency is common during the period of rapid growth. In mild forms of the deficiency, the eye conjunctiva may show a muddy discoloration. Instead of being moist and glistening, the conjunctiva may appear dry and lusterless. A characteristic feature is that at dusk the child gropes about for food on its plate. This condition is described as night-blindness, and it can be easily treated if diagnosed at this stage. In more severe forms, the cornea loses its transparency. Still later, the cornea becomes eroded, softens, and bulges. In the final stages, the cornea is ruptured and destroyed, and the lens inside may also be lost. Once the cornea is affected, even the most energetic treatment is of no avail, and permanent blindness cannot be prevented. The disease generally affects both eyes. In some fortunate children, one eye may be affected less seriously than the other, and intensive treatment may result in partial restoration of vision in at least one eye.

One of the common nutritional disorders affecting women of childbearing age in Kenya is anemia, in most cases caused by iron deficiency resulting from malaria, parasitic diseases, or other factors or conditions. Pregnancy aggravates anemia in women, and anemia in turn may deleteriously affect the course of pregnancy. Acting either directly or indirectly, anemia is a major cause of maternal mortality in Kenya. Anemia can be prevented by consuming such foodstuffs as green leafy vegetables daily.

Other food deficiency diseases include those resulting from inadequate intakes of the B-complex vitamins. For example, nicotinic acid deficiency leads to pellagra, a disease characterized by dermatitis in skin exposed to the sun. Other manifestations include diarrhea, soreness of the tongue, and some mental disorders. Foods rich in B vitamins prevent pellagra. Whole cereals and millets such as wheat, pulses, nuts, and oilseeds are rich in riboflavin and folic acid. Rice poses some B-complex nutrition problems because its nutrient-rich husk must be removed before consumption. Parboiled rice is particularly rich in thiamine, even after milling, so it would be better for rice-eating people to cook and consume parboiled rice instead of raw rice. However, in Kenya rice is not a staple food, so problems of vitamin B deficiencies are not prevalent.

Endemic goiter was found in about 30% of 28,520 schoolchildren studied between 1962 and 1964. The highland provinces of Central, Nyanza, Western, and Rift Valley are expected to have a higher incidence than the Eastern and Coast provinces. There is no doubt that increased iodine intake can counterbalance the goitrogenic effect of thiocyanates and perchlorates, but the action of thiocarbamide derivatives cannot be prevented by iodine.

Constraints to agricultural productivity

Agriculture is the largest and most important sector in Kenya's economy, providing the backbone of the nutritional and economic well-being of the people. Agriculture contributes approximately 27% of the gross domestic product and generates about 65% of all export earnings for the country. The agricultural sector employs more than 80% of the rural population. Several studies have shown that it is the most productive sector in Kenya for investment purposes, having a growth multiplier effect of 1.64, compared with an average of 1.23 for the rest of the economy. Agricultural productivity is critical to Kenya's economic performance and the improvement of the welfare of her people.

Despite the importance of the agricultural sector, its performance in the past 10 years has been disappointing. Although increased productivity is urgently required to meet the needs of an additional 10 million people in the next 25 years, Kenya's agricultural production remains uncertain and precarious. The growth rate of the agricultural sector has declined since 1989, and at this time the rate is declining.

The stagnation of agriculture in Kenya is due to many factors, including the following:

- Because of previous divisions of the family holdings, there is not enough land to produce minimal food requirements.
- The transition period from a subsistence economy to a monetary economy has not yet established an intensive exchange of goods and trade. The production for market is small, the farmer lacks cash, and there is little stimulus to produce more than the family needs.
- The slow acceptance of effective agricultural methods is facilitated by illiteracy, mainly in the older generation.

- The production of food crops in some areas is dominated by monoculture (maize, beans, cassava, and bananas), which restricts the exchange of products and their conversion into money and conserves the monotony and unhealthy composition of the diet.
- The production of animal protein among the cultivators is limited, although there are unused reserves. The cultivation of good breeds of cattle, the exploitation of fish resources, and the breeding of small domestic animals (poultry, rabbits, etc.) are practiced at very low levels.

Other considerations that are constraining Kenyan, as well as African, agricultural performance include a shortage of arable land, inadequate rainfall, poor soil fertility, pests and diseases, and a poor technological base.

Food-enhancing biotechnologies can provide opportunities for increasing national food yields and filling nutritional gaps, thereby contributing to household and national food security and even poverty reduction in Kenya. For example, a sweet potato that is resistant to a common viral disease is being field tested in Kenya. The viral infection causes a 20% to 80% crop loss. The biotechnology-derived crop should provide larger yields (at least a 15% increase) of this nutrient-rich food. The expected increase in farmer income is US$41 million annually, with up to one million people having access to the crop. The vitamin A content of these sweet potatoes may also be increased through genetic modification.*

African countries have started investing in biotechnology research and development in the past few years. Public research institutions are already involved in projects and programs to develop specific agricultural biotechnology farm products, some of which are beginning to enter the commercial market. However, the nature of activities and levels of investment in the technology varies from one country to another and from one sector to another.

African countries can be categorized into three phases of biotechnology development. The first category consists of those that are generating and commercializing biotechnology products and services using third-generation techniques of genetic engineering (i.e., using genetically modified organisms, or GMOs). Only South Africa belongs to this category at the moment. The second category consists of those that are engaged in third-generation biotechnology development but have no products yet, such as Kenya, Egypt, Zimbabwe, and Mauritius. The third category constitutes countries engaged in second-generation biotechnology, mainly tissue culture. The majority of African countries are in this category.

Barriers to the development of biotechnology in Africa

Major constraints hinder biotechnology development in Africa. What is needed is a policy environment that encourages biotechnology development, an educational effort to improve understanding of biotechnology, and policies to stimulate investment in biotechnology.

A major challenge for most African countries is how to create a positive, receptive environment to actively take advantage of biotechnology processes and applications that will increase the marginal productivity of their capital stock without compromising the health and environmental needs of society. There is an urgent need to create an enabling policy environment for the development and use of biotechnology in Africa that addresses the concerns of producers, consumers, environmentalists, trades, and others.

Producer concerns in Africa relate to the effects of inserted genes on target production constraints, costs of inputs, increased yields, and safe handling and marketing of their products. Knowledge of these issues is needed through appropriate education based on case studies.

Consumer concerns include product safety (specifically allergenicity toxicity concerns), antibiotic resistance, and cost. There is a need to train and educate consumers on the benefits and limitations of biotechnology and to strengthen biosafety systems, i.e., make them transparent and protective of the consumer. About 90% of the population in Africa have no idea how biosafety systems work, much less whether they are truly protective and provide safety assurance.

With regard to environmental risks, the major concerns are gene flow, weediness (ability to grow where not wanted) and effects on nontargets, the creation of monocultures, and impact on biodiversity. There is an urgent need for scientists in the biotechnology sector to share their knowledge and understanding of these events with environmentalists, the public, planners, and policy makers, using case studies such as those on the monarch butterfly and the grain borer to provide assurance that society and the broader environment are not put at risk by these new technologies.

Ethical issues relate to "man playing God" and to the social and cultural leanings of peoples and societies. These are not easy to handle but can still be solved through transparency-based education.

Governments, therefore, urgently need to create policies, mechanisms, and an incentive-based structure to provide insight and education to various societal groups on these issues, because they are causing apprehension and are impeding progress on biotechnology

* Wambugu F. Virus resistant sweet potato project in Kenya. Presented at a conference on "Agricultural Biotechnology, the Road to Improved Nutrition and Increased Production," held at Tufts University in Boston, Mass, USA, November 1–2, 2001.

development and trade in Africa.

A number of issues concern the level of public understanding of biotechnology that must be addressed for the successful application and use of biotechnology in Africa. These relate to a severe lack of understanding of the technology and its potential benefits and risks, as well as the challenges of dealing with the ethical aspects of biotechnology. This lack of public understanding of biotechnology and the issues surrounding it has resulted in negative backlash in many regions in the world, especially Europe. This backlash has resulted in selective trade barriers. In Africa, where the level of understanding of biotechnology is very low, a backlash could occur relatively easily. Such a situation can be solved through improved communication and better understanding of the scientific principles that underlie biotechnology. Public perception will determine the future of biotechnology. This is very crucial in Africa, where 96% of the population is ignorant about the technology. Negative media opinion and messages from antibiotechnology activist groups are, at the moment, working tirelessly to tilt the balance against biotechnology.

With regard to policies to stimulate investment in biotechnology, most countries in Africa, except South Africa, have no articulate national frameworks on biotechnology, so clear priorities and investment strategies are lacking. Biotechnology policies need to be based on clearly articulated national priorities and goals. In the absence of identified priorities, it is difficult for these countries to make informed, long-term policies.

Another policy issue relates to the long- and short-term financing of biotechnology development. Most countries in Africa invest less than US$0.5 million a year in biotechnology, although South Africa and Nigeria are investing about US$300 million and US$26 million per year, respectively. The main challenge for these countries is to find investment capital to sustain basic biotechnology development to bring laboratory findings to commercial use. Government policies to stimulate venture capital, contract research, partnerships with the corporate sector, and other forms of financing are much needed.

