Plant breeding: A component of public health strategy

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Micronutrient malnutrition leading to hidden hunger is seriously damaging the health of billions of people world over. Micronutrient malnutrition (e.g., Fe, Zn and vitamin A deficiencies) now afflicts over 40% of the world's population. Food fortification that involves adding of micronutrients to the food has played an important role in tackling the malnutrition problem to a great extent. Biofortification, on the other hand, improves the genetic potential of the crop plants to produce micronutrient-rich grains and thus offers self-sustaining solution.

Micronutrient malnutrition: the 'hidden hunger'

Billions of people in developing countries suffer from a sinister form of hunger called micronutrient malnutrition. Micronutrients are trace chemical compounds (such as vitamins) and trace elements required in small amounts for health and well-being. Most poor people in developing nations rely primarily on staple food crops, food sources notoriously poor in bio-available micronutrients. Often referred to as 'hidden hunger,' micronutrient malnutrition is seriously damaging the cognitive development of children, lowering disease resistance and vital growth in children and reducing the likelihood that mothers survive childbirth. Iron deficiency, is the most widespread nutritional disorder in the world and India is no exception (Table 1). More than 2 billion people globally are iron deficient, and the problem is severe enough to cause anaemia in 1.2 billion people. This condition impairs immunity, making humans susceptible to infection and increases the risk of complications during childbirth. It also adversely affects intellectual development and reduces the mental and physical capacity of populations. From birth to adulthood, iron deficiency is estimated to affect more than three billion people – well over two out of every three persons in developing countries[1]. It is interesting to note that better-nourished, healthier people have higher incomes and contribute more to national income growth[2]. A more direct route to better nutrition could bring considerable economic benefits.

Vitamin A deficiency is a leading contributor to child mortality in developing countries. This key nutrient is crucial for the effective functioning of the immune system. Though on the decline, vitamin A deficiency still affects the ability of 250 million children to fight-off deadly diseases that kill millions of children every year in developing countries. It is also the single most important cause of blindness among children. Micronutrient malnutrition (e.g. Fe, Zn and vitamin A deficiencies) now afflicts over 40% of the world's population and is increasing, especially in many developing nations. According to a World Bank estimate[3], at the current level of malnutrition existing in South Asia, 5% of the gross national product is lost each year due to deficiencies in the intake of just three nutrients, viz. iron, vitamin A and iodine. For each 50 million in population, this translates into an economic loss of US $ 1 billion per year, a whopping over US $20 billion for India.

Agriculture is partly responsible for the current malnutrition. Green Revolution cropping systems may have inadvertently contributed to the growth in micronutrient deficiencies in resource-poor populations. It has never made nutrient output an explicit goal of its production systems. Many agricultural policies have inadvertently fostered a decline in nutrition and diet diversity for the poor. Additionally, the nutrition and health communities have never considered using agriculture as a primary tool in their programmes directed at alleviating poor nutrition and ill health, globally. A new paradigm for agriculture and nutrition is now needed. We must explore ways that agriculture can contribute to finding sustainable solutions to food system failures through holistic food-based system approaches, thereby closely linking agricultural production to improving human health, livelihood and well-being. Such action will rouse support for agricultural research worldwide because it addresses consumer issues as well as agricultural production issues and is, therefore, politically supportable.

Table 1. Prevalence of nutritional anaemia in India

Age group	Per cent affected
Infants	65
Children (1–6 years)	60
Adolescent girls	88
Pregnant women	85

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The Indian scenario

Wheat and rice contribute around 75% of the total grain production in India. Innumerable products are made with these grains, but their consumption pattern is varied. While 85% of the total wheat production is consumed in the form of chapatti in northern, central, western and parts of eastern India, rice is consumed in a big way in southern and eastern parts of the country. A substantial decrease in the availability of legumes over three decades, from an average of 64.4 g during the pre-Green Revolution decade to about 33.6 g per capita per day during 1996 to 2002 (Table 2) in the country, has been largely responsible for protein malnutrition. Women in general and child-bearing women in particular, and the weanling children are the worst sufferers of the nutrient, protein and vitamin A deficiencies (Table 3). Additionally, it has been estimated that globally, about 28% children are undernourished (Table 4).

