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REVIEW

Incorporating nutritional considerations when addressing food insecurity

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Abstract Addressing the challenges of global food security will benefit from the simultaneous incorporation of nutritional priorities that contribute to the good health of populations. Inclusion of nutritional considerations, when increasing availability and access to food, broadens the scope and objectives of agriculture and food production and thus contributes to an integrated concept of food and nutrition security. The poor quality of food and lack of diversity in the habitual diet of many who live in the developing world imposes enormous costs on societies in terms of ill health, lives lost, reduced economic productivity and poor quality of life. Micronutrient deficiencies are a problem that is much greater than hunger and is a prime example of the need to integrate both food and nutrition security. Sustainable food-based approaches to enable adequate consumption of micronutrients include dietary diversification and biofortification. Agriculture and agricultural biotechnology not only offer the opportunity of increasing crop yields, thereby increasing food security, but also have the potential to improve the micronutrient content of foods, thus contributing to the achievement of both food and nutrition security. Ensuring food and nutrition security will facilitate the attainment of the targets set for the Millennium Development Goals.

Keywords Food and nutrition security · Micronutrient malnutrition · Dietary diversification · Agricultural biotechnology · Biofortification

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Introduction

Concepts of food security have focused predominantly on increasing agricultural production, the availability of food and access to food. Nutrition security on the other hand has emphasised more the physiological needs for nutrients and the role of the environment in determining good health and nutrition. Incorporating nutritional considerations when meeting the challenges of food security provides a holistic concept of food and nutrition security thus enabling integration of the two frameworks and contributing towards achieving the targets set out in the Millennium Development Goals. Addressing the global challenge of micronutrient malnutrition by sustainable food based approaches provides an excellent example of how these two concepts and frameworks can be integrated and shows how nutritional considerations can be prioritised while combating the global problem of food insecurity and hunger.

Food and nutrition security

Our current concept of food security has evolved over the last 50 or more years through a sequence of definitions and paradigm shifts (Weingartner 2005). The earliest definition provided by the historic Hot Spring Conference in 1943, which gave birth to the Food & Agricultural Organization of the United Nations (FAO), merely stated, 'a secure, adequate, and suitable supply of food for everyone' was internationally accepted. Concepts of food security have evolved over time since World War II and have changed according to the views expressed by several distinguished individuals over this period: these have been well summarized in several publications (Hall 1998; Shetty 2006; Shaw 2007) With the successes of the green revolution increasing food production and food availability in many parts of the world, mainly in Asia and Latin America, the awareness of the persistent vulnerability of specific communities to hunger due to decline in their purchasing power led to the concept of food security being broadened to include both physical and economic access to food. The definition of food security was then amended to, 'the access by all people at all times to enough food for an active, healthy life' (Campbell 1991). During this process of evolution, the concept of food security was broadened beyond notions of food supply or availability to include access, stability and sustainability. Since the 1990s the primacy of reducing global hunger and undernutrition within the development agenda and the recognition of the human right to adequate food and nutrition was reaffirmed internationally. Thus reduction of hunger and undernutrition was increasingly seen in the context of overall development, poverty reduction and the achievement of the Millennium Development Goals.

According to the UN's Food & Agricultural Organization (FAO) food insecurity is thus, 'a situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life' (FAO 2000). Thus food insecurity may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level. The concept of nutrition security is perhaps broader than food security since the term utilization in nutrition would encompass biological utilization (Gross et al. 2000). Thus from a nutritional perspective, adequate utilization refers to the ability of the human body to ingest and metabolize food. Nutritious and safe diets, an adequate biological and social environment, and proper nutrition ensure the adequate utilization of food. This, in turn, helps to promote health and prevent disease. An understanding of nutrition security is incomplete without appreciation of the widely accepted conceptual framework for the analysis of malnutrition developed by UNICEF (1990). According to the UNICEF framework, the immediate causes of malnutrition are twofold—inadequate dietary intake and unsatisfactory health status. In developing countries, infectious diseases such as diarrhoea and acute respiratory infections are responsible for most nutrition-related health problems. Consequently good nutrition or nutritional status i.e. nutrition security is a function of both food intake and health status. The UNICEF conceptual framework also identifies the importance of the role of care in these two determinants and recognises that the absence of proper care in households and communities is a necessary element of the underlying causes of malnutrition.