A third category of policy issues relates to concerns of trade and intellectual property rights. Trade concerns include the labeling of GMO products. It is difficult to contemplate how smallholder farmers in Africa will grapple with the labeling of GMO agricultural products, given the complex nature of the marketing systems. In developed countries this is more feasible, because the process is well defined from the producer to the consumer. There is an urgent need to educate the public, policy makers, and regulators about concerns such as these while there is still time.

Issues of interstate and regional trade can be solved only if member countries share a common understanding of the biotechnology issues discussed in the foregoing. It is only through such common understanding that harmonization of seed sectors and biosafety regulations can be developed to foster interregional trade through economic blocs. In Africa these include the Common Market for Eastern and Southern Africa (COMESA), the Southern African Development Coordination (SADC), and the Economic Community of West African States (ECOWAS). There is a need in Africa for education and transparency to create knowledge and trust on interstate and interregional trade issues, including intellectual property rights.

The potential for biotechnology to improve the nutritional value of cassava

Claude M. Fauquet and Nigel Taylor

Abstract

Cassava, a starch-rich plant that has poor protein content and usually poor vitamin content, feeds about 600 million people each day. When cereals can no longer be grown because of soil fertility problems, it is often still possible to grow cassava. It is the third most important source of dietary calories in the tropics, and reliance on the crop is especially high in West and Central Africa. The International Laboratory for Tropical Agricultural Biotechnology is promoting research to improve cassava productivity and is a leader in developing genetic engineering to improve the quantitative and qualitative traits of this essential food crop.

Key words: Biotechnology, nutrition, cassava, food security

In the last 30 years an average productivity increase of 2% to 5% per year was recorded for wheat, corn, and rice in tropical countries, according to the Food and Agriculture Organization of the United Nations. In the case of food crops, the increase was considerably less: cassava recorded a meager 0.7% gain and banana plantain 0%. Biotechnology can have an impact on all crops, but the biggest impact will be on vegetatively propagated crops, especially cassava. These crops are difficult or impossible to breed, so genetic engineering and mapping offer a unique possibility of integrating useful genes without disturbing the rest of the genome and thus maintaining all of the qualities of cassava roots appreciated by farmers.

Cassava: a staple food in many developing countries

Cassava (*Manihot esculenta* Crantz), also called tapioca, yucca, manioc, and mandioca, feeds about 600 million people each day, and this number is increasing at the rate of several million per year. In many instances when it is no longer possible to grow cereals for soil fertility reasons, it is still possible to grow cassava. Africa recorded a surface increase in cassava of 46% in the last 30 years. However, the productivity of cassava, with at most 15% of its potential, is one of the lowest of the tropical food crops, so the possible gain is huge. The biotic constraints on cassava are very high: viruses are prevalent in Africa and India and are a threat in South America. It is estimated that 50 million tons of cassava are not produced because of viruses in Africa alone. Biotechnology could be very instrumental not only in solving biological and genetic problems but also in responding to farmers' needs. The International Laboratory for Tropical Agricultural Biotechnology (ILTAB) is actively working to create virus-resistant cultivars appreciated by farmers. In addition, using very simple technologies, such as virus-clean in vitro propagation, could quickly and significantly impact cassava productivity.

Although cassava is cultivated mostly for human consumption, it is also used for animal feed and plays a role in the starch industry. Most of the time the roots are used, although some populations in central Africa use the top leaves. Cassava is essentially a starch-producing and starch-storing plant, with 20% to 40% of its fresh root weight being starch. Cassava roots are very poor in protein content (less than 1%) and usually very poor in vitamins, although there are cassava genotypes in South America that are extremely rich in vitamins or have high protein content. Development of biotechnological tools would allow corresponding genes to be moved to suitable genotypes.

ILTAB, at the Danforth Center, is promoting research to improve cassava productivity in developing countries, and is a leader in developing genetic engineering for cassava. ILTAB is actively working with three other founding institutions (the Centro International de Agricultura Tropical, the International Institute for Tropical Agriculture, and the Empresa Brasileña de

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Investigación Agropecuaria [Brazilian Agricultural Research Corporation]) to establish a Global Cassava Plan, with the objective of raising interest and funds and increasing activities on cassava to move it from an orphan crop to an industrial crop and to better feed many millions of poor farmers and others.

The cassava crop: central to food security and microeconomics in the tropics

After rice and maize, cassava is the most important source of dietary calories in the tropics and is a central factor in food security for many of the world's poorest regions. Although Amazonian in origin, cassava is now cultivated for its starchy storage roots and leaf tissues in 100 countries worldwide and is consumed by an estimated 600 million people daily. Africa is the world's largest cassava-producing continent, accounting for 65% of the 16 million hectares cultivated worldwide and 55% of the 160 million metric tons of cassava roots harvested in 2000. Reliance on the crop is especially significant in West and Central Africa, where production can be as high as 300 kg per person per year and where, in some regions, the total area cultivated in cassava is up to 10 times greater than that of all cereals combined.

Cassava will play an increasingly important role in supplying the growing urban centers in tropical countries with low-cost food products. Fresh and processed cassava products are traded in local markets throughout the tropics, thereby generating cash for resource-poor farmers. Industrial-scale cassava plantations are well established in Thailand and are being developed in Latin America to supply the animal feed industry.

Nutritional value of cassava

Cassava is cultivated primarily for its roots, although some cultures also consume the young leaf tissues. Reports of the nutritional content of cassava products vary owing to the cultivars, the age of the plant analyzed, and the processing technologies employed. Representative values are provided in table 1.

Consumers whose diets are heavily based on cassava roots run the risk of malnutrition because of insufficient protein intake. This is especially prevalent in recently postweaned children, who are at risk of developing kwashiorkor. Poverty and low purchasing power, which limit access to quality foods to supplement a cassava-rich diet, are the underlying problem, not the crop itself.

The toxic potential of cassava is not a health issue for consumers. Cassava is infamous for containing cyanogenic glycosides, which can release hydrogen cyanide (HCN) into the body after mastication and ingestion. However, some facts regarding cassava and cyanide are that HCN compounds are an essential plant defense component, postharvest processing of roots and leaves reduces toxicity to below harmful levels, billions of people have consumed cassava over millennia without adverse effects, and HCN in cassava is problematic only when consumers are in poor health and processing is inadequate, for example, during drought, famine, and social disruption.

Opportunities for biotechnology to enhance the nutritional content of cassava

Because conventional breeding is problematic in cassava, the direct introduction of desirable characteristics through genetic engineering holds great potential for improving quantitative and qualitative traits in this essential food crop. However, the challenges are significant. Table 2 lists some desirable characteristics that might be introduced in cassava by genetic engineering, along with the challenges of meeting these short- and long-term goals.

Deploying cassava with enhanced nutritional qualities will be problematic. To improve the nutrition of large numbers of people, nutritional traits will have to be inserted into many (20 to 23) cassava cultivars,

TABLE 1. Nutritional content of cassava per 100 g of product[a]

Cassava product	Energy (kcal)	Protein (g)	Iron (mg)	Vitamin A (mg)	Vitamin C (mg)	Niacin (mg)	H_2O (%)	Fiber (g)
Root (peeled raw)	150	1.0	1.0	—	34	0.7	60	1.0
Root, dried (flour)[b]	340	1.5	2.0	—	0	0.8	12	1.5
Leaves (raw)	90	7.0	7.6	2	310	2.4	70	4.0
Leaves (dried)	190	32.5	8.0	—	—	—	27	—

a. Cassava tubers are an excellent source of carbohydrate, but they are poor in protein, vitamins, and nutrients. Processing methods (chipping and drying, soaking, and fermenting) all influence the nutritional content of processed cassava products, but detailed information is lacking. Cassava leaves are an excellent source of iron and protein, providing eight essential amino acids, and combining cassava roots and leaves provides the basis of a balanced diet.

a. Approximately 5 kg of raw peeled tubers are required to produce 1 kg of cassava flour.

and these will have to be distributed to farmers (6,000 cassava stakes are required per hectare). For farmers to adopt the improved cultivars, the plant material will need to have other, more obvious agronomic benefits, such as virus resistance. This will increase the challenge to biotechnologists

Table 2. Nutritional goals for genetically modifying cassava

Goal	Associated challenges
Ongoing and near future	
Enhance protein content of roots	Ensure an appropriate amino acid balance; ensure the nonallergenic nature of the new protein; direct the storage protein to food parts, e.g., root core, not the peel; new protein must not be destroyed or washed out during processing
Enhance vitamin A content of roots	Ensure that the vitamin survives processing and does not affect cooking qualities and palatability
Elevate iron content of roots	Direct the iron to the roots, not the leaves (which already have a high content); ensure that the elevated iron will not be destroyed or washed out during processing
Modify starch quality	The major benefits should be to the starch industry, not the small farmer
Reduce cyanogenic content of roots	May have detrimental effects on pest resistance
Longer-term goals	
Elevate dry-matter content of roots	Manipulate the source and sink (make the plant store more compounds in the root system) in the plant to direct more energy to the root system
Elevate folic acid in roots	Target the folic acid to the roots; ensure its stability during processing
Produce glutenins in roots to enhance bread-making capacity of cassava	This is a technically difficult challenge—will the cassava starch complex with glutenins?—and there are allergenic concerns

Research and development of transgenic plants in Malaysia: An example from an Asian developing country

Marzukhi Hashim, Mohamad Osman, Ruslan Abdullah, Vilasini Pillai, Umi K. Abu Bakar, Habibuddin Hashim, and Hassan Mat Daud

Abstract

In 2000, agriculture contributed 13% to the national gross domestic product of Malaysia. The country of 23 million people has created a competitive program coordinated by the Ministry of Science, Technology and the Environment, research institutions, and universities to undertake biotechnology research in several areas. Intensified research efforts are under way on oil palm, rubber, rice, papaya, and orchids. Although the most progress has been made in rice and papaya, no transgenic crop is ready for field trials. Nonetheless, preliminary steps have been taken to prepare for the trials, and detailed testing protocols are being developed.