Approaches to handle malnutrition

Supplementation and fortification – partial solutions to hidden hunger in developing countries

Food fortification is likely to have played an important role in the current nutritional health and well-being of populations in industrialized countries. Starting in the early part of the 20th century, fortification was used to target specific health conditions: goitre with iodized salt; rickets with vitamin D-fortified milk; beriberi, pellagra and anaemia with B-vitamins and Fe-enriched cereals; more recently, in USA, risk of pregnancy affected by neural-tube defects with folic acid-fortified cereals. A relative lack of appropriate centrally-processed food vehicles, less-developed commercial markets and relatively low consumer awareness and demand, mean that it has taken about another 50 years for fortification to be seen as a viable option for the less-developed countries[4].

Traditional strategies for preventing micronutrient deficiencies in developing countries have focused on health-education programmes, long-term vitamin supplementation, and the fortification of important foods. Tireless efforts by the international public health community have made great strides in combating micronutrient malnutrition. Salt iodization, for example, has substantially reduced the negative health impacts of iodine deficiency. Iron, zinc and vitamin A deficiency, however, still plague the developing world, even as public and private nutrition campaigns work ceaselessly to fortify foods, supplement diets and educate mothers about the importance of diversified diets. Existing programmes have not been able to reach all the people who need them at affordable cost. Although often successful in the industrialized world, these approaches tend to be costly and unsustainable in developing countries.

Table 2. Per capita daily availability of pulses (in grams) in the country[11]

Period	Availability
1956–65	64.4
1966–75	46.3
1976–85	41.1
1986–95	38.7
1996–2002	33.7

Global efforts

The Micronutrient Initiative (MI) is a non-profit organization specializing in addressing micronutrient malnutrition. MI is governed by an international Board of Directors. MI supports and promotes food fortification and supplementation programmes in Asia, Africa and Latin America, and provides technical and operational support in those countries where micronutrient malnutrition is most prevalent. MI carries out its work in partnership with other international agencies, governments and the industry. MI is based in Ottawa, Canada and maintains regional offices in New Delhi, India and Johannesburg, South Africa.

This project aims to virtually eliminate iodine and vitamin A deficiencies and to reduce iron deficiency in women in four countries in South Asia (Bangladesh, India, Nepal and Pakistan). South Asia was chosen for special focus because of the magnitude of the problem in the region and the perceived political commitment to micronutrient programming. The project aims to help governments plan and implement national micronutrient programmes using

Table 3. Extent and consequences of micronutrient malnutrition

Deficiency	Prevalence in developing countries	Groups most affected	Consequences
Iron	3.5 billion people	All, but especially women and children	Reduced cognitive ability; childbirth complications; lowered physical capacity
Vitamin A	250 million children	Children	Increased child mortality; blindness
Zinc	May be as widespread as iron deficiency	Women and children	Poor child growth and health; pregnancy and childbirth complications; lower birth weight

an integrated combination of supplementation, food fortification and dietary approaches. The role of MI in this programme is to act as a facilitator and catalyst, provide technical input and encourage donor support. MI works closely with government ministries, UNICEF, World Bank and other agencies. Strategies for each country are tailored to national needs, taking into account political, developmental and operational potential in addition to available data on micronutrient malnutrition in each country. MI's South Asia Regional Office opened in 1997, to address the needs of the large proportion of the regional population suffering from micronutrient deficiencies. The first Director was appointed in 1997, and national programme officers for Bangladesh, India and Nepal joined in 1998. In 1999–2000, activity revolved around ongoing country programmes in Bangladesh, India, and Nepal, and during the last few months, foundational work is being carried out in Pakistan that may lead to a programme in the coming year. Programmes focus on micronutrient needs identified in each country's national plan of action on nutrition, with particular emphasis on population groups most-at-risk of micronutrient malnutrition: young children, adolescent girls and pregnant/lactating women. In South Asia, with the exception of feasibility assessments conducted by international consultants, MI works through local governmental, NGO and international donor partners to implement its activities.