The UNICEF conceptual framework of the causal factors for poor nutrition operates at different social-organizational levels (Gross et al. 1999). The immediate causes affect individuals, the underlying causes relate to families, and the basic causes are related to the community and the nation. The underlying causes may be due in part to tenuous access to health care or due to poor housing and/or environmental conditions. Hence, the more indirect the cause, the larger the population whose nutritional status is likely to be at risk. The two commonly used conceptual frameworks for food security and nutrition security thus show significant differences within the food security framework, emphasizing an economic approach in which food as a commodity has a central focus while the nutrition framework adopts a biological approach in which human beings are central (Gross et al. 2000). Both these frameworks promote interdisciplinary approaches and acknowledge that food production alone is not sufficient to secure a sustainable and satisfactory nutritional status and, therefore health and environment also need to be equally considered.

The necessity of incorporating nutrition into food security evolved over time (Weingartner 2005). Nutrition security is more than food security. The nutrition focus adds physiological requirements for different nutrients and the determinants of their bioavailability (i.e. the degree to which or rate at which the nutrient is absorbed and becomes available at the site of physiological activity) as well as aspects of caring practices and health services and healthy environments. These broaden the concept to what is more precisely termed 'nutrition security'. Hence nutrition security can probably be defined as 'adequate nutritional status in terms of protein, energy, vitamins, and minerals for all household members at all times' (Quisumbing et al. 1995). While this definition illustrates the consideration of the need for food to ensure adequate or optimal supply of these nutrients in the diet i.e. physiological needs, other definitions of nutrition security focus on the vulnerable individual and their needs related to non-food factors. While pointing out the need for a paradigm shift in policy formulation from attention to food security at the aggregate level to nutrition security at the level of each child, woman and man, Swaminathan (2008) defined nutrition security as, 'physical, economic and social access to a balanced diet, safe drinking water, environmental hygiene, primary health care and primary education'. This latter definition of nutrition security involves both food and non-food factors. Consequently food and nutrition security integrates both conceptual frameworks. The recognition that food, which includes water, is a substance that people eat and drink to achieve an adequate nutritional status i.e. maintain life and physical, cognitive, and social development, and that it has to meet physiological requirements in terms of quantity, quality, and safety and be socially and culturally acceptable, influenced and amended the definition further. Accordingly, 'food and nutrition security is achieved, if adequate food (quantity, quality, safety, socio-cultural acceptability) is available and accessible for and satisfactorily utilized by all individuals at all times to achieve good nutrition for a healthy and happy life.' (Weingartner 2005).

The increasing awareness of over consumption and over nutrition not just in developed, economically advanced populations but also in rapidly industrializing and urbanising developing countries has added a new dimension to food and nutrition security (Shetty 2000). There is increasing concern over the growing problem of over nutrition and its health consequences in developing countries which continue to struggle with the unfinished agenda of food insecurity, hunger and undernutrition thus contributing to the 'double burden' of malnutrition (Kennedy et al. 2006). To take this into account, food and nutrition security is broadly defined currently to 'encompass stability in availability, access, and utilization of safe and nutritious food to prevent both positive and negative deviation from nutritional balance for all, in a manner that is economically, environmentally, socially and culturally sustainable' (Dube et al. 2008, From Crisis to a New Convergence of Agriculture, Agri-Food and Health: What Business and Communities Can Do to Help Society to Afford Food and Nutrition Security Worldwide? Mc Gill Univ. (Unpublished document)). Food and nutrition security are fundamental to the achievement of the Millennium Development Goals (FAO 2005) and to reduce the burden of nutritional disorders that accompany economic development and urbanisation of societies worldwide.

Micronutrient malnutrition

Micronutrient malnutrition or 'hidden hunger' is an important dimension of food and nutrition security from a global perspective. Micronutrient malnutrition is an ideal example to illustrate the importance of nutritional considerations when addressing the challenge of meeting food security for all. Food based strategies to combat micronutrient malnutrition are eminently suitable for integrating food and nutrition security, unlike most other causative factors of under nutrition which in addition to diet are either health or environment derived.