Key words: Biotechnology, transgenic plants, Malaysia

The production of transgenic crops that have higher yields, are more nutritious, and have greater resistance to pests, diseases, and adverse environmental conditions heralds a revolution in crop improvement. Transgenic technology offers the opportunity to develop better crops beyond species boundaries with unprecedented power and precision. It also greatly extends our understanding of crop biology and provides us with cutting-edge tools to improve crops and ensure bountiful harvests beyond the conventional means.

Current status of transgenic crops in the world

In 1999, approximately 40 million hectares of transgenic crops were grown worldwide (excluding China), about 72% of which were in the United States. The other major growers were Argentina (17%), Canada (10%), and China, with significant expansion in Australia and South Africa. Between 1996 and 2000, 12 countries—eight industrial and four developing—contributed to a more than 20-fold increase in the global area planted in transgenic crops. As a result of intensive biotechnological research worldwide, many potential transgenic crops are now in the pipeline and are being tested in contained experiments, either in laboratories and greenhouses or in field trials. The markets of countries that have not yet planted transgenic crops have probably already received products from transgenic crops from other countries.

The seven most important transgenic crops grown commercially in 1999 were soybean, corn/maize, cotton, canola/rapeseed, potato, squash, and papaya. Transgenic soybean and corn continued to be ranked first and second in terms of the global area planted in transgenic crops.

The relative ranking of the major transgenic traits in 1999 was essentially the same as that in 1998: herbicide tolerance was the highest, at 71% of the global area, followed by insect resistance, at 22%. The use of stacked genes for insect resistance and herbicide tolerance in both corn and cotton recently increased significantly in the United States.

Transgenic crops in Asian developing countries

China is one of a handful of developing countries in Asia that have advanced in biotechnology research, field release, and commercialization of genetically modified organisms (GMOs). In recent years, China has intensified its research on transgenic crops and has made tremendous progress in adopting and commercializing them. In fact, China currently is the first and the only Asian country that is planting transgenic crops commercially on a large scale. Six transgenic crops granted

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Mention of the names of firms and commercial products does not imply endorsement by the United Nations University.

licenses for commercialization in 1999 were dominated by Bt cotton from the Chinese Academy of Agricultural Science and Monsanto, transgenic tomato from Beijing University and CCAU, and transgenic petunia and sweet pepper from Beijing University. Of these six crops, Bt cotton was planted on more than 350,000 hectares during 1999 and 2000 [1].

Intensive and advanced biotechnological research on local crops is being carried out in 5 of the 10 ASEAN countries—Singapore, Malaysia, Thailand, the Philippines, and Indonesia—while the other 5 are still at earlier stages of biotechnology.

Several ASEAN countries, for example, Thailand and the Philippines, have field-tested GMOs. Thailand is currently participating in the International Rice Genome Consortium project to sequence chromosome 9 of the Nipponbrae rice genome and is field testing Bt cotton and Bt corn and the Flavr Savr tomato [2]. Indonesia is reported to have commercial field release for Bt cotton in Sulawesi. Malaysia at the moment has not approved any field trial or commercial transgenic crops in the field; however, field trials of papaya ring spot virus–resistant papaya and tungro-resistant rice are expected in the near future, after enough seeds have been acquired and approval by the Genetic Modification Advisory Committee has been secured.

Malaysian agriculture and biotechnology

Agriculture

Located in the tropics, Malaysia, with a population of more than 23 million, consists of two major land masses straddling the South China Sea: Peninsular Malaysia and East Malaysia (Sabah and Sarawak on the island of Borneo). The country has an area of 330,000 km^2, with 138,000 km^2 in Peninsular Malaysia and the remainder in Sabah and Sarawak.

Malaysia covers a total of 33.06 million hectares of land, of which 7.15 million, 3.15 million, and 4.45 million hectares are estimated to be suitable for agriculture in Peninsular Malaysia, Sabah, and Sarawak, respectively. The sector is dominated by plantation crops, of which oil palm (2.0 million hectares) is the major crop, followed by rubber (1.2 million hectares) and cocoa (< 0.4 million hectares). Of the food crops, the area grown in rice is the largest, followed by fruits and vegetables.

Although agriculture was traditionally the most dominant sector in Malaysia, it has been supplanted by the rapidly expanding industrial and service sectors. Agriculture contributed 29% to the national gross domestic product in 1970, but it declined to 14.8% in 1994 and is estimated to have dropped to 13% in 2000.

Research on biotechnology

Intensified research on priority areas (IRPA) programs

Under the competitive IRPA program managed and coordinated by the Ministry of Science, Technology and the Environment, research institutions and universities undertake research on biotechnology in many scientific areas. Research is carried out as experimental, applied, or prioritized research or as strategic research projects. Top-down IRPA projects (both prioritized research and strategic research) are multi-institutional projects accorded very high priority because of their national importance.

Research on agricultural commodities is carried out by various research institutions: research on oil palm by the Malaysian Palm Oil Board; rubber by the Malaysian Rubber Board; cocoa by the Malaysian Cocoa Board; and rice, fruits, vegetables, and other crops by the Malaysian Agricultural Research and Development Institute. Many of these projects are complemented by research carried out by universities and other institutions.

As an integral program to enhance the productivity of these important crops, research on biotechnology has been given emphasis in such areas as genetic engineering for plant improvement, molecular marker technology, plant cell culture/bioreactor systems, and in vitro technology.

Research priorities

Although it is extremely difficult to develop research priorities, owing to limited resources and institutional crop mandated assignments, the following crops/plants with target traits have been recommended (quoted here from the Seventh Malaysia Plan) [3]:

- Oil palm: oil quality, secondary plant products
- Rubber: disease resistance, yield, production of high-value products
- Rice: disease resistance, yield
- Ornamentals: senescence, flower color, disease resistance
- Fruits: shelf-life, disease resistance, fruit quality
- Cocoa: insect and disease resistance, butter content, and cocoa flavor
- Forest species and medicinal plants: nutraceutical and pharmaceutical products

In the development of transgenic crops and genes of interest (see table 1) in the country, intensified research has been carried out in the following crops:

- Oil palm (Malaysian Palm Oil Board, Universiti Kebangsaan Malaysia)
- Rubber (Malaysian Rubber Board)
- Rice (Malaysian Agricultural Research and Development Institute [MARDI])
- Papaya (MARDI)
- Orchid (MARDI, Universiti Putra Malaysia)

TABLE 1. Current status of transgenic plant development in Malaysia

Crop and objectives	Gene of interest	Status
	Rice (MARDI)	
Resistance to rice tungro spherical virus (RTSV)	Coat protein and polymerase genes of RTSV	Stable (Taipei 309) transgenic lines, T147-3 and T147-4, carrying truncated and full-length polymerase genes, respectively [4]
Resistance to rice tungro bacilliform virus (RTBV)	Coat protein and polymerase of RTBV [5]	Transformation and screening ongoing
Resistance to sheath blight disease (Rhizoctonia oryzae)	Chitinase gene[a] [6]	Transformation and screening ongoing
Tolerance to herbicides	BAR gene [7]	Transformation and screening ongoing
Resistance to insects	Bt gene[a]; cowpea trypsin inhibitor (CPTi)[a]	Transformation and screening ongoing
	Papaya (MARDI)	
Resistance to papaya ring spot virus (PRSV)	Coat protein of local isolates of PRSV [8]	Transgenic plants obtained, in tissue culture; ready for greenhouse screening[b]
Improved shelf-life	ACC oxidase gene (antisense) [9]	Transgenic plants went for a field trial in March 2002[b]
	ACC synthase gene	Transformation ongoing [9]
	Oil palm (MPOB and UKM)	
Oil quality improvement	Stearoyl-ACP desaturase and β-keto-acyl synthase 1	Transformation system developed [10–12]
Herbicide tolerance		Transformation system developed [13]
Insect resistance	CPTi[a]; Bt gene[a] [14-16]	Transgenic plants obtained (4½ yr old), in planthouse; ready for screening [1, 14–16]
Fungal resistance (Ganoderma)	Chitinase[a] [14–16]; RIP[a]	Transgenic plants obtained (3 yr old), in planthouse; undergoing screening [15, 16]
	Rubber (MRB)	
Specific proteins (e.g., pharmaceuticals)	—	Transformation system developed [17, 18]
	Orchid (MARDI and UPM)	
Resistance traits	—	—
Improved flower color	Chalcone synthase (CHS)	Gene construct prepared [19]
Improved shelf-life	Flavanone-3-hydroxylase (F3H)	
	ACC oxidase [20]	Transformation ongoing

a. R. Ruslan, personal communication, 2002.
b. Potential breakthrough and applications for field trials are subjected to approval by the Genetic Modification Advisory Committee.
Abbreviations: MARDI, Malaysian Agricultural Research and Development Institute; MPOB, Malaysian Palm Oil Board; UKM, Universiti Kebangsaan Malaysia; MRB, Malaysian Rubber Board; UPM, Universiti Kebangsaan Malaysia.

