Nutrition, Rice, and Public Health

Perspectives on Ameliorating Vitamin A and Other Micronutrient Deficiencies in Low- and Middle-Income Countries, With Golden Rice as an Example

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White rice is the staple crop in many low- and middle-income countries (LMICs). It must be polished for storage and has very small amounts of vitamins and no pro–vitamin A (beta-carotene). People in LMICs often consume huge amounts of rice, and many people little else. Vitamin A deficiency and other micronutrient deficiencies, including iron, zinc, and folate, are common as a result. Micronutrient supplements and chemical fortification by adding micronutrients during the processing of foods have both undoubtedly reduced micronutrient malnutrition. However, both are unsustainable due to processing, packaging, and distribution costs. After decades of the use of these strategies, micronutrient deficiencies remain high in LMICs. Biofortification is an additional method of ameliorating micronutrient deficiencies. The earliest example, Golden Rice, has great potential, by itself and as a carrier for other biofortified micronutrients. However, unwarranted suspicions of the technology, and the motivations for using it, have significantly delayed progress. Nutritionists and development professionals need to appreciate that the suspicions around biofortification of crops hinder the ability to deliver public health for the poorest of human society.

HEALTH IMPLICATIONS OF RICE IN LOW- AND MIDDLE-INCOME COUNTRIES

Rice is the staple crop for half the world's population, providing more calories than any other crop (Table 1). Rice's importance has grown significantly in Africa since 2004, and now rice ranks as the continent's second-largest calorie source. Rice and wheat productions have both increased faster than the dramatic population growth in India (Table 2). Per-capita daily rice consumption varies dramatically by country (Table 3).

On January 17, 2025, *The Manila Times* reported, under the headline "Food Emergency for Rice Proposed," that rice purchase takes 10% of the average Filipino household budget and 20% of the household budget of less privileged families. From these percentages, and the price of rice in the Philippines, US $3.56/capita per day is the average Filipino household budget, and for the less privileged, the figure is US $1.77/capita per day. Poverty is grindingly hard in many low- and middle-income countries (LMICs), at levels hugely difficult to comprehend in industrialized countries.

In many LMICs where rice is the staple, diets lack variety. Rice is cheap, energy-rich, and easy to store and cook; provides good satiety; and is usually consumed near where it is grown. Animal products are expensive and even if included are a very small percentage of the diet.

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However, rice's nutritional profile can give rise to deficiencies. The diets of many in the population of LMICs often lack expensive animal products and rely on plant-based beta-carotene, which is poorly converted into vitamin A.

A recent editorial in the *New Scientist*[3] highlighted 2 monumental problems with the global food system today that must also be considered: millions of people lack access to nutritious food, and food production remains highly destructive. Rainforests are still being cleared for agriculture, and both conventional farming and organic farming generate significant pollutants. The *New Scientist* experts also noted that food production accounts for more than a third of greenhouse gas emissions. Similarly, a *Nutrition Today* editorial[4] recently argued that America needs a "Food Is Medicine" revolution, urging a closer integration of agriculture and health. This "revolution" is needed globally, as food is (arguably) humanity's first medicine.

Brown rice, which includes both the white endosperm and the aleurone layer, contains less beta-carotene than most nonrice cereals,[5] whereas milled white rice, an excellent energy source, contains none. Milling, or polishing, removes the husk and aleurone layer, essential to improve storage stability but eliminates beta-carotene, a crucial precursor to vitamin A (Table 4).

White rice's consumption therefore exacerbates vitamin A deficiency (VAD), particularly among poorer populations.

Vitamin A deficiency (usually defined as serum retinol <0.70 μmol/L[7]) impairs eyesight and weakens the immune system, increasing vulnerability to common illnesses such as diarrhea and measles. These diseases, typically survivable with a varied diet, can become deadly for vitamin A–deficient young children and mothers. Over the past 3 decades, VAD has killed millions of children annually, accounting for roughly 2 million deaths annually in the early 1990s alone.[8] This situation has probably

TABLE 1

Average Total Consumption (Million Calories per Day) of Selected Crops From 2002 to 2004

Crop	Africa	Latin America	South Asia	Central Asia	SE Asia	Total
Rice	125 124	75 238	1 130 648	14 880	660 979	2 006 869
Wheat	107 419	154 173	987 887	227 197	71 196	1 547 872
Maize	256 286	190 759	67 481	3100	63 906	581 532
Cassava	174 719	24 214	16 263	0	44 074	259 271
Potato	13 464	18 608	46 465	40 903	3324	122 764
Sweet potato	23 789	2155	3008	0	7526	36 478

Data courtesy Harvest Plus.