Micronutrient malnutrition is caused by lack of adequate micronutrients such as vitamins and minerals in the habitual diet. Micronutrient deficiencies are common in populations that consume poor quality diets lacking in dietary diversity as their habitual diet is often deficient in these nutrients. Diets deficient in micronutrients are characterized by high intakes of staple food and cereal crops, but low consumption of foods rich in bioavailable micronutrients such as fruits, vegetables, and animal and marine products. There are nearly 2 billion people worldwide who suffer deficiencies of micronutrients such as iron, iodine, zinc and vitamin A (Table 1). Micronutrient deficiencies are therefore important from a public health perspective and far exceed our current estimates of the global problem of hunger and food insecurity. Micronutrient deficiencies may impair cognitive development and lower resistance to disease in children and adults (UNICEF/Micronutrient Initiative 2004). They increase the risk of morbidity and mortality of both mothers and infants during childbirth and impair the physical ability and economic productivity of adults. The costs of these deficiencies in terms of lives lost and reduced quality of life are enormous, not to mention the economic costs to society.

Deficiencies of micronutrients are common in populations that habitually consume largely cereal-based, monotonous diets. However, some micronutrient deficiencies such as iron deficiency are also common in Developed Countries. The amount of bioavailable iron is dependent on the content and source of iron in the diet and on iron absorption during the digestive process. The absorption of iron of plant origin is relatively low and is considered to be a major factor in the causation of iron deficiency anemia, an exception being soybean, which is a good source of dietary iron (Murray-Kolb et al. 2003). Cereals also contain high concentrations of phytic acid, which is a potent inhibitor of

Table 1 Estimated global impact of micronutrient malnutrition

Micronutrient deficiency	Estimated impact
Vitamin A deficiency	140 million pre-school children affected with VAD[a]
	Contributes to 1.15 million deaths in children every year[b]
	4.4 million children suffer from xeropthalmia[a]
	6.2 million women suffer from xerophthalmia[a]
Iron deficiency	2.0 billion people (96 million of them pregnant women)[b]
	67,500 maternal deaths per year from severe anaemia[b]
Iodine deficiency	1.98 billion at risk with insufficient or low iodine intake[c]
	15.8% of population worldwide have goitre[c]
	17.6 million infants born mentally impaired every year[b]
Folate deficiency	Responsible for 200,000 severe birth defects every year[b]

[a] SCN (2004) *Fifth report on the world nutrition situation: Nutrition for improved development*

[b] UNICEF/Micronutrient Initiative (2004) *Vitamin and Mineral deficiency: A World progress report*

[c] WHO (2004) *Iodine status worldwide*

iron (and zinc) absorption. Foods that enhance non-haem iron absorption such as fruits and vegetables, which are rich in ascorbic acid, are often not consumed in adequate amounts in developing countries. Haem iron, which is relatively well absorbed by the human intestine, is found primarily in animal products such as meat, but animal sources of food are usually limited in the diets of people living in Developing Countries owing to cost and availability. Thus, iron deficiency and iron deficiency anaemia are prevalent in these countries. It is also important to note that infections such as malaria and hookworm infestation contribute to iron deficiency.

In general, cereal grains only contain low concentrations of carotenoid compounds (precursors to vitamin A). Consequently, Vitamin A deficiency often occurs where the diet is predominantly cereal-based and individuals have poor and irregular access to foods rich in pro-Vitamin A carotenoids. The bioavailability of vitamin A also varies with the source of the carotenoids in the diet (de Pee and Bloem 2007).

The global prevalence of vitamin and mineral deficiencies is remarkably high and it is estimated by UNICEF that a third of the world's people do not meet their physical and intellectual potential because of micronutrient deficiencies (UNICEF/Micronutrient Initiative 2004). Estimates based on data from more than 80 countries in the developing world indicate that iodine deficiency disorders (IDD) in pregnancy cause almost 18 million babies a year to be born mentally impaired. IDD is estimated to lower the intellectual capacity of almost all nations reviewed by the Joint Report of Micronutrient Initiative and UNICEF by as much as 10–15 percentage points, while iron deficiency in 6–24 month old children is said to impair the mental development of between 40% and 60% of the developing world's children. According to this report, severe iron deficiency anaemia (IDA) contributes to the deaths of more than 60,000 young women a year in pregnancy and childbirth while iron deficiency in adults is estimated to contribute to productivity losses of up to 2% of the GDP of these nations. Vitamin A deficiency (VAD) on the other hand, is likely to compromise the immune status of approximately 40% of the developing world's under 5 year old children and is probably the cause of approximately 1 million deaths of such children each year. Zinc and iron deficiency also compromise immune status and contribute to increase in morbidity and mortality in children. It is important also to recognise that half the children who have any deficiency actually have multiple micronutrient deficiencies.