The National Biotechnology Directorate, the Plant Biotechnology Cooperative Centre, and the National Biotechnology and Bioinformatics Network

An important event in the development of biotechnology in Malaysia was the establishment in 1995 of the National Biotechnology Directorate (NBD), a division of the Malaysian Ministry of Science, Technology and the Environment. The mission of NBD is to spearhead the development of biotechnology through research and related activities directed at the commercialization of biotechnology and to establish Malaysia as the leading center for the biotechnology industry.

To facilitate and enhance biotechnology efforts, NBD established seven specialized centers known as Biotechnology Cooperative Centres (BCCs): the Plant

BCC, Animal BCC, Food BCC, Biopharmacy BCC, Environmental/Industrial BCC, Molecular Biology BCC, and Medical Biotechnology BCC.

NBD also set up the National Biotechnology and Bioinformatics Network to develop an efficient biotechnology community for bioinformatics and biotechnology applications using the latest computer technology. The network uses a wide-area network to link BCCs and other biotechnology research centers nationwide, enabling biotechnology researchers to share information pertaining to their research and otherwise promoting interactions and communications among the individual research centers.

Research and development on transgenic plants

Crops being researched

The crops that are being intensively researched include oil palm by the Malaysian Palm Oil Board as the anchor institution, rubber by the Malaysian Rubber Board, rice and papaya by MARDI, and orchids by MARDI and the Universiti Putra Malaysia.

Although some research projects, such as those on rice and papaya, have almost completed transgenic development, there is as yet no transgenic crop candidate that is about to go into field trials. However, in anticipation of such an eventuality, steps have already been taken to familiarize scientists with applications and protocols for field testing transgenic crops (e.g., papaya), biosafety regulations, and biosafety concerns relating to transgenic crops and products* [21]. As a significant development for research, a transgenic greenhouse was constructed in MARDI early last year, and it is expected to be ready for use by this year. More funding was approved in 2001 for another transgenic testing greenhouse.

Potential breakthroughs

Of the five crops that are in different stages of transgenic development, two, papaya and rice, have reached an advanced stage of transgenic development from which breakthroughs could be possible in the near future. These two crops are followed closely by oil palm and orchids.

Papaya. At the beginning of the papaya research, researchers successfully cloned the ripening-related 1-amino-1-cyclopropane carboxylic acid (ACC) oxidase gene from *Eksotika papaya* and made an antisense gene cassette for plant transformation [9, 22]. They also developed an efficient transformation system for *E. papaya* using particle bombardment and successfully produced transformed papaya lines containing the antisense ACC oxidase gene [23, 24].

Transformation of papaya with the antisense ACC oxidase gene construct, *pCaPACO1AS*, was by the biolistic method. Molecular and biochemical characterizations were performed on the six most mature plants kept in the greenhouse.

Because papaya cannot fruit in the greenhouse, a contained field trial has to be conducted for fruit-ripening analysis. In the contained field trial, transformed plants will be grown and maintained under a netted structure. Only the roots will be in direct contact with the environment, whereas the other parts of the plants, including the pollen, will be contained. The trial will be for a "proof of concept." Nontransformed lines will be grown in border rows as controls.

The field trial application will be submitted to the Malaysian Genetic Modification Advisory Committee for approval soon after the data on gene copy number have been obtained. Funding has just been received from the International Service for the Acquisition of Agri-biotech Applications for the construction of a net house. Construction is expected to be completed by early 2002. The location will be in Mardi Serdang, an area that is free of papaya ring spot virus.*

Protection against papaya ring spot virus by coat-protein-mediated resistance has been shown to be strain specific [25]. To overcome this, a gene from a local isolate of the virus was isolated, and the construct was deployed in papaya transformation [8, 26]. Resistance tests will be done initially on segregating R_1 progeny and confirmed on the homozygous R_2 population.**

Rice. At present, the transgenic rice plant that confers pathogen-derived resistance to rice tungro spherical virus via polymerase genes has been advanced for several generations and is ready to be field tested [4]. However, this transgenic plant has been developed on Taipei 309, a japonica type that may not be agronomically suitable in the Malaysian environment. An attempt has been made to cross this transgenic japonica line with local indica lines. Progenies of this cross have

* Chan YK. Case study of proposed field releases of a virus resistant transgenic papaya in ASEAN region. Presented at the ASEAN Regional Workshop on Biosafety of Genetically Modified Organisms (GMOs), Kuala Lumpur, April 24–26, 2000.

* Abu Bakar UK, Vilasini P, Pauziah M, Lam PF, Chan YK, Hassan MD. Molecular and biochemical characterisations of *Eksotika papaya* plants transformed with antisense ACC oxidase gene. Presented at the Papaya Biotechnology Network of SEAsia Coordination Meeting, Hanoi, Vietnam, October 25–26, 2001.

** Vilasini P, Hassan MD, Flasinski S, Kaniewski WK, Ong CA, Chan YK. Presented at the Papaya Biotechnology Network of SEAsia Coordination Meeting, Hanoi, Vietnam, October 25–26, 2001.

the transgene and indicate that the transgene is inherited in a Mendelian ratio [27]. However, individuals with the transgene, which was positively confirmed by polymerase chain reaction, failed to express their resistance after being challenged with the virus and tested by enzyme-linked immunosorbent assay.

Work is now being carried out to produce transgenic rice resistant to rice tungro bacilliform virus, another form of the virus that is more destructive than the spherical virus. Both the coat protein (C. A. Ong, personal communication, 2002) and the protease genes [28] have been successfully cloned.

Oil palm, orchids, and rubber. Most research work on the transgenic development of crops other than rice and papaya is in the early developmental stages.

Transgenic palm oil plants with different model transgenes have been obtained [13, 14], namely, those with resistance to hygromycin, β-glucuronidase activity, and herbicide (Basta) resistance. Molecular analysis and physical screening confirmed the expression of the transgenes in the regenerated plants, obtained by both *Agrobacterium*-mediated and direct DNA transfers through particle delivery systems. Recently, Rashdan and Abdullah [16] and Abdullah et al. [29] reported significant progress with *Agrobacterium*-mediated transformation of chitinase into oil palm, and transgenic and chimeric oil palm plants carrying the cowpea trypsin inhibitor gene were found to be resistant to bagworm larvae.

Genes of the fatty acid biosynthetic pathway of the oil palm have been cloned, characterized, and used for gene construction. Vectors have been constructed with inserts of stearoyl-ACP (acyl carrier protein) desaturase and β-keto-acyl synthase 1 genes for oil palm transformation [30], and the isolation and characterization of cDNA clones encoding for oil palm thioesterase have been reported [10].

To date, orchid transformants (var. *Dendrobium*) with the objective of prolonged shelf life have been recovered in MARDI, but these transformants will need 1½ to 2 more years to flower to permit shelf-life analysis. Work by Universiti Putra Malaysia to effect color change in var. *Dendrobium* is still ongoing (U. K. Abu Bakar, personal communication, 2002).

For rubber, Arokiaraj et al. [17, 18] have established a protocol for gene transfer and plant regeneration technology using genes resistant to β-glucuronidase activity and kanamycin. One primary goal is to produce commercially valuable proteins by transgenic rubber trees. Taking advantage of the fact that the rubber tree yields copious latex when tapped, transgenic trees would become natural living factories for the production of foreign protein such as pharmaceuticals and proteins used in personal care products. By using the transformation systems that have been developed, it is hoped that such protocols can be used to incorporate any gene of interest into rubber.

Research and development problems encountered in transgenic crops

Based on our experience, the following problems have been encountered in the course of developing transgenic crop plants, and these need to be addressed.

Research

Regeneration problems, specifically for indica rices, papaya, and oil palm

Failure to obtain sufficient numbers of successful transgenic plants occurs because of the genotype specificity of the protocol, especially for rice and papaya [31]. Some local indica rice varieties (e.g., MR 81) could be successfully transformed with foreign genes and regenerated [7, 32], whereas efforts with other MR varieties have encountered difficulties in regeneration to produce enough R_0 individuals for selection and screening. This problem has been highlighted elsewhere [33].

Gene silencing and expression

The results from several research activities, for example, in rice, indicated the presence of transgenes and confirmed their Mendelian inheritance; however, these transgenic plants failed to express the specific target trait(s). Perhaps this is related to the problem of gene silencing and expression.

Resistance traits conferred by location-specific pathogens (biotypes, pathotypes, etc.)

In the development of resistance traits in transgenic plants, there are instances in which location-specific pathogens become very relevant, such as for papaya, because readily available foreign genes for resistance may not be effective.

Availability of construct's components

For various reasons, researchers sometimes confront problems and delays in procuring components of specific construct(s) for their work.

