ENGINEERING SOLUTIONS TO MALNUTRITION

GRAIN
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We must resist attempts at such commercial exploitation of malnutrition – whether with respect to genetically modified foods or with respect to the misuse of vitamins.[1]

C. Gopalan, 1999

Introduction

Some 40% of the world's people suffer from micronutrient deficiencies. In the name of the poor, genetic engineering is being promoted as the solution to this problem. Researchers have developed transgenic rice containing beta-carotene and claim it will combat vitamin A deficiency in rice-eating regions. Not only will it address a global public health problem, but it is being promised free to farmers. These nutrient-enhanced crops are receiving a good deal of attention internationally, with an emphasis on delivering the promise of genetic engineering in the guise of humanitarian cause. Critical assessements of the technology have been few and far between, either as a solution to malnutrition, or as a model for delivering the 'benefits' of genetic engineering to the poor.

In the face of growing resistance to the first generation of genetically modified foodstuffs, vitamin A or 'golden' rice provides an opportunity to restore biotechnology to public acceptability. The same goes for Monsanto's development of high beta-carotene mustard. Originally conceived for the market, Monsanto is targeting – for free – poor farmers in the South. But beyond the hype, 'golden rice' may glitter with false promise. Not only could intellectual property rights hamper accessibility and the technology's deliverance to the poor, but the whole 'nutraceutical' approach is fundamentally flawed.

This briefing investigates the problem of malnutrition in context, and argues that as a solution to vitamin A deficiency, genetic engineering is part of the problem, not the solution. Vitamin A deficiency rarely occurs in isolation. It is only one of a whole range of nutrients, the lack of which occurs within the context of poverty, environmental degradation, and social disparity. Technical fixes such as 'golden rice' only treat the symptoms of micronutrient deficiency whilst reinforcing the underlying problem, which is caused by the decline in the diversity of food that is being grown, produced and consumed.

The Green Revolution paradigm of market driven, industrial agriculture that genetic engineering is an extension of, has reduced agricultural biodiversity, and, as a result, dietary diversity, thus increasing micronutrient malnutrition among the poor. The tragedy is that the local varieties this model of agriculture destroys are an excellent source of not only vitamin A but a whole host of other nutrients, in the very countries that suffer from malnutrition. Dietary diversification would provide a sustainable, equitable solution to malnutrition.

This underlying problem affects most profoundly precisely those people nutraceuticals purport to help: those suffering from hunger and malnutrition.

VITAMIN A DEFICIENCY: MALNUTRITION AND BIODIVERSITY LOSS

Engineering vitamin A into crops

Vitamin A rice, developed to counter vitamin A deficiency in the populations of poor countries, was showcased in *Science* in August 1999.[2] This genetically-engineered rice produces beta-carotene in its endosperm, giving it the distinct yellow colour that affords it the name 'golden rice.' It was developed with funds from the Rockefeller Foundation and the European Commission.

Meanwhile, Monsanto developed a high beta-carotene mustard plant which it planned to offer to poor subsistence farmers around the world. The company claimed that it had 'created a *High Beta-Carotene Oil* team that was to work through the *Global Vitamin A* partnership and local stakeholders to identify those areas in greatest need to develop appropriate varieties of crops for those areas and climates.'[3]

Since 'golden rice' has been developed outside the private sector, way-laying concerns over the corporate control of the technology, it has served as a much-needed and timely public relations tool for the promoters of genetic engineering. It is being hailed as proof that genetic engineering does have the potential to end many of the plagues that affect the world's poor. There can be no doubt that golden rice has generated much desperately needed positive publicity for the technology, both to the five corporations that dominate agricultural genetic engineering, and the governments that continue to bid for it as a motor for future growth, during a time of huge levels of public resistance to the technology.

Aside from any genuine concern on the part of the Monsanto's decision-makers and scientists regarding the devastating effects of vitamin A deficiency (VAD), the donation of the high beta-carotene mustard plant reinforces their case for the relevance of agricultural biotechnology to the problems faced by the world's poorest. It could prove helpful in getting the technology accepted on the grounds of the public good, and in countering the very bad reputation the company has managed to earn for itself, mainly in Europe and in India.

Beyond all the hype, critical assessments of the implications of the technology, both as a tool to fight VAD, and as a justification of crop genetic engineering, have been scarce. However, it is only common sense that the relevance of the solutions offered can only be evaluated by assessing them in terms of the problem to be solved.

So what are the causes of vitamin A deficiency? And how appropriate are provitamin A genetically engineered crops as a solution?

Malnutrition

Despite improvements in global food supplies, malnutrition remains one of the most devastating problems facing society. Malnutrition caused by deficiencies in specific vitamins and minerals afflicts some 40% of the world's population, especially women and children. Ironically, the largest numbers of people suffering from micronutrient malnutrition live in South Asia, a region with an incredible diversity of fruits and vegetables that are excellent sources of micronutrients.

Table 1. Micronutrient malnutrition in developing countries

Prevalence	Number of persons (millions)	
	1995	**2025**
Iron deficiency	3,580	2,750
Goiter (iodine deficiency)	834	350
Xerophtalmia (VAD)	2.85	0.17

Source: The World Health Report, 1998, WHO

Vitamin A deficiency (VAD) is considered a serious public health problem and several high level initiatives have been launched to tackle it. Heads of state and top policy makers at the World Food Summit For Children in 1990 set out a goal of eliminating VAD in 2000, a commitment reiterated at the International Conference on Nutrition in 1992 and the World Food Summit in 1996. Despite the progress that has been made, the goal is still a long way off.[4]

Childhood blindness

Within the framework of VISION 2020 of the World Health Organization, childhood blindness is a priority area. Cataract, trachoma and glaucoma, together account for more than 70 % of the world's blindness and visual disability.

Vitamin A deficiency is considered a leading cause of preventable blindness (xerophthalmia) and visual disability in the developing countries. An estimated 350 000 children go blind annually due to this deficiency. The lack of vitamin A has also been shown to impair the immune system, increasing the chances of dying in childhood by about 20%. Pregnant and lactating women in some countries with endemic vitamin A deficiency also exhibit night blindness.

The World Summit for Children in 1990 set a goal to eliminate blindness resulting from vitamin A deficiency by the year 2000. In some countries, this has been achieved. However it remains a public health problem in 78 others. Of the estimated 1.5 million blind children in the world, approximately 1 million live in Asia and around 300 000 in Africa.

Main source: WHO Fact Sheet No. 214, February 1999

Vitamin A deficiency (VAD) is one of the leading forms of micronutrient malnutrition in developing countries, ranking third after iron and iodine deficiency (Table 1). Historically, severe vitamin A deficiency has been associated with blindness, particularly childhood blindness (see Box). More recently, its role in helping to fight infections has come to light. Vitamin A helps prevent diseases such as diarrhea, respiratory ailments, tuberculosis, malaria and ear infections, and helps prevent transmission of Human Immunodeficiency Virus from mother to child, as well as reducing incidence of mortality among pregnant women. According to the World Health Organisation (WHO), around 2.8 million children under five years of age currently exhibit a severe clinical manifestation of vitamin A deficiency known as xerophthalmia. Africa has the highest prevalence of clinical VAD, while the highest number affected clinically and sub clinically are in Southeast Asia.