It is now becoming apparent that micronutrient deficiencies are sufficiently widespread to warrant concern and action as they cause enormous health, economic and social costs. These can only be appreciated by recognizing that in children, in addition to impaired health, they affect cognitive and physical development and decrease school performance, while in adults they compromise work output, productivity and earning capacity. They also impair immunity and increase susceptibility to infectious diseases and increase mortality, particularly among vulnerable groups such as pregnant women and children (UNICEF/Micronutrient Initiative 2004).

The World Bank (1994) estimated that deficiencies of the three major micronutrients i.e. Vitamin A, iodine, and iron alone could reduce the gross domestic product (GDP) of Developing Countries by as much as 5% but that addressing them comprehensively and sustainably would cost less than 0.33% of GDP. The World Health Organization (WHO 2002) estimated that while 3.7 million deaths per year in children is attributable to underweight, deficiencies of vitamin A, iron and zinc each caused an additional 750,000–850,000 deaths. More recently it has been estimated that undernutrition is responsible for 2.2 million deaths and 21% of disability-adjusted life-years (DALYs) for children younger than 5 years (Black et al. 2008). Deficiencies of vitamin A and zinc together were estimated to contribute to 1.0 million deaths of children while iron deficiency as a risk factor for maternal mortality added 115,000 deaths. This analysis of co-exposure of these nutrition-related factors, were together estimated to be responsible for about 35% of child deaths and 11% of the total global disease burden. Effective nutritional interventions including breast-feeding, complementary feeding and micronutrient supplementation would reduce child mortality significantly and save the lives of several million children each year (Bhutta et al. 2008).

Food based approaches to combat micronutrient malnutrition

The enormous problem of micronutrient malnutrition worldwide poses numerous challenges and some attempts have been made to address them. The time-tested strategies universally promoted to combat micronutrient malnutrition have hitherto focused on supplementation and fortification of commonly consumed foods with micronutrients. Supplementation and food fortification, however, only address the symptoms and not the underlying causes of micronutrient deficiencies. Other complementary interventions include the treatment of parasitic infestations, which very often are important contributors to micronutrient deficiencies such as that of iron. While these strategies have been tried with varying degrees of success and continue to play an important role in improving community nutrition, increasingly more emphasis is being placed by international agencies on food fortification strategies (Darnton-Hill and Nalubola 2002) since they can be categorized as food based approaches and hence are probably sustainable in the long term.

In this paper only food-based approaches (excluding food fortification) will be discussed as they illustrate the integration needed for the achievement of food and nutrition security in populations. The International Conference on Nutrition (ICN) Declaration (FAO/WHO 1992), advocating a strategy to combat 'hidden hunger' stated: "Ensure that sustainable food-based strategies are given first priority particularly for populations deficient in vitamin A and iron, favouring locally available foods and taking into account local food habits." Supplementation as an intervention strategy was to be progressively phased out as soon as micronutrient-rich food-based strategies enabled adequate consumption of micronutrients. Alternative strategies, which are food-based and are sustainable, alter behaviour and include nutrition education and the promotion of dietary diversity through investment in home vegetable gardens.

Food based approaches to improving vitamin A status by increasing the intake of fruits and vegetables has been shown to improve vitamin A status in many studies. The challenge posed, however, relates to the bioavailability of dietary carotenoids and their conversion to retinol, which appear to be influenced by a host of other factors (de Pee and West 1996).

As previously mentioned, the availability of dietary iron is low in populations consuming monotonous plant-based diets with little meat since most dietary iron is non-haem, and its absorption is often less than 10% (Zimmermann and Hurrell 2007). The absorption of non-haem iron is increased by meat and ascorbic acid, but inhibited by phytates, polyphenols, and calcium. Because iron is present in many foods, and its intake is directly related to energy intake, the risk of iron deficiency is highest when iron requirements are greater than the energy needs. Zinc deficiency is now recognized as micronutrient malnutrition of significance. The challenge of addressing zinc deficiency in developing countries is related more to the role of inhibitors of zinc absorption such as phytates in the largely cereal based diets rather than inadequate intakes in the diet (Lönnerdal 2000). Evidently food based strategies pose their own set of challenges in addressing micronutrient malnutrition.