Transparency in biotechnology research techniques

As in most research work, researchers are not always willing to disclose and share their techniques with other colleagues, and these techniques may be very useful for transgenic development. This is understandable, since they may not want to lose the rights to patent their new findings. Although this may not be a critical problem, it can slow down research and increase "reinventing of the wheel" work.

Infrastructure

Insufficient number of scientists and inadequate research support

In general, there is a lack of a critical mass of scientists and research support needed to develop transgenic crops in Malaysia. To make matters worse, researchers in research and development institutions, such as the Malaysian Palm Oil Board, the Malaysian Rubber Board, and MARDI, and those in universities are confined to working on mandated crops. This limits the pool of expertise available to work on problems outside of their respective institutional mandated crops. There is also a need to train more scientists to provide more research support [21].

Limited knowledge of the molecular and plant biotechnology of local crops

With the exception of rice, there is little plant biotechnology research conducted outside the country on local crops important to the Malaysian economy. This leads to limited availability of construct elements (e.g., genes, promoters, enhancers, terminators, and other DNA sequences) and of scientific literature on crops such as oil palm and rubber [21].

Research and development funding for transgenic crops

Since the creation of the NBD in 1995, the amount of funding for research on biotechnology, including transgenics, has increased significantly. In 1996, there was a total research and development expenditure of US$144.5 million in 15 fields of research, and of this, US$32.3 million, or 22.4%, was for the biological and agricultural sciences. In the five-year-plan period 1996–2000, more than US$13.0 million was allocated for biotechnology (US$1 is equivalent to RM [ringgit Malaysia] 3.8).

Biosafety

The responsibility for regulating GMOs in Malaysia lies in the Ministry of Science, Technology and the Environment, the National Biodiversity Committee, the Genetic Modification Advisory Committee, and the Institutional Biosafety Committee.

Cartagena protocol on biosafety and the biosafety bill

After the derailment of the Cartagena Protocol on Biosafety in 1999, many countries, particularly developing countries, including Malaysia, began tightening their controls and undertook policy, legislative, and administrative measures to regulate the transboundary movement, handling, and use of GMOs and to minimize their adverse effects on the environment and on human health.

Malaysia, a signatory to the protocol, has international obligations on biosafety issues with regard to laboratory tests, field trials, and commercialization. As one of the world's most biodiverse countries, Malaysia is cognizant of the fact that GMOs may have adverse impacts on the conservation and sustainable use of biodiversity.

Together with many other countries, Malaysia signed the Cartagena Protocol on Biosafety at the Fifth Meeting of the Conference of Parties to the Convention in Nairobi, Kenya. After a number of national consultative discussions in 2001, Malaysia finalized a draft law on biosafety (referred to as the Biosafety Bill). The Biosafety Bill regulates and manages the importation, deliberate release into the environment, market approval, and contained use of GMOs and products thereof. It is expected to be passed by the Parliament in 2002.

Genetic Modification Advisory Committee (GMAC)

The Ministry of Science, Technology and the Environment established the Genetic Modification Advisory Committee (GMAC) with the objectives of ensuring that any risks associated with genetic modifications and GMOs arising from such activities be identified and safely managed, and of advising the government about matters of genetic modification. GMAC is also responsible for the assessment of proposals on the planned release of GMOs into the environment. Malaysia has been proactive in its regulatory activities: GMAC formulated National Guidelines for the Release of Genetically Modified Organisms (GMOs) into the Environment, which were officially issued by the Minister of Science, Technology and the Environment in January 1997 [34].

To date, only one application for the release of a GMO has been received by GMAC. This was for the importation into Malaysia of the glyphosate-resistant Roundup Ready soybean from Monsanto for food and feed. Notwithstanding that the application was for food and feed and not for planting, a cursory assessment of the likely impact of the GMO on the environment was nonetheless carried out. Since Malaysia is neither the center of origin nor the center of diversity for soybeans, coupled with the fact that soybeans are not cultivated widely in the country, the likelihood that it would cause harm to the environment was considered to be very low [33].

National Guidelines for the Release of Genetically Modified Organisms (GMOs) into the Environment

The guidelines were issued in 1997 to cover all GMOs (including plants, animals, microbes, etc.) at all stages of research and development, use, handling, transboundary movement, release, and placing in the market of GMOs and products containing GMOs, and to address biosafety issues in biotechnology such as risk assessment, risk management, and monitoring. The guidelines were based on those of the United Nations Environment Programme. According to the guidelines, risk assessment is conducted based on the precautionary principle and on a case-by-case basis, and considers all related social, religious, and ethical issues. The guidelines were developed to promote biotechnology and not to hamper it, and they are intended to be dynamic and flexible. To ensure compliance, many relevant elements have been incorporated into the biosafety bill.

Institutional Biosafety Committee

The establishment of a biosafety committee within an institution is vital in providing a focal point for the overall monitoring of genetic modifications and the execution of the national guidelines. Committee members are not involved in the review or approval of their own research projects or of commercial applications.

Public awareness and acceptance of transgenic crops or products

There has been a great deal of controversy about the introduction of genetically modified crops and foods. Many people the world over are concerned that genetically modified crops could have harmful effects on human health and cause irreversible damage to the environment.

Transgenic soybean has been available in Malaysia since GMAC approved its importation in 1997, and since then there have been calls from consumers to ban its import. It has been decided, however, that there will be no moratorium on its import until findings to the contrary are made with regard to its safety for human health.

There has been a significant effort to increase public awareness of GMOs via television and radio programs, newspapers, public forums, discussion groups, task forces, and committees in which scientists, nongovernmental organizations, consumers, and others participate. In April 2000, the Ministry of Science, Technology and the Environment organized the ASEAN Regional Workshop on the Biosafety of Genetically Modified Organisms, in Kuala Lumpur, with the participation of ASEAN delegates.

In view of concerns raised about transgenic crops—concerns that have exceeded, in scope, actual experience with their use—and criticisms of the regulatory process and controls, it is pertinent that steps be taken to clarify the regulatory process and controls. All transgenic crops carry risks and benefits to a greater or lesser extent. Whether consumers accept or reject transgenic crops or products very much depends on their confidence in risk assessment and risk management and in the regulatory process itself.

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References

1. Mohamad O, Habibuddin H. Transgenic crops in ASEAN countries and China. In: Saad MS, Faridah QZ, Kadir MA, Khalid MZM, Mohamad O, Saleh GB, Panadam JM, eds. Genetic manipulation: challenges. Proceedings of the Fourth National Congress on Genetics. Kuala Lumpur: Genetics Society of Malaysia, 2000:246–61.
2. Sutat S. Thailand Biotechnology Strategy Program. In: Proceedings of the ASEAN Regional Workshop on Plant Biotechnology, Bangkok, Thailand, October 5, 2000. Bangkok: Institute of Nutrition, Mahidol University (INMU) and the National Center for Genetic Engineering and Biotechnology (BIOTEC), 2000:38–49.
3. Seventh Malaysia Plan 1996–2000. Kuala Lumpur: Percetakan Nasional Bhd., 1996.
4. Ong CA, Fauquet CM, deKochko A, Huet H, Sivamani E, Beachy RN, Hassan MD. Genetic engineering for rice tungro resistance—a Malaysian experience. In: Proceedings of the General Meeting of the International Program on Rice Biotechnology, Malacca, Malaysia, September 15–19, 1997. Rockefeller Foundation, 1997:348.
5. Ong CA, Siti Mariam O, Tan CS. Nucleotide sequence of the coat protein gene of two isolates of rice tungro bacilliform virus. In: Proceedings of the 10th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1998:226.
6. Zulkipli MS, Hamidah G, Naziah B, Rosmawati MS, Nik Aziah NA, Marzukhi H, Hassan MD. Production of transgenic indica rice with chitinase gene. In: Proceedings of the 11th National Biotech Seminar. Kuala Lumpur: MOSTE, 1999:385–6.
7. Hamidah G, Zulkifli AS, Hassan MD, Naziah B. Regeneration of transgenic plants of rice (*Oryza sativa* L.) via *Agrobacterium tumefaciens*-mediated transformation of embrogenic calli. In: Proceedings of the 10th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1998:241.
8. Vilasini P, Chan YK, Hassan MD, Lam PF, Ong CA, Tan CS, Umi Kalsom AB. Development of improved variety of *Eksotika papaya* using conventional and non-conventional methods. In: Larkin PJ, ed. Proceedings of the 4th