Vitamin A deficiency in context

Deficiency of a single micronutrient seldom occurs in isolation, but is one aspect of a larger context of deprivation and multiple nutrient deficiencies.[5] Vitamin A deficiency (VAD) is mostly prevalent amidst poverty, environmental deprivation and social disparity.[6] It is considered as one of the components – and a minor component at that – of the syndrome of undernutrition.[7] In many countries, malnutrition with significant health consequences results from lack of zinc, vitamins C and D, folate, riboflavin, selenium, and calcium,[8] in addition to the three micronutrients – iron, iodine, vitamin A – to which so much attention is now given. In the context of multiple nutrient deficiencies and inter-relationships of nutrients, the use of a single nutrient to combat micronutrient malnutrition simply does not make sense.

Table 2. Recommended dietary intakes of vitamin A (retinol equivalents)*

Age bracket		Basal	Safe
Infants		180	350
Children	1-6 years	200	400
	6-15 year	250-350	400-600
Males		300-400	500-600
Females		270-330	500
Pregnancy		+100	+100
Lactation		+180	+350

*The FAO/WHO recommends a basal and safe level intake of vitamin A to prevent deficiency and for adequate liver storage respectively.

Source: FAO. Requirements of vitamin A, iron, folate and vitamin B12. Report of a joint FAD/WHO expert committee. FAO Food and Nutrition Series, no. 23. Rome: Food and Agriculture Organization, 1988.

There are two basic ways the body obtains dietary sources of vitamin A. Provitamin A such as beta-carotene and other carotenoids need to be converted into retinol in the body before they can function as vitamin A. Fruits and vegetables are known to be rich sources of beta-carotene as well as other vitamins and nutrients (see Table 3). Pre-formed vitamin A, known as retinol, is present exclusively in animal foods such as liver, milk and eggs, has the highest vitamin A activity, and is utilized directly by the body.[9]

Vitamin A

Vitamin A was first identified in 1913, but its miraculous properties have really only been revealed in the past decade. Historically, vitamin A is known for its prevention of night blindness and total blindness. More recently, it has been demonstrated that vitamin A could lower childhood mortality by about one-third in many parts of the developing world.

Vitamin A is a key modulator of the immune system. It helps fight infections, preventing diseases such as diarrhea, respiratory ailments, tuberculosis, malaria and ear infections, and helps prevent transmission of HIV from mother to child. It is essential for the proper functioning of the reproductive system and growth of all body tissues. Studies have also linked vitamin A to prevention of cancer by stopping volatile chemicals from oxidizing cell walls.

Vitamin A is a catalyst needed in very minute doses. As a fat-soluble vitamin, it can be stored in the body and used when there is decreased intake. Since it is fat soluble, large amounts can be toxic, especially the preformed vitamin A. Except for yellowing of the skin, large quantities of provitamin A such as beta-carotene from the diet is said to be non-toxic.

Vitamin A is absorbed primarily in the small intestine. Absorption is reduced with alcohol use, with vitamin E deficiency and with excessive iron intake. Storage of vitamin A is decreased in times of stress or illness unless intake is increased. Body needs mineral zinc to help release stores of vitamin A for use.

Vitamin A intake is often inadequate because of the seasonality of food sources, the early abandonment of breastfeeding, and the practice of not giving vitamin A rich foods to young children. Improper processing and storage also destrOys vitamin A, which decomposes in light. Vitamin A absorption may also be impaired where the diet is very low in fat or where intestinal parasites are prevalent. [10]

The origins of vitamin A deficiency in childhood can be traced to poor vitamin A nutrition status of the mother during pregnancy and lactation, resulting in poor liver reserves of vitamin A in newborns and in the breast milk; and poor intake of foods rich in either preformed or provitamin A by the infant after weaning and thereafter.[11] A logical approach then to the prevention of vitamin A deficiency must seek to address these basic causes, rather than relying on a single technological fix. Fortunately, the heritage of abundance of natural foods in developing countries should be able to achieve such dietary improvements.

Table 3. Micronutrient content of drumstick leaves compared to common foods (values per 100 g edible portion)

Nutrient	Drumstick leaves	Other foods	
Vitamin A activity (mcg RE)	1,130	carrots:	315
Vitamin C (mg)	220	oranges:	30
Calcium (mg)	440	cow's milk:	120
Potassium (mg)	259	bananas:	88
Protein (g)	6.7	cow's milk:	3.2

Source: C. Gopalan et al. Nutritive Value of Indian Foods. *National Institute of Nutrition, India, 1994.*

Farms, not pharmacies!

Three measures are currently being employed worldwide to control vitamin A deficiency: supplementation, food fortification and dietary diversification. Those assessing existing methods of countering VAD have already identified the desirability of moving away from the 'quick-fix' approach of fortification and supplementation, and towards dietary diversification approaches.

Supplementation

At the time of its introduction in the 1960s, supplementation was thought of as a short term emergency measure. But most of the current strategies worldwide rely still rely heavily on health interventions – usually the administration, at periodic intervals, of massive oral dosages of synthetic vitamin A supplements to children under three years of age. This was pioneered in India in the late 1960s. [12] What was originally envisaged as a temporary and short-term measure, and an adjunct to dietary improvement of communities in India, became the default model for current programs to eliminate VAD.[13] UNICEF estimates that half of the children in the world who were at risk of vitamin A deficiency received at least one high dose of vitamin A in 1998. The ease of supplementation has meant neglection of research into and promotion of better use of inexpensive beta-carotene rich foods[14].

This 'drug-based approach' to synthetic vitamin A distribution has received wide criticism, even from the very individuals who have pioneered the work.[15,16] Some of the limitations cited based on the 30-year experience of India are: ineffectiveness in correcting VAD (especially in populations where milder signs of deficiency are widespread), the limited shelf-life of vitamin A, and logistical problems in ensuring supply. Supplementation programs are often expensive and unsystematic, and coverage may be poor. Frequently, the key target groups are different for each micronutrient, and operational constraints are severe.

As a result, a more physiological approach, addressing the root causes of the problem has been called for – one that improves carotene-rich food intake, available in abundance in the very regions where VAD is a public health problem. This, it is claimed, is a more logical approach towards combating VAD – or any nutritional deficiency for that matter – and must be the basis of corrections in the habitual diets of affected populations. This was codified at the 'World Declaration and the Plan of Action on Nutrition',[17] unanimously adopted by 159 countries at the International Conference on Nutrition jointly organized by FAO and WHO in 1992. While recognising that severely deficient populations may require short term supplements, Item 43 states that strategies to combat micronutrient malnutrition should:

> Ensure that sustainable food-based strategies are given first priority particularly for populations deficient in vitamin A and iron, favoring locally available foods and taking into account local food habits.