Dietary diversification and modification for combating micronutrient malnutrition

Food based strategies focusing on dietary modification and dietary diversification to enhance intakes and bioavailability of micronutrients at the household level have been summarised by Gibson and Hotz (2001). While promoting the addition of animal and marine foods to the predominantly plant based diets of populations in developing countries may be the ideal, recognising the socio-economic circumstances and being sensitive to the cultural and religious beliefs of those who live there is important. Gibson and Hotz (2001) have enumerated strategies that do not involve substantial changes in habitual diets.

Home gardening, horticulture and homestead food production have been promoted for a long time in order to provide low cost variety in the diet. Although home gardening as an activity has been extensively promoted in developing countries there are few evaluations of its proven benefits and sustainability (Chadha and Oluoch 2003). A recent study in rural South Africa has not only shown how effective this can be but also provides insights into what activities ensure success and sustainability in the community. These include the integration of community-based monitoring of children's growth, the active participation and involvement of women and their consequent empowerment as well as maternal awareness of vitamin deficiencies through nutrition education (Faber and Benade 2003). This study showed that locally produced vegetables and the promotion of the consumption of vitamin rich foods, such as orange flesh sweet potatoes, can provide households with direct access to foods rich in beta carotene and that home gardens can make a valuable contribution towards vitamin A intake and, ultimately, the alleviation of Vitamin A deficiency (Faber et al. 2002).

Promotion of homestead gardening programmes in Bangladesh improved the production and consumption of vegetables year round and was shown to be sustainable over several years while increasing the economic contribution and empowerment of women in the households (Bushamuka et al. 2005). The development and expansion of the Bangladesh homestead gardening programme has successfully increased the availability and consumption of vitamin A–rich foods and has been expanded nationally (Talukder et al. 2000). Home-garden interventions are most effective when combined with promotional and educational interventions (Ruel and Levin 2000). Food-based approaches to addressing malnutrition and food and nutrition security should necessarily include educational inputs and the promotion of the awareness of nutrition related health problems.

Alongside the promotion of home gardening aimed at dietary diversification are other related household or community strategies broadly considered as homestead food production. These include the promotion of small livestock production, encouragement of integration of aquaculture into farming systems, and the investment at community level in village based technologies for refrigeration, drying and preservation of food (Gibson and Hotz 2001). The contribution of foods from animal sources by the promotion of small livestock production in the homestead can help to combat undernutrition and provide the range of micronutrients that are deficient in a wholly plant based diet. Such foods diversify the diet and enhance its nutritional quality by providing a good source of protein and a number of key micronutrients that are readily bioavailable. They are of particular benefit to vulnerable segments of the population such as infants and children, pregnant and lactating women and the elderly. Several intervention and community development programmes have used livestock promotion to achieve improvements in nutrition and health (Murphy and Allen 2003). FARM-Africa promoted a Dairy Goat Project in Ethiopia, the objectives of which included the improvement of family welfare through the generation of increased income and milk consumption. The project adopted an integrated approach and increased the productivity of local goats managed by women and demonstrated an increase in milk and meat products in local diets, and a considerable improvement in the nutritional status and family welfare of participants (Ayele and Peacock 2003). The VAC programme (V = Vuon i.e. garden, A = Ao i.e. pond, C = Chuong i.e. cattle shed) in Vietnam showed remarkable increase in incomes and in the health and nutrition of the rural populations. The Vietnamese government now considers this to be an effective solution for the alleviation of poverty, the improvement of diet and the prevention of malnutrition (Hop 2003). National programs in Thailand have also prioritized the production of livestock by the poor, resulting in improvements in the quality of their diets and better nutrition and health. Integration of these programmes with national policies for poverty alleviation is now recommended to ensure long-term sustainability (Smitasiri and Chotiboriboon 2003). The Nutrition Collaborative Research Support Program (NCRSP) reported on three parallel longitudinal studies in disparate ecologic and cultural parts of the world i.e. Egypt, Kenya and Mexico. Strong associations between the intake of foods from animal sources and better growth, cognitive function, and physical activity in children, better pregnancy outcomes and reduced morbidity due to illness were found (Neumann et al. 2003). Access to foods of animal origin through the promotion of small livestock is thus considered a strategic intervention for avoiding the poverty-micronutrient-malnutrition trap (Demment et al. 2003).