Asia-Pacific Conference on Agricultural Biotechnology. Fyshwick, Canberra, Australia: CPN Publications, 1998: 359–61.
9. Abu Bakar UK, Lam PF. Isolation and characterisation of ACC oxidase cDNA clones from Eksotika II papaya fruit. In: Ghazali HM, Yusoff KM, Mahmood M, eds. Proceedings of the 8th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1996:115–7.
10. Farida HS, Arni M. Isolation and characterisation of cDNA encoding oil palm thioesterase genes. In: Dean JFD, ed. 5th International Congress of Plant Molecular Biology, September 21–27, 1997. Singapore: Kluwer Academic Press, 1997: Abstract 707.
11. Farida, HS. Genetic engineering of oil palm. In: Proceedings of the 10th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1998:33.
12. Jalani BS, Cheah SC, Rajanaidu N. Genetic breakthroughs and new frontiers in oil palm breeding. In: Proceedings of the 3rd National Congress of Genetics. Kuala Lumpur: Genetics Society of Malaysia, 1998:2–22.
13. Parveez GKA, Harikrishna K, Christou P. Production of herbicide resistant transgenic oil palm (*Elaeis guineensis* Jacq.) plants via microprojectile bombardment. In: Larkin PJ, ed. Proceedings of the 4th Asia-Pacific Conference on Agricultural Biotechnology. Fyshwick, Canberra, Australia: CPN Publications, 1998:322.
14. Ruslan A, Alizah Z, Wee YH, Siti Zubaidah S, Muhammad Rashdan M. The development of genetic transformation methods for oil palm improvement. In: Dean JFD, ed. 5th International Congress of Plant Molecular Biology, September 21–27, 1997. Singapore: Kluwer Academic Publishers, 1997: Abstract 336.
15. Ruslan A, Yeun LH, Rashdan MM, Joseph JL, Yap WSP, Chari C, Siti Azma Y, Lee MP, Ridwan AR, Leaw CL, Lee GF. Current status of genetic engineering of oil palm for pest and disease resistance. In: Proceedings of the Asia Pacific Conference on Plant Tissue Culture and Agribiotechnology. Singapore: National University Singapore, 2000:88.
16. Rashdan MM, Abdullah R. *Agrobacterium*-mediated transformation of chitinase into oil palm (*Elaeis guineensis* J.). In: Proceedings of the 10th Scientific Meeting of Malaysian Kuala Lumpur: Society for Molecular Biology and Biotechnology, 2000:47.
17. Arokiaraj P, Hafsah J, Cheong KF, Jafri S, Chew NP, Yeang HY. Sustained activity of inserted GUS gene over four vegetative generations of transgenic Hevea. In: Zulkiflie Z, Wan KL, eds. Proceedings of the 9th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1997:59–63.
18. Arokiaraj P, Yeang HY, Cheong KF, Hamzah S, Jones H, Coomber S, Charlwood BV. CaMV 35S promoter directs β-glucuronidase expression in the laticiferous system of transgenic *Hevea brasiliensis* (rubber tree). Plant Cell Rep 1998;17:621–5.
19. Manickam S, Ong WK, Abdullah S, Harikrishna K, Maziah M, Umi Kalsom AB. The cloning and characterization of floral pigmentation genes from *Oncidium* spp. In: Proceedings of the 11th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1999:1–4.
20. Hasnida H, Umi Kalsom AB, Vilasini P, Mohd Shaib J. Genetic engineering to increase the shelf life of *Oncidium goldiana* flower. In: Proceedings of the 11th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1999:428–9.
21. Hassan MD. Priority setting in plant biotechnology. In: Research priority in biotechnology. Kuala Lumpur: National Biotechnology Directorate, 1999:1–13.
22. Umi Kalsom MB, Abu Bakar UK, Khairun N, Tan CS. Isolation and characterisation of ACC oxidase cDNA clone in senescing *Phalaenopsis* flower. In: Proceedings of the 11th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1999:409–11.
23. Abu Bakar UK, Otheman Z, Bahari UM. Cloning and characterisation of two differentially expressed ACC oxidase genes from pineapple. In: Proceedings of the 12th National Biotechnology Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 2000:485–6.
24. Pillai V, Abu Hassan AH, Talib SS, Jaafar MS, Abu Bakar UK. An efficient transformation for Malaysian orchids. In: Proceedings of the 12th National Biotechnology Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 2000:421–2.
25. Tennant PF, Gonsalves C, Ling KS, Fitch MMM, Manshardt R, Slightom RL, Gonsalves D. Differential protection against papaya ring spot virus isolates in coat protein gene transgenic papaya and classically cross-protected papaya. Phytopathology 1994;84:1359–66.
26. Hassan MD, Noorshinah H. Designing primers for cloning of papaya ring spot virus coat protein gene. In: Ghazali HM, Yusoff KM, Mahmood M, eds. Proceedings of the 8th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1996:172–5.
27. Habibuddin H, Ong CA, Marzukhi H, Hassan MD. Inheritance of truncated polymerase gene of RTSV in a cross between a transgenic japonica and non-transgenic indica rice. In: Proceedings of the 11th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1999:397–9.
28. Nor Hasnida H, Ismail A. Cloning of protease gene of rice tungro bacilliform virus (RTBV) into *Escherichia coli*. In: Zulkifli Z, Wan KL, eds. Proceedings of the 9th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1997:334–8.
29. Abdullah R, Leaw CL, Winnie YSP, Lim GF, Chari C, Yeun LH, Rashdan MM. Transgenic and chimeric oil palm plants carrying the cowpea trypsin inhibitor gene were resistant against bagworm larvae. Plant Mol Biol Reporter 2000;18(2, suppl):1.
30. Hanafi S, Ruslan A, Farida HS. Construction of vectors for transformation of the fatty acids biosynthetic pathway in oil palm via biolistic method. In: Dean JFD, ed. 5th International Congress on Plant Molecular Biology, September 21–27, 1997. Singapore: Kluwer Academic Press, 1997: Abstract 706.
31. Hassan MD. New developments and strategies in transgenic plant research in Malaysia. In: Proceedings of the 3rd National Congress on Genetics. Kuala Lumpur: Genetic Society of Malaysia, 1998:75–80.

32. Ruslan A, Leong CW, Asiah NS, Ng SS. Transformation of indica rice mediated by *Agrobacterium rhizogenes*. In: Ghazali HM, Yusoff KM, Mahmood M, eds. Proceedings of the 8th National Biotech Seminar. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1996:176–8.
33. Low FC. The biosafety regulatory framework in network member countries: Malaysia. In: Hautea R, Chan YK, Attathom S, Krattiger AF, eds. The Papaya Biotechnology Network of Southeast Asia: biosafety considerations and papaya background information. ISAAA Brief No. 11. Ithaca, NY, USA: International Service for the Acquisition of Agri-biotech Applications, 1999:62–3.
34. Genetic Modification Advisory Committee. National guidelines for the release of genetically modified organisms (GMOs) into the environment. Kuala Lumpur: Ministry of Science, Technology and the Environment (MOSTE), 1997.

Opportunities for nutritionally enhanced maize and wheat varieties to combat protein and micronutrient malnutrition

David Hoisington

Abstract

Naturally occurring variation detected in the germplasm of maize and wheat, two of the top three cereal crops in the world, provides options for incorporating higher levels of iron, zinc, and β-carotene into these grains. In addition, quality protein maize (QPM) has been developed from naturally occurring variation; its seed contains enhanced levels of lysine and tryptophan, two essential amino acids lacking in cereals. The International Maize and Wheat Improvement Center, along with its many partners, has identified several maize and wheat varieties with 25% to 30% higher grain iron and zinc concentrations. Wild relatives of wheat have been found to contain some of the highest iron and zinc concentrations in the grains. Although these accessions are often low yielding and have poor grain quality, backcrossing to bread wheat could result in highly nutritious cultivars. Options are now available for conventional and biotechnology-assisted improvement of the nutritional content of maize and wheat germplasm.

Key words: Nutritionally enhanced, maize, wheat, micronutrient malnutrition

Maize and wheat are two of the top three cereal crops in the world. Maize is the preferred staple of more than 1.2 billion consumers in sub-Saharan Africa and Latin America, where 30% to 50% of the population, particularly the poor and women and children, are affected by malnutrition. In Africa alone, many poor people subsist on a maize-based diet low in iron and zinc [1]. As an example, 30% of pregnant and lactating women in Zimbabwe are thought to be iron deficient [2]. Wheat is an important staple in the low- to lower-middle-income countries, where the annual per capita consumption ranges from 40 kg to more than 200 kg. Wheat contributes significantly to the caloric and protein requirements of consumers in these countries.

The International Maize and Wheat Improvement Center (CIMMYT), based in Mexico, has conducted research on nutrition-related traits for more than two decades and has arrived at several options for addressing nutritional deficiencies through maize and wheat improvement. In collaboration with governments and national agricultural research institutions in several countries (such as Brazil, China, El Salvador, Ethiopia, Ghana, Guatemala, Malawi, Mexico, Mozambique, and Uganda), CIMMYT has been promoting the use of quality protein maize (QPM). QPM is visually indistinguishable from normal maize, but it is of superior nutritional value because the levels of lysine and tryptophan are effectively doubled. Varieties of QPM have been released in several countries. It is estimated that they are currently grown on almost 1 million hectares, and the area is increasing. Apart from providing better-balanced protein, lysine is a known promoter of iron and zinc absorption in humans. Even with an unchanged iron or zinc concentration, iron and zinc uptake in humans consuming QPM is expected to increase.

Few if any studies have investigated whether a more balanced amino acid profile is feasible in wheat, but it should be. One difficulty may lie in the fact that wheat is usually processed into breads or other baked products. It is known that flour quality is greatly affected by changes in the protein composition of the grain. Thus, amino acid modifications in wheat would need to be carefully studied for their effect on grain quality.