It concludes:

> Supplementation should be progressively phased out as soon as micronutrient-rich food-based strategies enable adequate consumption of micronutrients.

Furthermore, the International Conference on Nutrition pleads forcefully in its Plan of Action for a policy of:

> …promoting the dissemination of nutrition information and giving priority to breast-feeding and other sustainable food-based approaches that encourage dietary diversification through the production and consumption of micronutrient-rich foods, including appropriate traditional foods. Processing and preservation techniques allowing the conservation of micronutrients should be promoted at the community and other levels, particularly when micronutrient-rich foods are available only on a seasonal basis.

These statements are a clear call for the action that is urgently needed to promote dietary diversification for the prevention and control of micronutrient deficiencies.

Fortification

Fortification of butter, margarine and sugar with vitamin A is already being implemented in some countries. It too has drawbacks. In most instances, food fortification is only feasible in countries that possess well-developed, efficiently monitored and properly regulated pharmaceutical and food processing sectors.[18] Like supplementation, fortification does not lead to awareness building and changes in wider dietary habits ,[19] and its impact is limited to those who can access these fortified products.

Diversification

Dietary diversification is cheaper than any form of supplementation or fortification. First and foremost, it requires a minimal amount of foreign currency, it promotes intakes of a whole range of micronutrients rather than singling out and tackling just one, it is sustainable, it fosters community and individual involvement, and can help stimulate local food economy.

Furthermore, this approach does not 'medicalise' food and nutrition, rather it enables individuals, families and communities to maintain their own health and nutrition.[20] The key to this solution lies in bringing about a shift away from the growing of just staple crops, to a diversity of crops in the fields.

Revealing 'Hidden Hunger'

> Because people for the most part are not aware that their diets are lacking in this trace nutrients and hence do not associate these deficiencies with listlessness, poor eyesight, impaired cognitive development and physical growth, and more severe bouts of illness (sometimes leading to death), this general problem of poor dietary quality has been dubbed 'hidden hunger.[21]
>
> H. Bouis, 1995

An individual feels hunger when his or her calorie intake declines. In contrast, there is no corresponding immediate ‘warning signal’ when the intake of micronutrients declines. This is why micronutrient malnutrition has been dubbed 'hidden hunger'. Because deficiencies of this sort often go unnoticed, developing slowly and subtly, the connection to adverse health outcomes is not apparent to people.

Given this, it would seem obvious that a solution to 'hidden hunger' is education. This means ensuring that people, and in particular the most vulnerable, are fully aware of the causes underlying micronutrient malnutrition, and that the connections between dietary quality and diversity, nutrition, and health are emphasised. Promotion of micronutrient rich foods through education is still the safest and most sustainable way of controlling and preventing most deficiencies. Furthermore, it improves not just a single nutrient deficiency, but improves nutrition overall, and works through increased self-reliance.[22] It is should be made apparent that inexpensive sources of vitamin A and other nutrients abound, where even low-income groups can easily satisfy their dietary vitamin A requirements,[23] without having to rely on capsule deliveries and other 'medicalised' interventions.

Making use of diversity

Green leafy vegetables are the predominant sources of micronutrients for poor people. In India, for example, the prevailing vitamin A malnutrition reflects the inadequate intake of these beta-carotene rich foods. Efforts in combating vitamin A deficiency must therefore, be logically directed towards augmenting the availability and intake of these relatively inexpensive foods.

Abundant sources of vitamin A exist. However, the contribution of such plants to alleviating micronutrient deficiencies is greatly underappreciated. Among the wide range of green leafy vegetables, drumstick leaves (*Moringa oleifera*) in particular provide a very rich and inexpensive source of pre-formed vitamin A, in addition to other important micronutrients. Native to India, the tree grows abundantly in all tropical countries where vitamin A deficiency is a problem. A glassful of fresh *Moringa* leaves contains the daily requirement of vitamin A for up to ten people, or small amounts of less than 10 gm of fresh can meet the day's requirement of vitamin A of preschool children.

Ivy gourd, popularly known as *'tum leung'*, has been the subject of a successful nutrition information intervention project in Thailand which helped improve knowledge, attitudes and practices of local populations. Having identified remarkably low vitamin A and fat intakes among people living in one of Thailand's poorest regions, researchers from Institute of Nutrition, Mahidol University in Thailand focused on creating a 'nutrition information environment' in target groups. People were encouraged to grow *tum leung* in their gardens. Almost 5,000 households participated. Given the right education tools, Dr. Suttilak Smitasiri of the Institute of Nutrition believes that the poor can be very receptive to changing their eating habits.

In Western Africa, one of the richest sources of provitamin A is the oil of the oil palm *Elaeis guineensis.* This is being actively being promoted by FAO in certain northern parts of Benin, Ghana, Nigeria and northwestern United Republic of Tanzania where conditions prevent the establishment of palm-oil production and also where clinical vitamin A deficiency exists. One of the ways of increasing access to this nutritionally valuable plant is to raise the extraction yields by improving village technology, a strategy that has been successfully promoted by FAO in the Luapula valley in Zambia. As a component of backyard home gardening, FAO is introducing tenera palms from Costa Rica to the Luapula region with the objective of increasing access to oil-palm fruit even for the poorest people in the community. In Brazil a local tree called 'burité' produces oil as rich in B-carotene as that of the oil palm, and this is being promoted as part of the national efforts to prevent vitamin A deficiency.

The Green revolution: feast and famine

> *The trend for more and more people to be nourished by fewer and fewer plant and animal food sources has reached the point today where most of the world's population is absolutely dependent on a handful of species. The four crops at the head of the list contribute more tonnage to the world total than the next 26 crops combined. This is a relatively recent phenomenon and was not characteristic of the traditional subsistence agriculture abandoned over the past few centuries. As the trend intensifies, man becomes ever more vulnerable. His food supply now depends on the success of a small number of species, and the failure of one of them may mean automatic starvation for millions of people. We have wandered down a path toward heavy dependence on a few species....*
>
> Harlan, 1976

The prevalence of micronutrient deficiencies now far exceeds protein and calorific malnutrition in Asia. Despite substantial increases in cereal supplies, which have contributed to increased intake of calorie- and protein-rich foods, the supply and consumption of foods rich in micronutrients have not increased proportionally, and in many cases have actually declined.