Fish are considered a good source of animal protein although their role as a source of vitamins and minerals in the diet of populations in developing countries is often overlooked. In poor, rural households, mean fish intake was between 13 and 83 g raw, whole fish per person per day; the frequency of intake of small fish was high, and made up 50–80% of all fish eaten during the fish production season in rural Bangladesh and Cambodia (Roos et al. 2007). Many small fish are eaten whole and therefore are a rich source of calcium; some are also rich in vitamin A, iron, and zinc. However, the results of randomized control trial using small fish in Bangladesh has been disappointing, showing no changes in biochemical indicators of vitamin A status in children following a 9 week feeding trial (Kongsbak et al. 2008). Where fish is consumed, use of small dried whole fish eaten with the bones is encouraged. As fish flour or relish they can be used to enrich cereal-based foods for infants and children. Gibson and Hotz (2001) also identify food based strategies more specifically targeted at infants and children such as (i) use of soaking to enhance micronutrient availability; (ii) use of fermentation which decreases phytate, an inhibitor of mineral absorption, and thus enhances micronutrient availability; and (iii) use of germinated cereals and legumes to increase nutrient density and bioavailability of nutrients in prepared foods.

The role of agriculture and agricultural biotechnology in combating micronutrient malnutrition

It has been stated that a sustainable solution to the problem of malnutrition owing to the lack of micronutrients will only be possible when their concentration in the major staple crops is adequate (Pinstrup-Anderson and Pandya-Lorch 2001). This is particularly true of cereals given that a major proportion of the diet of vulnerable populations in the developing world is cereal based. For example rice alone contributes to 23% of the energy consumed worldwide and countries that rely on rice as the main staple often consume up to 60% of their daily energy from this cereal (Khush 2003).

Agricultural approaches to improve the nutrient content of crops have included field fortification strategies, which enhance the micronutrient and trace element content of crops by applying enriched fertilizers to the soil. There is good evidence that deficiencies and excesses of micronutrients and trace elements in soils have a profound impact on the well-being of plants and animals that depend on soil to thrive (Lal 2009). Enrichment of soil with fertilizers fortified with micronutrients and trace elements to increase their content in cereal grains has been attempted for selenium, iodine and zinc and in the case of iron to enhance its content in leaves. The best studies showing soil fortification through fertilizers being an effective strategy has been with zinc. Gibson et al. (2007) have demonstrated an increase of almost double the zinc intake of children in North East Thailand achieved through the application of zinc fertilizer to rice fields deficient in the element.

The advent of modern biotechnology has generated new opportunities in agriculture to address both food and nutrition security. Biotechnology strategies can help to improve the amount and availability of nutrients in plant crops. These strategies include simple plant selection for varieties with high nutrient concentration in the seeds, cross-breeding for incorporating a desired trait within a plant, and genetic engineering to manipulate the nutrient content of the plant (King 2002). In agriculture, biotechnological or molecular biology based approaches are used primarily in one of two ways: (i) Genetic engineering to create transgenics or genetically modified organisms (GMO) by manipulating, deleting or inserting genes in order to change the organism; and (ii) Marker-assisted selection to speed up conventional crop and animal breeding. Both can and have played a part in providing biotechnology-based solutions to improving the nutritional quality of agricultural products and thus address the challenge of micronutrient malnutrition.

Agricultural biotechnology provides an important opportunity to tackle the global problem of food and nutrition security in a sustainable manner. The production of "Golden Rice" was a major event involving the transfer of the genes necessary for the accumulation of carotenoids (vitamin A precursors) in the endosperm that are not available in the rice gene pool. As the endosperm of rice does not contain any provitamin A, the initial objective was to introduce the entire biochemical pathway for its synthesis. Several years of research by a Swiss group resulted in transgenics based on daffodil genes which contained substantial increases in provitamin A, visible as a "golden" colour of different intensities in different lines (Ye et al. 2000; Potrykus 2003). The best provitamin A line had 85% of its carotenoids as beta carotene. Other lines had less beta carotene, but high levels of lutein and zeaxanthin, both substances of nutritional importance because they have other positive nutritional effects (Ye et al. 2000). The first generation Golden Rice with a gene from daffodil and a common soil bacterium drew considerable criticism as a technological solution to a problem associated with poverty and hunger. It was argued that Golden Rice would encourage people to rely on a single food rather than the promotion of dietary diversification. Detractors also noted that a normal serving of Golden Rice contained only a small fraction of the recommended daily allowance (RDA) of beta carotene. However, the development of Golden Rice 2 by replacing the daffodil gene with an equivalent gene from maize increased the amount of beta carotene by about 20-fold resulting in about 140 grams of the rice providing a child's RDA for beta carotene (Raney and Pingali 2007). It has also been recently demonstrated that beta carotene from golden rice is efficiently converted to vitamin A in humans (Tang et al. 2009).