More than one-third of the world's population is iron deficient, and some 1.2 billion people are anemic. The problem for women and children is more acute because of their greater physiological need for iron. Zinc deficiency has received less attention than other micronutrient deficiencies, but zinc deficiency is assumed to be widespread. Since the early 1990s, CIMMYT has been evaluating maize and wheat accessions and varieties for

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genetic variability of grain iron and zinc concentration. Experimental maize hybrids and varieties with 25% to 30% higher grain iron and zinc concentrations than are found in currently grown cultivars have been identified. Similar studies in wheat have indicated that iron and zinc concentrations in cultivated varieties can differ by 30% to 40%.

Some of the best sources of high iron and zinc concentrations in wheat are the wild relatives: *Triticum dicoccon, T. boeoticum*, and *Aegilops tauschi*. These are often low yielding, with poor grain quality, but through backcrossing to bread wheat, good cultivars can be obtained. Preliminary feeding studies carried out using rats have indicated a positive correlation between higher iron in the grain and higher levels of bioavailable iron in the diets fed to the rats. Further studies are under way to develop appropriate genetic populations for genomic studies of high iron and zinc concentrations in maize and wheat.

The World Health Organization reported in 1994 that 3.2 million preschool-age children have eye damage as the result of vitamin A deficiency and that another 228 million are subclinically affected at a severe or moderate level. CIMMYT and its sister institute, the International Institute of Tropical Agriculture, are exploring avenues for overcoming vitamin A deficiency resulting from maize-based diets. Yellow maize contains naturally occurring and significant amounts of provitamin A carotenoids (e.g., β-carotene) that can be converted to vitamin A in humans. Unfortunately, most consumers in sub-Saharan Africa and a considerable proportion in Latin America reject yellow maize for cultural and historic reasons. These consumer preferences might be overcome by promoting the consumption of high-β-carotene (yellow) maize as fresh, boiled, or roasted maize, or by developing high-β-carotene maize with a distinctive yellow grain color. CIMMYT has found considerable amounts of carotenoids in landraces of maize with sun-red grain color. There are plans to introduce these grain colors, along with higher β-carotene levels, into local varieties and to assess consumer preferences for elite, tasty, and more nutritious maize. A higher-technology solution may be via the genetic engineering of β-carotene production only in the embryo. This should lead to a less yellow-colored grain, which may be more acceptable. Issues surrounding the use of genetic engineering and grain processing (the grain is often degermed for storage) will need to be addressed.

There are already high-yielding varieties of both bread and durum wheat that are yellow in color, although the levels of provitamin A carotenoids are still being determined. Only a small fraction of the wheat genetic resources available have been screened appropriately for the level of carotenoids. It is possible that significant variation does exist and could be used to increase the level of β-carotene in elite varieties. One interesting observation is that wheat does produce detectable levels of β-carotene [3]. These levels are detected early in grain development but are absent in the fully developed grain. Thus, it appears that wheat possesses all of the necessary enzymes for β-carotene production, but that it processes β-carotene to other products in the carotenoid pathway (e.g., luteins). Given that all of the major enzymes in the carotenoid pathway are known and have been cloned [4], it should be feasible to block the pathway immediately after β-carotene production and thus elevate the levels of β-carotene in the grain. Other enzymatic steps may also need to be modified to produce the highest and most stable levels of β-carotene while not affecting other characteristics of the grain.

Enhanced nutritional quality of staple grains is of high priority. The naturally occurring variation already detected in maize and wheat germplasm provides options for incorporating higher levels of iron, zinc, provitamin A, and better-balanced protein into the grain of these important cereals. Genomic approaches, including genetic engineering, offer novel ways to further enhance these traits, especially those involving micronutrients such as iron, zinc, and β-carotene. Providing nutritionally enhanced cereals to resource-poor populations in developing countries offers an excellent opportunity to combat many of the devastating nutritional-deficit diseases affecting the world.

References

1. CIMMYT. 1997/98 world facts and trends. Mexico City: International Maize and Wheat Improvement Center (CIMMYT), 1999.
2. Bhebe S, Sikosana PLN, Katuli DS. A prevalence survey of iron deficiency and iron deficiency anaemia in pregnant and lactating women, adult males and preschool children in Zimbabwe. Harare: Ministry of Health and Child Welfare of Zimbabwe, 1997.
3. International Food Policy Research Institute. Update No. 3: CGIAR micronutrients project. Washington, DC: IFPRI, 1998.
4. Cunningham FX, Gantt E. Genes and enzymes of carotenoid biosynthesis in plants. Annu Rev Plant Physiol Plant Mol Biol 1998;49:557–83.

Biotechnology-derived nutritious foods for developing countries: Needs, opportunities, and barriers: Discussion Summary

Abstract

Improvements in diet diversification and quality can be facilitated by greater cooperation between the agricultural and the nutrition communities, according to an expert panel that met in early 2002. Encouraged to think innovatively, the panelists agreed that modern technology offers the potential to increase the amount and nutritional content of the food supply in developing countries, especially if the enhancements are made to the highest-yielding indigenous staple crops and if a total food-systems approach is taken. All types of interventions should be evaluated for their cost-effectiveness in preventing nutritional deficiencies in the developing world and for their sustainability.

Key words: Nutrition, biotechnology, biofortification, diversity

A distinguished group of international experts met in Cancun, Mexico, on January 15–17, 2002, to address nutritional deficiencies in developing countries through improvements in diet diversification and quality. These improvements, they agreed, would be facilitated by greater cooperation between the agriculture and nutrition communities. Modern biotechnology was explored as a potentially significant method to achieve this goal in the context of other approaches, such as traditional plant breeding, dietary supplementation, and fortification of food staples.

The objectives of the workshop were to identify

» nutritional needs that could be effectively met through biotechnology-derived foods;
» opportunities and areas in which the applications of the techniques of biotechnology could benefit nutritional needs;
» products under development that would meet these needs;
» opportunities for and barriers to the development of such products and their acceptance; and
» next steps: research, technology transfer, information dissemination, and additional workshop discussions and expert panel deliberations.

Because each developing country or region presents particular challenges, participants encouraged the development of innovative solutions to unique problems. Infrastructures, such as research facilities, regulatory agencies, and biosafety procedures, need to be put in place in many areas even before much-needed funding can be spent efficiently. Increased dialogue among networks of the nutrition and the agricultural communities is needed for capacity building in developing nations to successfully implement these and other strategies.

The group noted that the array of tools provided by modern biotechnology offers the potential to increase the amount and nutritional content of the food supply in developing countries. The group also noted that nutritional enhancements would probably be most effective if they were made in locally grown and familiar crops. The greatest potential for modern biotechnology to address real problems may lie in using a total food-systems approach that focuses on enhancing indigenous crops in developing regions, coupled with the use of the highest-yielding staple crops to boost both food security and nutritional quality.

All types of interventions, participants agreed, need to be evaluated for their cost-effectiveness in preventing nutritional deficiencies in the developing world, and their costs and benefits should be considered broadly. Assessment should include sustainability and the likelihood that the different strategies will promote, support, and improve dietary diversity.

Nutrition issues facing developing countries

The nutritional status of populations of the developing world is affected by several factors, including population density and rate of growth, the ability of the population to grow or buy enough staples for its own use, and economies of scale in agricultural research that decrease the diversity of the food supply. Thus, there is often tremendous variability in nutritional status among countries within a region.

The global population of 6.1 billion in 2000 is expected to grow by 800 million per decade to at least 8.2 billion by 2030, with just six countries accounting for most of the growth. Today 800 million people in the world are hungry, 400 million suffer from vitamin A deficiency, and 3 million children die from this deficiency each year. Two billion people suffer from iron deficiency, and many more have inadequate or unbalanced intakes of protein, carbohydrates, lysine, iron, iodine, niacin, and zinc. The prevalence of anemia in South Central Asia runs as high as 75%. Low birthweight and the resultant stunting of growth affect nearly 30% of children in developing countries (165 million children). Undernutrition is one of the most significant factors facing the developing world, but some regions are also experiencing diet-related chronic diseases of overnutrition, such as diabetes, obesity, hypertension, and cardiovascular disease, that are related to the consumption of excess energy and other dietary imbalances.

Twenty percent of the world's people are food insecure: they rely on their own or just a few other resources for their food. Only 20% of the world's people are affluent enough to have access to nutritious diets. Lack of dietary diversity is common in many developing nations. In one extreme example, Bolivia relies primarily on 10 different foods for sustenance, down from 64 over the past few decades. This lack of diversity and overdependence on a few staple crops results in a wide variety of micronutrient deficiencies, the so-called multinutrient deficiency syndrome, that is likely to be a harbinger of reduced physical productivity, decreased cognitive ability, higher rates of infant mortality, and other problems that plague undernourished populations. Food-based approaches using plant breeding and/or biotechnology to address nutrient deficiencies should be implemented in a manner that does not exacerbate the malnutrition problems associated with a declining diversity in the food supply.

Another factor affecting nutritional status relates to a population's ability to devote resources to sustain the health and welfare of its people. For example, 70% of the world's senior citizens live in developing nations. Many of these individuals, particularly in Africa, are facing even more difficult challenges in caring for AIDS victims and their orphans while sustaining their own lives. Time spent tending to the aged, the sick, and orphaned children competes with time needed to obtain and prepare food and to foster a nurturing environment.