Only 30 crops 'feed the world', providing 95% of dietary energy and protein requirements. More than half of these come from wheat, rice and maize alone.[24] It is these three crops that have received the most investment in terms of conservation, improvement and breeding, and served as the cornerstone of the Green Revolution in the 1960s. Monocultures of these crops were encouraged, justified on the grounds that staples played an important role in satisfying food adequacy[25] by providing the much needed calories to support a growing population and avert famine. In effect, nutrition was equated to adequacy in the supply of macronutrients alone. The result was the growth of food supply that provided more and more of the macronutrients but did not provide the much-needed micronutrients, which were already in short supply.[26]

Even more alarmingly, micronutrients may have actually declined in diets. According to the UN ACC/SCN report, the introduction and expansion of the Green Revolution in many countries has resulted in a decreased availability of and access to micronutrient rich food crops for millions of poor people.[27] Many traditional micronutrient-rich plant foods have since become less abundant and more expensive to obtain, either because their production has fallen and/or has not kept abreast with the demand due to increased population pressure. Some can no longer even be found in the field. Today, more than two billion people consume diets that are less diverse than 30 years ago, leading to deficiencies in micronutrients, especially iron, vitamin A, iodine, zinc and selenium.[28] The Green Revolution, with its increased global caloric output, is said to have contributed to micronutrient malnutrition afflicting more than 40% of the world population,[29] and it continues to take its toll in developing countries.[30]

The replacement of traditional crop varieties in the field – the major cause of genetic erosion around the world – also had its impact in small homegardens. A farm household survey in the

Republic of Korea, for example, revealed that out of 143 crops cultivated in home gardens in 1985, only around 26% of landraces remained cultivated by 1993. These results are disturbing since such home gardens have traditionally been important not only as conservation sites especially for vegetable crops[31] but also as an important source of vitamins and minerals at the household level. Thus the decline in the availability of genetic resources in the field results in the consequent decline in the sources of important nutrients.

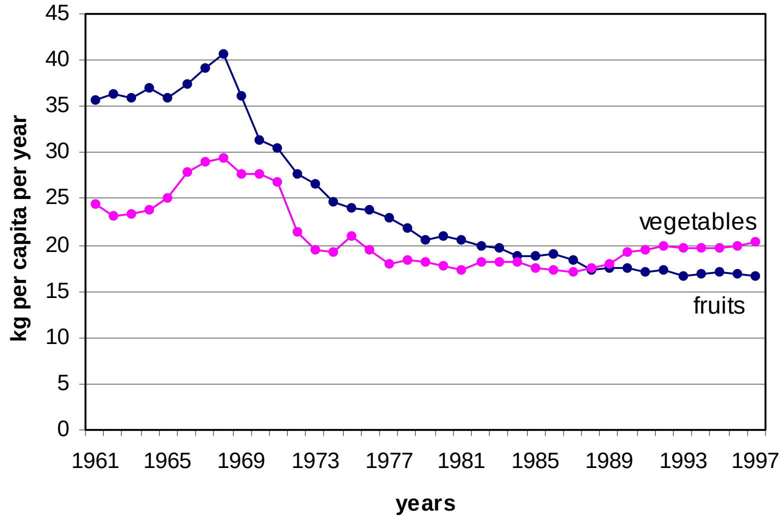
Farmers have also abandoned planting nutrient-balancing crops, such as pulses, in favor of the highly yielding new cereal varieties.[32] Furthermore, the adoption of industrialized staple crop monocultures does not allow the farmer to grow mineral- and vitamin-rich legumes together with rice or wheat. With the use of fertilizers and semi-dwarf varieties, those legumes gained a competition advantage and turned into 'weeds' which were then attacked with herbicides.

One example of this from India is that of *bathua*, an important green leafy vegetable, high in nutritional value and rich in vitamin A, which grows as an associate of wheat. However, with intensive chemical fertilizer use, *bathua* becomes a major competitor of wheat and has been declared a ’weed’ that is killed with herbicides and weedicides. Thus we see the industrial model of agriculture actually destroying freely available sources of vitamin A.[33]

To take an example of another nutrient, the amount of iron in peoples' diets actually fell in most developing regions of the world between 1970 and 1989. The most dramatic case was in South and Southeast Asia, which were also the regions where the Green Revolution had its greatest impact. In India, per capita consumption of pulses – an important source of protein and iron – dropped from 23 kg per capita per year to 13.4 kg per capita per year from 1981 to 1990.[34] Once known as a ‘poor man’s crop’, decreased production has led to a dramatic increase in the market price, which makes it less accessible to the poor – a scenario repeated for other regions and nutrient-rich crops.

For example, a consistent decline in per capita consumption of green leafy and yellow vegetables occurred in the Philippines.[35] The same is true for vegetables, fruits, pulses and spices in Bangladesh,[36] and the bias still persists today.

Losing out on precious nutrients?
Per capita availability of fruits and vegetables in Bangladesh



Source: Compiled by GRAIN from FAO Food Balance Sheet, updated 21 June 1999

An emphasis on rice, wheat and other cereal crops over the years, led to a decline of vegetable-growing areas, which eventually turned into marginal land. From 68 g of vegetables per capita per day in 1950, availability was more than halved to 24 g per capita per day in 1995.[37] The continued neglect of other non-cereal crops has resulted in unchanging food habits over the years. This situation caused the Director of the Horticultural Research Center of Bangladesh Agricultural Research Institute to suggest that:

> Food patterns could have been changed and we could have attained self sufficiency in food and nutrition much earlier with 300 g cereal/capita per day as against achieving food self sufficiency today with 500 g cereals.[38]

It is true that the Green Revolution created more bulk of food, feeding a needy population in Bangladesh, but we cannot ignore the negative impacts of the programme which resulted in a national diet that over time has become more restricted and less nutritious.[39] The ‘commodity bias’ of the Green Revolution meant a favouring of cereals which came ultimately at the expense of non-cereal food crops which are important sources of micronutrients. Non-cereal food prices in Bangladesh during the Green Revolution period increased both relative to cereal prices and in real absolute terms. While real incomes on the average did not increase, the poor could no longer afford traditional vegetables such as the the ß-carotene rich carrots, fruits and red pumpkin, and were forced to rely increasingly on cereals to fill the bulk of their diet.

The solutions to vitamin A deficiency, and malnutrition generally, should not therefore be yet another ‘techno-fix’ to solve the problems the original ‘techno-fix’ of the Green Revolution. Rather, a multidisciplinary approach that encourages diversity in agricultural systems, and spreads knowledge about the causes of malnutrition, has proven to be successful . Research in Bangladesh showed that traditional meals with rice and cheap, easily available vegetables like amaranth, are adequate to ensure a sufficient vitamin A supply to children.[40] And experimental education programs for women demonstrated that health education has a significantly positive effect on the quality of meals they prepare for their children.[41]

Table 4. Vitamin content of some common green leafy vegetables (values per 100g of edible portion)

Leafy vegetable	Carotene (μg)	Total Folic acid (μg)	Vitamin C (mg)	Iron (mg)	Calcium (mg)
Spinach	5580	123	28	1.14	73
Amaranth	5520	149	99	3.49	397
Bathua leaves	1740		35	4.2	150
Drumstick leaves	6780		220	0.85	440
Fenugreek leaves	2340		52	1.93	395
Agathi	5400		169	3.90	1130
Radish leaves	5295		81	0.09	265

Source: Gopalan et al. 1989.

The diversity of agricultural produce is the basis of balanced nutrition. People cannot rely on rice or wheat or maize alone: they need a variety of crops and animal products in the diet. As such, we need to highlight the crucial role of plant diversity, not just in filling the bowls with food bulk, but filling them with nutritious food that improves human health overall.