Indian efforts

In recent years, there has been tremendous emphasis at the national level to reduce malnutrition through fortification. Whole meal wheat flour that is used to make chapatti is being fortified with iron; salt is fortified with iodine and made available to the consumers. Such products are available in the markets of metros and cities, and hardly reach the rural folk who really need such fortified products. There are several reasons responsible for widespread anaemia among women from rural settings. Chemical fortification and supplementation, which are the traditional ways of balancing the diet, largely failed to nail the problem of malnutrition. Another important issue responsible for malnutrition among Indians is that around 27% of the population, which is below the poverty line, hardly manages to get two meals a day.

The MI's Indian programme is housed within IDRC's regional office, using its infrastructure to create individual research and intervention projects that address micronutrient needs. MI-India mainly focuses on the directions set out in its strategic plan for food fortification and supplementation at the national level and the control of micronutrient deficiencies, with specific emphasis on IDA, VAD, and IDDs, through integrated health and nutrition programmes at the state level. Research into the fortification of foods like wheat flour, oil, sugar and salt was taken up in partnership with national research institutions like the Central Food Technological Research Institute, the National Institute of Nutrition, the Vasantdada Sugar Institute and others. At the state level, an integrated programme was developed in West Bengal and Gujarat by establishing state-level task force committees and advisory committees, and with the assistance of consultants focusing on fortification, supplementation, dietary diversification and public-health measures (provision of water and sanitation facilities and de-worming). Although the scope of work is wide, fortification and supplementation are the main focus areas.

Table 4. Per cent prevalence of undernutrition in children less than 5 years

Region	% Prevalence
World	28
South Asia	49
Developing countries	29
India	42

Source: Ref. 12.

Biofortification: the lasting self-sustaining solution

Commercial fortification of foods is easier to practice and is a more common intervention to tackle malnutrition. The required micronutrients are added to the food item midway between the farm and the consumer. Imagine, if it were possible to tailor plants which by themselves would do this act of fortification. This indeed is possible and is known as the process of biofortification. Whether achieved through the conventional method of breeding or through biotechnological approaches, this unquestionably is a better option for containing the menace of malnutrition; however, this has its own limitations. Biofortification uses agriculture as an instrument for improving human health and nutrition, as well as for increasing agricultural productivity. The breeding efforts focus on improving the micronutrient content of the staple foods people already eat, providing a relatively inexpensive, sustainable means of delivering micronutrients to the poor. This reduces the number of more severely malnourished people who will still require treatment by complementary, but more costly, conventional methods. The biofortification approach provides a truly feasible means of reaching malnourished populations in relatively remote rural areas and delivering naturally fortified foods to people with limited access to supplements or to commercially marketed fortified foods. Thus, the breeding strategy will complement other successful ongoing interventions to reduce micronutrient malnutrition.

Once in place, the biofortified crop system is self-sustainable. A one-time investment in breeding research will yield nutritionally improved varieties that will continue to be grown and consumed year after year, even if government attention and international funding for micronutrient issues fade. It is this multiplier aspect of plant breeding across time and distance that makes it cost-effective. Mineral-packed seeds sell themselves to farmers because, as recent research has shown, these trace minerals are important to plant nutrition as well. Healthy plants use inputs such as water, fertilizer and soil trace minerals more efficiently, so that the new seeds can be expected to be environmentally beneficial as well[5]. Benefits for agricultural productivity and the environment are complementary aspects of breeding for trace mineral density, which further enhances the cost-effectiveness and sustainability of biofortification. These desirable agronomic traits will also contribute to local food security and greater adoption of biofortified crop varieties by poor farmers interested in increasing their income.

Cereal grains such as wheat, maize and rice furnish the energy that people need to survive. Cereal grains are not good sources of micronutrients, but, at least in wheat, there is good reason to believe that levels of iron and zinc can be increased through plant breeding. If micronutrient-rich wheat were widely available in developing countries, the malnourished poor who eat wheat everyday, would automatically receive iron and zinc without having to take supplements or purchase more expensive foods.

Can wheat pack more nutritional power?