Challenges to improving nutrition and food security

Nutrition and agricultural experts from developing nations who participated in the workshop cited a number of factors that prevent their populations from improving their nutritional status. Among them are deteriorating socioeconomic status; the persistence of widespread poverty; high disease burden; reduced public investment in nutrition and agricultural programs and related research and development; lack of education, which is a factor in both under- and overnutrition; limited technical capacity to provide solutions; diminishing land and water resources; political instability and/or lack of political will to allocate resources; and costs associated with yearly farm inputs, such as seed, fertilizer, and pesticides. Even where plans to address nutrition and food security issues have been developed, often there are not adequate resources to implement the plans.

Examining potential solutions

The participants were asked to consider current and future approaches best suited to meet priority nutritional needs in developing countries. They compared and contrasted approaches that included supplementation, fortification, dietary diversification, traditional plant breeding, and modern biotechnology based on the following criteria: benefits, cost, proven efficacy, difficulty of implementation, long-term and short-term impacts, and reachable population. Each of these approaches was seen as having strengths and weaknesses relative to specific nutritional problems and the biologic, economic, and behavioral dimensions of the problems. These approaches need to be seen as a portfolio of strategies rather than as competing approaches.

A consensus emerged that in each developing country, it is necessary to examine alternatives comprehensively—from a total food-systems approach—rather than focusing on certain micronutrients or on single crop-oriented strategies. Supplementation was seen as a short-term approach that is already being used in a number of countries with limited success. Concerns about cost and ability to reach enough people place limits on the potential for the sustainable success of traditional biomedical, i.e., supplementation, approaches. More experience is available on the sustainability of fortification practices, but this option also should be evaluated from a total health-systems approach.

Education is needed in all areas to encourage a total dietary approach that maximizes the consumption of fruits, vegetables, cereals, and legumes using the best available crop varieties. Diversifying plant and animal food sources was also cited as a critical component of any potential solution. Although improving dietary diversity was seen as the most desirable strategy for improving the nutritional status of populations, the experts acknowledged that this may be a difficult strategy to implement over the short term, because current economic structures favor the production of a few crops and because of the lack of attention given to maintaining accessibility to diverse diets.

Other approaches include biofortification, a term coined by the Consultative Group on International Agricultural Research (CGIAR), that covers the use of both traditional breeding and modern biotechnology to increase the levels of nutrients in crop foods, education, and social marketing. Although biofortification is yet to be implemented and carefully evaluated in the field, preliminary evidence suggests that it should be exceptionally cost-effective. The acceptability to farmers and consumers of biofortification requires evaluation, especially when consumer characteristics (e.g., color) are altered.

As populations increase and as other pressures on the demand for food drive up the prices of mineral- and vitamin-dense nonstaple foods, biofortification strategies should seek to redress in part the greater dietary dependence by the poor on a few staple crops. At the same time, more productive varieties of food staples have been developed through investment in agricultural research in developing countries, which has lowered the prices of cereals and roots and tubers and has ensured better food security in terms of energy intakes.

Creative approaches might involve not only enriching nutrients in plants but also making a more diverse array of plants able to thrive in a particular area, reducing postharvest losses, especially for tropical fruits, or even enabling lifestyle changes that reduce the time needed to tend fields that could be better spent caring for people in need. Likewise, "orphan crops," i.e., crops of nutritional importance to local areas or regions, can help diversify the diet and avoid overdependence on a few staple crops. Although these strategies can serve a critical need by promoting more diverse diets, a careful evaluation of costs and benefits is yet to be undertaken.

Investment in new technologies is essential to improving nutritional status, but other factors are also essential. These include the promotion of an effective dialogue among scientists, farmers, consumers, and policy makers; within-country capacity building in research and the creation of enabling regulatory frameworks; and the support of key decision makers. With these capabilities in place, agriculture and nutrition can form new partnerships to improve public health. The participants called for a new paradigm in linking the agriculture and nutrition sectors, as well as the environmental sector, in both research and community development. Research will determine which agricultural practices—conventional breeding or biotechnological methods—offer the best approaches for achieving specific nutritional and environmental goals. Strong community-level communication among all of the interested parties is essential to translating research findings into practice. In addition, there must be political and financial commitment at the local level to foster an environment in which enabling policies and regulatory structures can be developed.

Focus on biotechnology

The participants were asked to focus specifically on the types of nutritional issues that might benefit from the use of modern biotechnology. In approaching this question, the participants noted that discussions of biotechnology are often narrowly focused on genetic engineering of agricultural products rather than on the full range of innovations introduced by biotechnology. This array of tools provides flexibility and new approaches for improving crops. These tools include the ability to transfer genes from nonplant sources into crops to provide desirable traits not available from plant sources; more efficient and effective breeding by using markers to confirm gene transfer; the use of tissue culture to produce disease-free cultivars and cultivars with improved traits; improvements in disease diagnosis to manage existing diseases or to reduce the risk of disease in livestock and plants; and the production, testing, and delivery of vaccines. The advantages of using biotechnology will depend on the specific trait and crop of interest.

The participants stressed that modern biotechnology should be based within a systems context and should be used where biotechnology offers the best approach or application. Biotechnology must also gain greater public acceptance through information sharing and education. Achieving greater acceptance will require information sharing and education of industry, government, and the public. Although the participants acknowledged that foods developed by modern biotechnology can be as safe as their traditional counterparts, representatives from a number of developing nations stressed the need to address the low level of understanding of the needs of the developing world and the diverse misperceptions of industry, governments, and the public regarding the nature and basis for acceptability of bioengineered foods. Some were of the view that biotechnology offers great hope for improving nutrition but expressed concern about how it can be implemented in the current environment. One strategy for moving beyond the status quo is to increase public-sector support for research and development of crops of interest to regional consumers and producers.

Some participants noted that we have the knowledge to make a major difference in the lives of many less fortunate people in developing countries. However, knowledge is not enough; the challenge is to empower and build capacity in these populations to successfully advocate for solutions that meet their needs. As their leaders understand the dimension of their food-security and nutrition problems, they need access to the full portfolio of strategies, including new technologies such as modern biotechnology, to tackle these problems.

Barriers to the implementation of biotechnology solutions include a lack of tools for evaluating the safety of transgenic foods and the effects of transgenic crops on the environment before public concerns can be satisfied; the lack of a track record for transgenic foods and the concomitant fear of the unknown, which also occurred for some conventionally bred crops; limitations in the types of crops developed to date; high startup costs; lack of public investment; lack of research funds beyond those for major crops; lack of incentives for farmers to adopt transgenic crops and the private sector to invest in them; limited access to the new technology owing to intellectual property rights; inadequate local regulations; and lack of awareness of the potential of biotechnology.

In the 1960s and 1970s, the Green Revolution succeeded in meeting the food needs of a growing world population partly because the public invested in the development of high-yielding varieties of food crops. Funding for the next food-production revolution in the early twenty-first century will require both public and private partners. This new funding paradigm creates new challenges, given the interest in and need for specialty or indigenous crops for developing countries that might attract public funding but are less likely to attract investment from the private sector. New models are needed to balance the roles of private and public funding in meeting the nutritional and food needs of developing countries.

Next steps to move agricultural biotechnology projects forward

Each workshop participant provided a number of recommendations in the areas of science, capacity building, opinion leader outreach, and funding to move modern biotechnology products closer to becoming part of the solution to providing nutritious foods for developing countries. Consensus emerged in several areas:

» Develop evidence to support the hypothesis that improving dietary diversity is an achievable and sustainable approach to improving health in developing countries.
» In developing this evidence, focus some research efforts on developing transformation systems for tropical food crops, particularly indigenous crops in areas of poor agricultural output and limited dietary diversity.
» Based on documented nutritional need, add specific nutrients to high-yielding crops and/or improve yields of nutrient-dense crops.
» Increase and sustain South–North and South–South interactions and cooperation to promote the development of infrastructure and regulatory frameworks, and to share scientific learning and genetic resources.
» Encourage opinion leaders to stress and fund capacity building in the area of food and nutrition in developing nations.
» Develop networks for sustained interactions between the agricultural and nutritional communities within developing nations and regions.
» Develop an intellectual property rights clearinghouse to facilitate technology transfer to developing nations.
» Build models that integrate biotechnology in portfolios, such as the plant-breeding and seed programs of the Food and Agriculture Organization of the United Nations, that include a broad array of tools for improving the availability of and access to diverse diets.
» Increase consumer awareness of, and confidence in, biotechnology by engaging stakeholders, local scientists, and journalists in discussions of the implications of the latest scientific and product developments, and increase industry understanding of stakeholder concerns and issues.
» Form a consortium of opinion leaders to encourage funding and cooperation on agricultural approaches that include, but are not limited to, modern biotechnology for the improvement of nutritional status, and seek a respected organization to convene.
» Examine other models, such as GAIN (Global Alliance for Improved Nutrition), to raise funds for public investment in new agricultural technologies.
» Develop a network whereby agriculture and nutrition leaders can communicate the imperative of meeting global food and nutrition needs and evaluate and recommend promising strategies.
» Continue the effort that began with this workshop by meeting at least annually to provide the necessary leadership development to bring agriculture and nutrition scientists together in a new health-promotion paradigm.
» Periodically review progress to determine the impact of new technologies and strategies to improve diet diversification, adequacy, and nutritional value.

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