Thus it is becoming evident that the Green Revolution represented a trade-off between quantity and quality in peoples' diets, especially amongst the poor. Even IRRI admits that the Green Revolution may have actually increased micronutrient malnutrition among the poor.[42]

But IRRI can not look beyond the Green Revolution model for a solution to this problem, and is looking to genetic engineering to get it out of the hole it has dug for itself. Like many other international organisations involved in agricultural development, IRRI sees the answer to micronutrient malnutrition in engineering the missing elements back into Green Revolution crops. Some of the most advanced research in this arena is on engineering vitamin A into rice and mustard plants. These vitamin A crops are being hailed as evidence that genetic engineering holds promise for the poor as well as the rich, and that transgenic crops can benefit humanity as well as generating profits for the gene giants. This new approach is expected by many to supplant existing strategies for dealing with VAD, hopefully overcoming their limitations.

WILL GENETIC ENGINEERING SOLVE THE PROBLEM?

State of the art: 'golden rice'

'Golden rice' is the product of two research teams under the direction of Dr Ingo Potrykus of the Swiss Institute of Technology in Zurich, and Dr Peter Beyer of the University of Freiburg. The idea of genetically engineering beta-carotene into rice emerged nine years ago, in the light of UNICEF and WHO reports on the high incidence of VAD in countries where rice serves as a staple food. Dr Potrykus submitted a funding proposal for the project to the Rockefeller Foundation. After brainstorming sessions with biologists (which included biochemists, microbiologists, beta-carotene specialists) to asses the viability of the proposal in 1991, the Rockefeller Foundation took over the responsibility over the project and funded the research,[43] a commitment it has maintained until 1999.

The researchers genetically engineered a laboratory variety of *japonica* rice (Taipei 309, adapted to temperate weather in Europe rather than to tropical areas) and introduced in it a metabolic pathway so that part of a naturally-present precursor of a hormone (geranyl geranyl diphosphate) is converted into beta-carotene. The use of specific gene promoters (DNA sequences that switch genes on) ensures that this methabolic pathway is only expressed (only 'works') in the rice endosperm (the part of the grain that remains after milling). The team has added three genes: two of them (the first and the last in the methabolic path) are new to genetic engineering and come from daffodils (*Narcissus pseudonarcissus*). The third comes from a bacterium, *Erwinia uredovora*,[44] which has been already used by Kirin Brewery. Although there have been reports that the golden rice has been crossed with another rice line resulting in a higher iron content, this second trait is, in words of Dr. Beyer, still in the pipeline[45].

The amount of hype given to 'golden rice' seems a little premature given that only a handful of genetically engineered seeds have so far been developed. All that is certain is that some of the transformed seeds contain beta-carotene in the endosperm, but it is not even clear yet whether or not it is available for human absorption.[46]

Even if the rice proves to be a success, the beta-carotene trait still needs to be transferred to the *indica* rice varieties, the types grown in Asia. This work will be done by several of the International Agricultural Research Centres (IARCs), including the Philippine-based IRRI, the India-based ICRISAT and the Colombia-based CIAT where further cross-breeding and field testings will be done. IRRI, together with the Philippine Rice Research Institute (PhilRice), is set to transfer the golden trait to other varieties as soon as its application receives approval from the National Committee on Biosafety of the Philippines.

Thus IRRI's approach to deliver the benefits of this 'golden rice' as rapidly as possible is to insert the trait into high yielding varieties such as IR64 – varieties which are widely grown in irrigated and better environments. According to Dr. Khush, one of the principal plant breeders at IRRI, it would be important to prioritize these environments because 80% of rice comes from these areas. It is these areas which happen to provide rice for the megacities[47]. PhilRice also wants to transfer the genes to 'elite rice varieties and breeding lines in the Philippines', rather than to locally-adapted varieties. The promises of the 'golden rice' certainly do not include a transition towards a more sustainable, low-input agriculture.

Vitamin A rice has a long way to go still. Success in the laboratory means little in the field. Transgenic plants which perform well in laboratories often fail in nature, especially if they contain not one, but three added gene-constructs.[48] Besides the potential impact of the golden rice on the environment, about which only speculation can be made right now (see box), there are also potential social and cultural obstacles, such as palatability and public acceptance of the rice.

But ultimately, one of the biggest problems with the technology is that of approach. The team who developed vitamin A rice appear to have begun with a solution, and only afterwards enquired into the real problems of VAD. According to Dr. Beyer, one of the co-directors of the project, with the exception of one nutritionist, the team consisted entirely of plant scientists, who had no involvement or expertise in relevant fields such as extension or nutrition education. On the other hand, the references to the problem of VAD in the scientific paper published in *Science* in January 2000 are dated 1992 or before. Both facts appear to indicate a lack of awareness on the part of the developers of golden rice technology, of the most recent findings about the actual problem which associated VAD with hidden hunger. It was only *after* provitamin A was a reality in the laboratory, that Potrykos' and Beyer's team even bothered to contact international institutions with experience – and a much broader approach and perspective – around VAD, institutions such as the UNICEF, the FAO and the WHO. Had they done so prior to undertaking the research, the project might well have never happened.

Another cultural issue around the golden rice is that of its acceptability. Consumers could very well reject a rice which is yellow instead of white. Although Dr. Beyer acknowledges that this issue is beyond his expertise (and beyond that of his team), his own view is that people accept something they know is good for them. However, people will only realise this through some kind of education effort. But if it is nutritional education efforts that are needed, why devote them to convincing people to eat genetically engineered rice that will provide them with one vitamin source, instead of promoting dietary diversification and the increased consumption of green leafy vegetables that are already available, thus solving a whole host of micronutrient deficiencies beyond just VAD?

However well-intentioned they were, ultimately, the specialisation and isolation of the teams developing the 'golden rice' has led to a kind of blindness of their own. That is, to use a purely technological approach that has not bothered to take into account either their scientific colleagues who work on broader issues of nutrition and agriculture, or to the realities of global problems which require a participatory and interdisciplinary approach that takes into account the context in which the problem occurs, the grassroots needs of local communities, the appropriateness of the solutions being posited, and the social, ecological, economic, and cultural realities of the people one is attempting to help.

‘Golden rice’ and biosafety - by Hartmut Meyer, GENET

The PhilRice document pertaining to biosafety says: 'Transgenic rice plants … are expected to have no harmful effects on the ecology and environment.' They are taking the optimist‘s don’t-look-don’t-see approach to biosafety, asserting that the transgenes involved already occur widely in nature and therefore pose no risk: 'The transgenes are involved in the biosynthesis of carotenoids which are a widely distributed class of natural pigments synthesized in all photosynthetic organisms and some non-photosynthetic organisms as certain bacteria and fungi.' This approach ignores that not the existence of ß-carotene in plants as such but only its availability and distribution in a specific plant has to be the basis of every reasonable risk assessment.