Wheat is the world's most important food crop and any improvement in its genetic potential to pack more nutritive value will have far-reaching results. The nutritional value of some wheat products is given in Table 5. More specifically, the micronutrients range in wheat and other related species is presented in Table 6. There is an urgent need to improve the level of bioavailable Fe (iron) in plant foods. Modern molecular techniques now make it possible to genetically modify plants in ways that can result in more accumulation of Fe in edible plant organs. Significantly, increasing the total amount of Fe in edible portions of food crops will not be enough to satisfy human Fe requirements for several reasons. First, plant foods can contain substances that interfere with the absorption or utilization of Fe by humans (e.g. certain tannins, certain fibres and phytic acid). Second, greatly increasing Fe levels in plant tissues could result in decreased crop yields, consequences which would not be acceptable to farmers. Anti-nutrients in food crops can be significantly lowered via genetic manipulation. However, many of these substances play important metabolic roles in plant growth and development and in plant resistance to environmental stress. Further, they provide important health benefits (e.g. as anticarcinogens and lowering the risk of heart disease). Reducing their levels could be detrimental to both plant and human health. Increasing substances that enhance Fe bioavailability is another possibility. Promoter substances can counteract the negative effects of 'antinutrients' on Fe bioavailability. Promoters should be identified and significantly increased in important staple food crops. Doing so would lower the prevalence of iron deficiency in the world.

To raise the micronutrient content in wheat grain, researchers first need to explore whether some wheats, or wild species related to wheat, have higher levels of iron and zinc than others. Preliminary studies conducted at CIMMYT-Mexico, CIMMYT-Turkey, and the University of Adelaide, Australia have suggested that this variability

Table 5. Nutritional value of wheat products[13]

	Amount of nutrient (g)/100 g*				
Nutrient	Whole grain wheat	Whole wheat bread	White bread	Whole wheat pasta (boiled)	Wheatgerm
Energy	340	246	267	124	360
Protein	10.69	9.7	8.2	5.33	23.15
Fat	1.99	4.2	3.6	0.54	9.72
Carbohydrate	75.36	46.1	49.5	26.54	51.8
Fibre	12.7	6.9	2.3	4.5	13.2
Water	10.42	37.7	36.7	67.15	11.12

*All nutrients in grams, except energy which is in kcal.

Table 6. Range of micronutrients available in wheat and related species

	Range of micronutrients (μg/g DW)			
Crop	Fe	Zn	Mn	Cu
Bread wheat	17.6 to 42.3	7.1 to 60.6	12.0 to 46.8	0.16 to 8.3
Durum wheat	22.3 to 34.1	11.7 to 60.4	15.3 to 33.2	0.92 to 4.67
Triticale	61 to 67	8.3 to 62.4	13.5 to 34	2.4 to 6.1
Rye	41 to 47	23 to 32.3	24.6 to 44.6	2.9 to 4.6

in micronutrient levels does exist, especially in wild relatives and wheat landraces. Since only 1% of the materials available at CIMMYT has been tested, much more variability is likely to be found. Our own experimentations have revealed existence of utilizable variability (Table 5) for these micronutrients in the wheat germplasm available with the breeding group.

Another positive finding is that increased micronutrient content in wheat is not linked to lower wheat yields. There is a good possibility of breeding wheat varieties that will produce high quantities of micronutrient-rich grain. Breeders also need to consider that there may be sufficient micronutrients in the grain, but they may be present in forms that are not available to human beings. Ivan Ortiz-Monasterio, CIMMYT wheat agronomist, points out that micronutrients must be available not only in plants but in soils. 'Soils often contain high amounts of minerals, but they aren't available to crop plants,' he says. 'If plants can't take iron and zinc from the soil, the grain they produce won't have enough of these nutrients either.' Breeders will have to improve the efficiency with which wheat extracts these nutrients from the soil, and just as importantly, the efficiency with which it stores them in the grain.

If researchers develop wheat varieties that deliver more minerals in their grain, agricultural productivity will improve, because plants, like people, need micronutrients. Seed with high concentrations of micronutrients produces more viable and vigorous seedlings. Wheat varieties that are better at taking minerals from the soil have better disease resistance, nutrition and yields, particularly in mineral-deficient soils in arid regions.

Plant breeding as a public health strategy

Maarten van Ginkel and Richard Trethówan, CIMMYT bread-wheat breeders, have raised some important points related to breeding wheat with higher levels of micronutrients. 'Farmers growing the micronutrient-rich wheats will get higher yields and use fewer chemicals to control diseases,' points out van Ginkel. Adds Trethowan, 'Once the genes that increase grain micronutrient content are incorporated into all our wheats, the costs of continuing to breed these wheats will be no different than the costs of breeding "normal" wheats.' Because wheat is the most widely consumed crop in the world, the impact on nutrition could be extensive. In the long run, a breeding programme may cost less and reach more people than most nutrition programmes (another reason why plant breeding could be a sound public health strategy).