Another approach with similar objectives was to increase the availability of iron while reducing the inhibitor content or adding a resorption-enhancing factor. Only 5% of the iron in the rice plant is in the seed and hence an attempt was made to create a sink for iron storage within the endosperm by expressing a ferritin gene from *Phaseolus* . This resulted in a 2.5-fold increase in iron content of the endosperm. Feeding studies with peptides from muscle tissue showed that cystein-rich polypeptides enhance iron resorption. In the case of the phosphate rich compound phytate, which inhibits iron absorption, care had to be taken as interference with phosphate storage may affect germination. Expression of a phytase gene therefore had to be achieved in such a manner as not to interfere with this. Transgenics were selected in which the enzyme was excreted into the extra-cellular space and one line expressed phytase to levels 700-fold higher than the endogenous phytase. However, the transgenic enzyme in this line had lost its thermo-tolerance and did not refold properly after cooking and was therefore ineffective. New transgenic plants aimed at targeting the enzyme to phytase storage vesicles to reduce the phytate content directly are being developed to overcome the loss of enzyme during cooking. These three genes, which influence iron availability and absorption, are being combined with the provitamin A genes by crossing (Lucca et al. 2002) as it is now well recognised that vitamin A deficiency indirectly interferes with iron resorption. This is because higher intakes of beta carotene (converted to retinol after ingestion) may promote absorption of iron and vice versa.

Work at FAO along with its partner in the International Atomic Energy Agency (IAEA) as well as by other investigators have approached this problem in a different manner aimed at agricultural improvement by induced mutation using nuclear techniques (Jain 2000). The aim here is to produce strains of cereals with higher concentrations of micronutrients and improvement of their bioavailability by reduction in the concentration of phytic acid. Raboy (1996) has developed low phytic acid (or lpa) mutant varieties of maize, rice and barley using these techniques. The phytic acid content of lpa seeds was reduced by 50–80% compared with non-mutant seeds but the total amount of phosphorus remained the same as the phytic acid was replaced by inorganic phosphorus. This does not bind trace minerals, thus allowing them to be potentially available for absorption. Unfortunately, unless the levels are reduced below 5% that of the wild type, the strong inhibitory effect of phytate on iron absorption persists (Hurrell 2004).

Careful examination demonstrates wide variation in the nutrient content of a range of food crops such as rice, cassava, beans and maize. Kennedy and Burlingame (2003) have shown that the micronutrient content of rice varieties grown throughout the world varies widely. There is therefore substantial useful genetic variation in the germplasm of key crops which affects micronutrient content and which may be exploited by conventional plant breeding, but this takes a long time. Using molecular markers associated with specific traits, known as Marker Assisted Selection (MAS), can speed up the process.

A strategy of breeding plants that contain high concentrations of minerals and vitamins in their edible parts has the potential to reduce substantially the recurrent costs associated with fortification and supplementation. But this will be successful only if farmers are willing to adopt such varieties, if the edible parts of these varieties are palatable and acceptable to consumers, and if the incorporated micronutrients can be absorbed by the human body (Bouis 2002). According to Bouis (2002), for a plant breeding strategy to combat micronutrient deficiency to work and to be universally adopted, particularly in Developing Countries, five crucial questions need to be addressed. They are: (i) Is it scientifically feasible to breed micronutrient-dense staple food varieties? (ii) What are the effects on plant yields and will farmers adopt such varieties? (iii) Will micronutrient-density change the characteristics of the staple for the consumer? (iv) Will the extra micronutrients in staple foods be bioavailable to humans? (v) Are there other cheaper or more easily sustainable strategies for reducing micronutrient malnutrition?

Thus the ICN goal of promoting sustainable 'food-based strategies' to enable adequate consumption of micronutrients in the developing world can be achieved by the introduction of 'bio-fortified' crops which are varieties bred for their qualitative aspects and not merely to improve yields. The feasibility of plant breeding approaches for improving the micronutrient content of staple crops is real (Bouis 1996). This is an approach that uses both classical plant breeding and modern biotechnology. Breeding programmes can readily manage nutritional quality traits, which for some crops are highly heritable, simple to screen, with the possibility of increasing the content of several micronutrients in the same variety. The desirable traits are sufficiently stable across a wide range of growing environments and in addition, these traits for quality and high nutrient content can be combined with the traits for which staples are specifically bred e.g. superior agronomic characteristics and high yields. Biotechnology enables the identification of markers and thus facilitates marker assisted selection that will enable the transfer of these desirable traits through conventional plant breeding.