Thus the widely recommended case-by-case-approach will not be applied to vitamin A rice. Conventional rice exhibit no significant ß-carotene concentrations in the grains. This will change with 'golden rice' which, applying the OECD guidelines, will propably not be 'substantially equivalent' to existing rice varieties. Every organism feeding on rice grains can be affected in an unintended and unforeseeable manner.

Some questions on biosafety of vitamin A rice in a wider sense arise from the new biochemical pathway itself. As already mentioned this pathway uses the chemical compound geranyl geranyl diphosphate (GGDP) as source for ß-carotene synthesis. In unaltered rice grains GGDP serves as source for the synthesis of a certain class of plant hormones, the gibberellins, and some other socalled 'secondary' metabolites. The genetic modification of the rice seed could disturb the plant hormone system which plays a crucial role in the germination of seeds and the development of seedlings. The research team communicated to GRAIN that compared to control plants, the genetically modified rice seems to have the same fertility and germination rate. Possible effects on the rice hormone system could not only pose problems concerning ecological and health biosafety aspects but can directly affect the quality of the seeds. A predictable germination behaviour, unchanged from sudden and unforseeable influences of the engineered genes, is crucial for farmers’ role to ensure a secure and stable food supply.

In the face of GE plants with marked alterations in biochemical pathways and nutritional value, extensive ecological testing of the new varieties must be performed before any decision about their introduction is made. Only further research and publically available data will allow a valid assessment of the safety of ‘golden rice’.

Monsanto’s mustard

While the development of vitamin A rice seems to be genuinely well-intentioned, if perhaps misdirected, Monsanto’s beta-carotene mustard has more questionable roots. Calgene, which was bought by Monsanto in 1996, first developed rapeseed (*Brassica napus*) with elevated carotenoid levels in order to serve the food and feed industries colouring, supplementation and fortification markets. Unlike the ‘golden rice’ initiative, the objective was purely commercial. Transferring the technology to mustard (*Brassica juncea)*, a close relative, was an afterthought.

Monsanto’s donation should be viewed within the context of public rejection of genetic engineering and corporate-led international pressure for India to adopt patents on plants. These measures will prevent farmers from saving their seeds, and thus enlarge the market for seed companies, in a process that runs parallel to the turning of mustard into an international trade commodity. Monsanto's beta-carotene mustard - the most important oil crop in South Asia – arrives on the scene just as the crop is entering the commercial seed market.

It is not that rapeseed or mustard are new in South Asia. According to FAOSTAT, in 1961 India and China accounted respectively for 37% and 11% of the then 3.6 million tones output. In 1999, world's production increased ten times – reaching 42.24 million tones. The increase has been accounted for mainly by the countries within the European Union, Canada and China. However, India is still the world's fourth rapeseed producer. That year, China and India ranged respectively first and second as producers of rapeseed oil, and third and fourth as rapeseed oil importers. By far, the most important exporters of both rapeseed and rapeseed oil are developed countries, headed by Germany, France, Canada, Australia and Germany.

It is the development of an Indian seed industry, and, more recently, its association with transnational agrochemical companies that is pushing mustard (the Indian relative to rapeseed) into the corporate domain. In 1994, it was estimated that Indian farmers purchased 33% of their mustard and rapeseed seed from companies – the rest was obtained from seed they saved.[49] In 1998, the Indian market for mustard and rapeseed was estimated around US$ 12 million.[50] Monsanto is present in the Indian seed market through its agreements with Mahyco and its ownership of Cargill.

It is in this frame that a technology developed for profit has become a handy public relations tool. Calgene, which was bought by Monsanto in 1996 had been developing rapeseed plants capable of producing an elevated level of beta-carotenes and a host of other carotenoids, which turned out to already have a different – and potentially more profitable – proportion of fatty acids. The aim of their work was to turn oil plant seeds into factories for the production of modified oils. Calgene made use of genes from *Erwinia uredovora,* a bacteria that also provides one of the genes involved in the golden rice, with a Calgene-patented promoter specific for the seed (napin promoter, US 5,420,034). Subsequently, Calgene applied for a patent holds covering 'a transgenic plant which produces seed having altered carotenoid levels' (WO9806862), which has been applied for in both developed and developing countries. Calgene signed in November 1996, a royalty-bearing cross license agreement with Kirin Brewery Co., Ltd. of Tokyo, Japan for commercial use of their patented carotenoid biosynthesis genes from *Erwinia uredovora* (EP0393690). The move to cater for small and subsistence farmers only came in later after its parent company faced immense public opposition for its genetically engineered crops and its IPR policies.

Monsanto is at work, but the promised vitamin A rapeseed oil is still far away. The company's R&D center at the Indian Institute of Science in Banglore is developing a protocol to genetically engineer the gene that induces beta-carotene production in rapeseed (*Brassica napus*) into several public varieties of its close relative, mustard (*Brassica juncea*). The company hopes to obtain genetically engineered mustard varieties by the end of 2000. Field testing will take a further 2 to 3 years. Meanwhile, many questions remain. Since beta-carotenes are fat-soluble, Monsanto expects that the oil from its transgenic mustard will be readily absorbed by the human body. However, heat destroys beta-carotene, and mustard oil is most often consumed after cooking, so the beta-carotene needs to be stabilised somehow.[51] Another drawback is that the modified rape seed oil is orange in colour, which could affect public acceptance.

Despite Monsanto's claims to work through local stakeholders, so far it only points to only the new Delhi based TATA Energy Research Institute as an actual partner. The company's bullish approach to testing its Bt cotton in India, as well as bad publicity over its plans for Terminator seeds has created widespread bad feeling in the country. Thus the charitable nature of the vitamin A mustard donation cannot mask, in the eyes of many, the other, less well press-released activities of the company that may directly result in a decrease of diversity and in farmers' disempowerment.

Public good … private patents?

An important issue that has not been considered in the press debates over vitamin A enhanced crops is that of intellectual property rights. It may come as a surprise given the project's public research origins that, according to a member of the Swiss team that developed the golden rice, a patent application has been filed for it. But this is direct consequence of the very nature of the development of genetic engineering as a technology that has been tied into private profits and patent systems to protect them.

In the case of Monsanto, the case is straightforward. The company owns – through Calgene – the patent on the rapeseed and on the promoters it has used. Monsanto is, in principle, bound to pay royalties to the developers of the transformation method it has used to produce the transgenic rapeseed and to Kirin Brewery for the *E. uredovora* gene that is inserted in the plant.

Monsanto has announced that it aims to provide the high beta-carotene mustard free of charge to poor and subsistence farmers 'not fully participating in the world economy'. What this means in practice is not yet clear. What will be the limit for the sale of the rapeseeds or the oil thereof? Will they gain entry into the commercial circuits? Will they only affect the purchase of the seeds or oil by large national or international corporations? How would such limitations affect the availability of the beta-carotene oil to the poor? And, how will it negotiate with Kirin Brewery? Sources from Monsanto's R&D Institute say that while the project is philanthropic, the company has no clear policy to answer these questions.