Exploring possibilities to establish fortified crops

Before one undertakes a programme for the development of a transgenic, preference of the consumers needs to be considered. As is understandable, golden rice[6] fulfils many of the requirements that will help in containing malnutrition but for the yellow colour, and throughout the world yellow rice hardly finds a place on the dining table. More often, consumers prefer white products (e.g. milled rice, wheat flour, maize, etc.). Improving the β-carotene level in durum wheat would have been an easily acceptable preposition from the consumer point of view, since yellow or orange pasta products would have easy acceptance. There may be several such examples, which might fit in this framework. The scientist who is the main architect would himself have to take the initiative to popularize his product. This, however, goes against the temperament of the scientist, but it is imperative to work in this direction. The concerned scientist should involve scientists from different disciplines like biochemistry, nutrition, plant pathology, agronomy and extension services, and a scientist to evaluate the end-product potentialities of his biofortified product. The group of scientists will generate data on the product from different perspectives, which in turn will help convince the needy policy-makers. Major nutrition education programmes would have to be undertaken to convince consumers to switch over to these coloured varieties. However, if these programmes are successful, then the yellow-orange colour will work as a marker for the more nutritious varieties compared to the less nutritious ones and a disadvantage might have been turned into an advantage[7]. Biofortification through conventional breeding is a time-consuming process and has so far proved to be of little or no significance when it comes to enhancing nutrients like iron in wheat, which remains linked to phytate and is not freely available to the body unless the genes for phytase are incorporated. This is an issue that has not been studied in detail and needs attention. To handle the peculiar situation where the biofortified foods are struggling to serve their purpose, it would be appropriate to work out some other option which would be practical and would receive wider acceptability.

Conclusion and economics involved

Wide diversity exists for the micronutrients in wheat and related species (Table 6). Conventional breeding methodology assisted by molecular markers tools can effectively be employed to develop wheat genotypes containing significantly higher amounts of critical micronutrients. Presence of phytate is said to be responsible for obstructing the bioavailability of Zn and Fe. Information is inadequate to demonstrate the difference in the availability of these nutrients when it comes to comparing high nutrient varieties with those carrying low amount of nutrients. Efforts made to transfer phytate genes from microbes have not been successful because of the thermosensitive nature of the enzyme. Development of GM crops is a feasible option to augment various crops with the required micronutrients. Several transgenics covering various crops are available today. Golden rice is a well-known example in which genes for lysine, iron, zinc and β-carotene have been successfully incorporated. An indica strain enriched with β-carotene and zinc is also now available[8]. Such transgenics are becoming increasingly popular and currently occupy over 40 million hectares globally[9]. It is important to note that most of the transgenics have been developed in the West and the US, where the problem of malnutrition is not a major one. Certainly, the beneficiaries of these GM crops would be the developing and underdeveloped nations. The irony of the problem is that most developed nations are not ready to bring GM crops under cultivation, obviously because they are not sure of their possible undesirable effects. The situation is not at all different in developing countries. Now, the question is whether we continue to develop the transgenics in various crops or we concomitantly work for their logical acceptance as well, without which many of these transgenics may not see light of the day.

Although benefits from supplementation and fortifiction programmes are immediate and carry high benefit-to-cost ratio, benefits disappear fast if investments are not sustained to meet increasing level of investments year after year. If investments are sustained, benefits disappear fast. Some rough calculations may be made for these interventions. The cost of micronutrients and vitamin pills is not high, say Rs 50 per person per year. If one out of every ten persons were to receive supplementation, the whole exercise would require over Rs 500 crores per year on a regular basis for sustained benefits. Plant breeding on the other hand, would require one-time investment of only a few crores to develop micronutrient-rich wheat varieties which would be self-multiplying and self-sustaining. Although plant-breeding research has a longer gestation period before it makes an appreciable impact, an investment of a few crores in two crops, rice and wheat, can take care of malnutrition on a long-term basis in a self-sustainable manner. Once introduced into the working germplasm, these traits will remain in all future cultivars and insulate the population at large against malnutrition.

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