There is considerable progress in this new area of biofortification of staple food crops (Nestel et al. 2006). Good examples are iron rich rice (International Rice Research Institute, Philippines), quality protein maize (International Maize & Wheat Improvement Centre, Mexico), high carotene orange flesh sweet potato (International Potato Center, Peru), and high carotene cassava (International Center for Tropical Agriculture, Colombia) (IFPRI 2002). Orange flesh sweet potato has been shown to be an efficacious source of vitamin A both in Mozambique (Low et al. 2007) and in South Africa (van Jaarsveld et al. 2005). It is important to note that while the potential for the breeding of biofortified crops by the agricultural community is high we are quite some way from establishing the efficacy and sustainability of the nutritional benefits of many of these crops. The major advantage of the 'biofortification' approach is that this strategy does not depend much on the change in behaviour of the producer (farmer) although there may be implications for acceptability of these staple foods on the part of the consumer (Bouis 2002). High yielding varieties that already exist can be used and these are widely consumed. The increase in nutrient content is natural variation and hence breeding specifically for these qualities need not necessarily alter appearance, taste, texture or cooking qualities, which influence consumer behaviour. Combining nutritional quality traits with those for high yield or pest or drought resistance ensures ready adoption by the farmer and market success. An added advantage is the increasing recognition that high levels of trace minerals in seeds also aids plant nutrition and may thus contribute to better growth and yields of staple crops (Briat et al. 2007). Because trace minerals are important not only for human nutrition but also for plant and animal nutrition, plant breeding has great promise for making a significant, low-cost, sustainable contribution to reducing micronutrient deficiencies even among livestock and other agricultural food products (Graham et al. 1999). It may thus have other important spin-off effects for environmentally beneficial increases in farm productivity for developing countries and may thereby contribute to agricultural trade from the South.

Conclusions

The persistence of undernutrition and micronutrient malnutrition, despite the phenomenal successes in increasing agricultural production, underlines the need to improve agriculture's interface with other sectors such as health and nutrition (World Bank 2007). Achieving food security alone without tackling nutrition security is to continue to invest in the agriculture sector's customary focus on productivity and yields rather than to broaden agricultural interventions and investments to improve nutrition outcomes of populations in low and middle income countries. Sustainable 'food-based strategies' for food and nutrition security and adequate consumption of micronutrients to reduce the global problem of undernutrition and micronutrient malnutrition can be achieved by dietary diversification and modification strategies and the introduction of 'bio-fortified' crops. Dietary diversification strategies which include home and homestead gardening, small livestock production and other related activities such as nutrition education are sustainable strategies. These provide rural employment, active participation of women and their further empowerment as well as making a contribution to increased awareness of the importance of adequate nutrition for health. Another sustainable approach to reducing micronutrient malnutrition among vulnerable populations in developing countries is to enrich major staple food crops with micronutrients through plant-breeding strategies assisted by biotechnology, which can offer direct and indirect benefits to producers and consumers in developing countries (FAO 2004). Breeding nutrient-dense staple foods can make a major contribution to reducing the global problem of micronutrient deficiencies and at the same time to achieving food and nutrition security. Improving the micronutrient composition of plant foods may become a sustainable strategy to combat deficiencies in human populations, complementing or even replacing other strategies such as food fortification or nutrient supplementation (Zimmermann and Hurrell 2002). Plant breeding thus has great potential for emerging as a long term sustainable agricultural strategy for improving nutrition security as opposed to food security alone. Dietary diversification and biofortification are outstanding examples of how nutritional considerations can be incorporated while addressing the challenge of food security thus integrating the achievement of food and nutrition security of communities worldwide.

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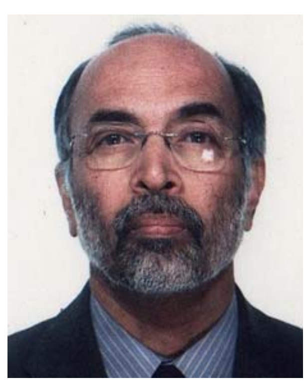

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