In the case of the 'golden rice', its developers intention and claim is that it is to be given free of charge to farmers. However, we will have to see whether this claim can be borne out by reality given the patent hurdles it faces. Despite being funded by the public sector, the 'golden rice' is to a large extent the product of private companies. The development of the rice has involved processes, genes and promoters of which at least six were already patented (see Table 5), and this will surely effect how it is going to be delivered to the poor, and to the rest of society. On top of these six patents, the teams of Zurich and Freiburg have filed a patent application covering the insertion of the metabolic pathway to produce beta-carotene in seeds. The scientists involved claim this was to prevent other parties (i.e. corporations) from patenting the technology.

The scientists have presented themselves as willing to break the patenting laws in order to fight poverty. They argue that they know personally some of the scientists holding some of the patents involved, who have promised they will license the technology for free. They also argue that no company is going to want to be vilified as profiteering on the backs of the world's poor by preventing the use of their patented processes, genes or promoters.

However, the first argument is weak: it is the companies funding the research, not the 'inventors' themselves, that hold the patents. And the second argument, backed up by the claim that the researchers are willing to break the law for ethical reasons against patents, is at odds with their own application for patent protection.

The patent was not necessary to prevent others from appropriating the results of a charitable research: putting it into the public domain through publication would have averted such a risk. The application covers the introduction of this methabolic pathway into any given crop, and any company wishing to use the process for any plant will have to negotiate – and possibly pay royalties – to the patent owner. Paradoxically, the patent renders the main objective of the not-for-profit research project, rice for poor farmers, into the exception. It is only under some circumstances – as specified in a contract between the 'inventors' and the international agricultural research centers – that the technology is transferred to the tropical varieties poor farmers grow. GRAIN has not had access to this contract, but Dr. Beyer has stated that it is intended to guarantee that the use of the varieties will be purely non-commercial. Under the contract, according to Beyer, 'Subsistence farmers and their surroundings will have this for free and are free to multiply… and exchange with other farmers'.

Table 5. Golden rice: IPR auditing required

Processes and sequences	Patent number	Owner/Company
Agrobacterium transformation	WO8603776 (1986)	Plant Genetic Systems (Aventis)
Daffodil Phytoenhe-Synthase (PSY) and Lycopene-Cyclase (LYC) genes	Patent applied for by developers	University of Freiburg (Peter Burkhardt)
Erwinia uredovora phytoene desaturase gene (CrtI)	EP0393690 (1990)	Kirin Brewery
Use of constructs comprising a carotenoid biosynthesis gene	WO9806862 (1998)	Calgene* (Monsanto)
Endosperm-specific glutelin (Gt1) Promoter of the Daffodil genes	J6391085 (1988)	Noriinsho
CaMV 35S promoter of the E. uredovora gene	US5106739 (1992)	Calgene (Monsanto)
AphIV marker gene	US5668298 (1997)	Eli Lilly

* Claims property on 'A transgenic plant which produces seed having altered carotenoid levels '. Patent asked for in developing countries. Calgene has an agreement with Kirin Brewbery.

Source: Compiled by GRAIN from Xudong Ye et al. (2000), Derwent Biotechnology Abstracts and Esp@cenet.

There are precedents on agreements between international agricultural research centers and private sector companies in order to allow the first to further develop technologies patented by the second and then distribute the results under restricted conditions to farmers in developing countries. Ciba-Geigy (which merged with Sandoz to form Novartis) made Bt genes available to IRRI to develop rice, and the rice produced with this gene can be made freely available to rice producers in all countries except Australia, Canada, Japan, New Zealand, United States, and members of the European Patent Convention as of 1994. Plant Genetic Systems has provided the CIP (Centro Internacional de la Papa) Bt genes and technologies , and the results of collaborative research are freely available for developing countries, provided the recipient will not appropriate them unfairly or seek profit through their commercialization in industrial countries.[52] The control ultimately remains in the hands of the corporation that holds the patents.

The ‘golden rice’ research team’s patent application complicates everything. It turns public-interest funders into for-profit entities in direct competition with the companies owning part of the patents they have used. For example, Monsanto-owned Calgene has both a patent on the Cauliflower Mosaic Virus CaMV 35S promoter used in the golden rice, and another one that covers 'A transgenic plant which produces seed having altered carotenoid levels'. In this light, Monsanto is both a needed contributor to the ‘golden rice’and a fierce competitor when it comes to the market for commercial carotene-rich crops. How will this affect Monsanto’s permission for the free use of its otherwise controversial CAMV 35S promoter (see Table 5) under the conditions set by Zurich and Freiburg?

In order to solve these complicated issues, the Rockefeller Foundation has requested an IPR audit to be conducted by the International Service for the Acquisition of Agri-Biotech Applications, ISAAA. ISAAA is an international organization specialized in brokering the transfer of plant biotechnologies into developing countries, and is supported by donors including AgrEvo, Monsanto, Novartis and Pioneer Hi-Bred, together with non-profit donors such as the Rockefeller Foundation and DANIDA. It is doubtful whether those promoting the relevance of genetic engineering for developing countries – prominent among them the ISAAA and its donors – will announce the outcomes of the audit of this patent-puzzle quite as extensively as they did the ‘golden rice’ itself.

However, even if this patent-puzzle was untangled satisfactorily for everybody involved, and an agreement was reached allowing any single farmer or poor consumer to benefit from provitamin A rice (or mustard), two issues would remain outstanding.

The first is that of patents themselves. Many of the countries in the South where VAD is a problem do not currently accept patents on genetically engineered plants, but are being pressured to do so through international and bilateral trade agreements. 'Effective *sui generis*' protection of plant varieties is one of the most controversial issues of the Trade Related Intellectual Property Rights Agreement at the World Trade Organisation (WTO). Negotiations are currently taking place at the WTO to review such a provision. The US had been pushing for patents on plants to be compulsory for any member country. They have come into conflict with those, such as the group of African countries, that want the WTO to forbid any patent on any living organism or part thereof and acknowledge traditional innovation systems. On the other hand, countries as

Thailand have received bilateral pressure from the US to adopt intellectual property rights regimes on biodiversity that suit the interests of the US industry. In this light, free-licensing agreements could be viewed as bait for developing countries to adopt stringent patent systems which go against the free exchange of germplasm and knowledge which forms the basis of a biodiversity-based agriculture. The implied message is: 'IPRs are needed to develop the kind of agriculture that your populations need. And, in any case, there will always be mechanisms to allow that the poorest have access to what they need the most for free.'

But most fundamentally of all, this example shows that in order to be rendered accessible to the poorest, the patents covering any biotechnological innovation have to be ‘neutralized’. This contradiction arises because genetic engineering has been adopted by the North as a research and development strategy that allows them to develop new markets and to control them through the acquisition of intellectual property rights (in 1997, the Rockefeller Foundation reported that annual public and private investment in agricultural biotechnology research might total US $2.5 billion, with no more than US$ 75 million in the developing countries[53]). Any direct benefit to the poorest, who by definition have little purchasing power thus generate little of a market, is to be generated as a 'side effect', or an exception to the rule, over which the poor do not have any control. Scarce resources should be directed, instead, to policies that do have the poor – starting with resource-poor farmers – as their main objective, not as incidental beneficiaries.

All that glitters is not gold…

The unveiling of ‘golden rice’ is giving impetus to the application of genetic engineering to combat micronutrient malnutrition. But it is highly unlikely that poor people stand to benefit from this strategy. This ‘band aid’ approach will merely perpetuate the declining quality of food grown under the industrial agricultural system at the expense of fruits, vegetables, and underutilized and wild crops. Without shifting the focus of nutrition efforts towards a more diverse agricultural base, there is no doubt that micronutrient deficiency will persist. The real impacts of vitamin A crops will be:

- ***Reducing biodiversity, reducing dietary and nutritional diversity***
  Focusing on engineering micronutrients into staples instead of promoting natural sources will further skew agricultural research and development and consequently food availability further away from diversity. It will perpetuate the commodity bias towards staples or a limited range of so-called functional foods such as high beta-carotene oil. This will exacerbate genetic erosion, decimate farming systems and reduce nutritional diversity.

- ***Decreasing overall nutritional status***
  The very narrow target of just providing a single micronutrient such as vitamin A into commonly consumed crops will do little to overcome micronutrient deficiencies. The transfer of an exotic gene into a monoculture crop can do little to make up for the dietary deficiencies of those suffering from monoculture malnutrition[54]. The nutritional value of a combination of rice and *Moringa* leaves is far greater than that of the ‘golden rice’. Providing only a single nutrient via food to a population which currently requires a range of nutrients may be

unethical especially where a range of nutrients can be obtained easily in locally-available fruits and vegetables and in wild and underutilised crops.

- ***Ignoring the cause and perpetuating the problem***
  The claim that 'golden rice' or beta-carotene mustard will help eliminate VAD in the South has great appeal. Yet the genetic engineering approach erroneously assumes that VAD exists due to a general lack of vitamin A food sources. This type of intervention tends to maintain the status quo, where rice remains to be the predominant food in poor peoples' diets, instead of encouraging people to diversify their food sources. Instead of solving the problem, it merely masks the shortcomings of the Green Revolution and perpetuates the problem.

- ***Promoting technical fixes again***
  This one-dimensional technical fix approach to VAD is reminiscent of the Green Revolution paradigm. Here was another techno-fix solution to a complex problem: that of poverty and hunger. 'Golden rice' is another simple, universal solution to the problems of the poor decided upon and developed by scientists and experts from the North. It comes as no great surprise that the Rockefeller Foundation, one of the main architects of the Green Revolution, has been financing this approach to solve a problem which it helped to create in the first place.

- ***Accessibility and equity***
  The *'poor'* are a major target for vitamin A crops. Yet many of the poor, particularly women, have not benefited from Green Revolution crops, so it is unlikely they will benefit from the next wave. Any direct benefit to the poorest, who by definition have little purchasing power and thus generate little of a market, is to be generated as a side effect, or an exception to the rule, upon which the poor do not have any control. Scarce resources should be directed, instead, to policies that have the poor as their main objective, not as incidental beneficiaries.

- ***Dietary diversification or dietary uniformity?***
  Although improved dietary habits, particularly the increased production and consumption of beta-carotene-rich foods, have long been advocated as the only acceptable long-term solution to combat VAD[55,56] very few concrete steps have been taken in this direction in the past twenty years. In the words of the 1991 laureate of the World Food Prize, Dr. Nevin Scrimshaw: 'It is ironic that some of the worst concentrations of xerophthalmia and blindness due to vitamin A deficiency occur in populations surrounded by abundant sources of the vitamins and minerals in local vegetables and fruits, yet, no country has yet mounted a successful campaign to solve the vitamin A problem in this way.'[57]

Breaking away from micronutrient malnutrition

Supplementation and fortification programs treat the symptoms but not the underlying cause of micronutrient malnutrition. Poor quality diets consisting primarily of staple foods are the underlying cause of micronutrient malnutrition.[58] 'Golden rice' is merely an extension of the fortification approach and also fails to address the cause. Even worse, it actually perpetuates malnutrition because it fails to address peoples' requirements of other minerals and vitamins, which would be met by adopting a dietary approach to VAD.

Improving dietary diversity by stimulating the production and consumption of micronutrient-rich foods is the only sane and sustainable approach to overcoming micronutrient deficiencies. There is a great scope for improving direct household supplies to such foods in rural and urban areas.[59] The real cause of VAD is that vulnerable populations are not empowered enough to access these natural sources of vitamin A. This should be the starting point of any strategy to combat VAD. Diversity is the basis of balanced nutrition. Agricultural and nutritional policies should promote the availability of micronutrient-rich foods and targeted nutrition education programs should help increase their consumption. Only by providing a diversity of food sources in the field and by increasing awareness of food's relevance not just to fill the bowl with calories but to improve nutritional well-being, can we break away from the vicious cycle of hunger and malnutrition.

Table 4. Vitamin A activity in various crops

Crop	Description	Carotene Equivalent	Vitamin A activity (Retinol Equivalent RE)
Green vegetables			
Amaranth	leaf, raw	5,400-9,260	900-1,543
Carrot	leaf, raw	7,200	1,200
Cassava	leaf, raw	3,000	500
Cowpea	leaf, raw	4,500	750
Jute, potherb	leaf, raw	6,400	1,066
Kale	leaf, raw	900-7,580	150-1,263
Sweet potato	leaf, raw	1,100-2,700	183-450
	leaf, boiled	1,745	291
Taro	leaf, raw	5,535	922
	leaf, boiled	4,695	783
Raddish leaves		5,295	882.5
Celery	leaf, raw	3,990	665
Fruits			
Banana	yellow, raw	60-130	10-22
	red, raw	90	15
Mango	ripe, raw	708-2,400	118-400
	unripe, raw	60	10
	dried	4,400-5,261	733-877
Papaya	raw	300-2.500	50-417
Plantain	raw	475	79
	boiled	345	58
Storage organs and seeds			
Bitter gourd	raw	17,040	2,840
	cooked	13,260	2,210
Carrot	raw	3,890-21,000	648-3,500
	dried	36,000-135,000	6,000-22,500

Finger millet	flour	25	4
Maize	yellow, raw	360	60
	yellow, dried	125	20
Potato	white, raw	2-20	trace-3
Sweet potato	white, raw	35	6
	yellow, raw	300-4,620	50-770
Plant oils			
Buriti palm oil	oil	304,000	50,667
Palm kernel oil	oil	22	4
Red palm oil	oil	12,210-87,881	2,035-24,647

*The body converts beta-carotene into vitamin A according to physiological needs. Typically, six micrograms of beta-carotene is converted into one microgram of vitamin A.

Source: Various sources.

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