TABLE 3

Rice Consumption per Capita Selected Countries[2]

Countries	Rice Consumption in 2021		
	kg/Capita per Year	g/Capita per Day	oz/Capita per Day
Bangladesh	264	723	25.5
Philippines	191	523	18.5
India	104	285	10.1
Nigeria	33	90	3.2
United Kingdom	14	38	1.4
United States	12	33	1.2
Switzerland	4	11	0.4
Tunisia	1	3	0.1

existed for decades or centuries in countries where rice is the staple food, many of which are classed as LMICs today.

In 2019, 890 million children in LMICs experienced VAD, including nearly 334 million with severe cases. Approximately 33% of children younger than 5 years suffer from VAD, contributing to 2% of deaths in those younger than 5 years.[9] In 2022, according to one expert group, "Over half of preschool-aged children and two-thirds of nonpregnant women of reproductive age worldwide had micronutrient deficiencies."[10] These 2022 global estimates likely understate the issue in LMICs.

Prevention of micronutrient deficiencies is possible! VAD and other micronutrient deficiencies are theoretically easy to prevent while offering immense benefits for human health and national productivity. For example, among undernourished children living in LMICs, supplementary vitamin A can halve measles mortality[11] and reduces global mortality in children younger than 5 years by 23% to 34%.[12]

Nearly 70 years ago in 1958, when VAD was believed to affect only eyesight, the World Health Organization of the United Nations (UN) and US National Institutes of Health convened a meeting to combat it. That meeting marked the World Health Organization's initial efforts to address micronutrient deficiencies. [12]

In the mid-1980s, Prof Alfred Sommer of Johns Hopkins University and Indonesian colleagues discovered that even mild VAD, although not severely impairing eyesight, significantly increased child mortality.[12] This finding gave impetus to vitamin A supplementation programs. Knowledge that early VAD has these dire side effects drove the UN to intensify efforts and focus specific efforts to combat VAD and also other micronutrient deficiencies at these meetings[13]:

1990: UN World Summit for Children.

1992: UN International Conference on Nutrition.

2000: UN's Millennium Development Goals, 1990-2015.

2004: UN's International Children's Emergency Fund and Micronutrient Initiative Report "Vitamin and Mineral Deficiency"

2015: UN's Sustainable Development Goals 2015–2030.

2021: UN's Global Nutrition Report: The State of Global Nutrition

Possible interventions for micronutrient deficiencies include supplementation (with pills, syrups, or capsules containing micronutrients) and chemical fortification (adding micronutrient premixes to processed food).[12] These interventions, alongside efforts such as promoting home gardens for dietary diversity, have advanced the fight against micronutrient deficiencies, but significant challenges remain.

TECHNOLOGY DRIVES CROP YIELD IMPROVEMENTS

Humans are omnivores and easily adapt to new food sources. Figure 1 shows that, for the past 5000 years, plants have also

TABLE 2

Indian Cereal Production and Population Growth 1960–2013/2014[1]

Years	Population (Millions)	Crop Production	
		Rice Production (Millions of Tons)	Wheat Production (Million Tons)
1960 (pre–Green Revolution)	350	34.6	10.3
2013/2014	1 300 000	154 (exported 10.7, #1)	97.0
Increase from 1960 to 2013/2014	3.7	4.6 X	9.4 X

TABLE 4

Percentage Contribution of Milled White Rice to Nutrient Intakes in the Philippines in 2015

Nutrients	Percent Contribution to Intake of Nutrient	Nutrients	Percent Contribution to Intake of Nutrient
Carbohydrates	76	Protein	40
Energy	59	10 of 11 Amino acids	30–40
Manganese	53	Pantothenic acid (vitamin B_5)	57
Zinc	41	Niacin (vitamin B_3)	45
Magnesium	38	Thiamine (vitamin B_1)	39
Iron	33	Vitamin B_6	32
Phosphorus	33	Riboflavin (vitamin B_2)	20
Copper	32	Folate (vitamin B_9)	10
Calcium	20	Vitamin C	0
Potassium	15	Beta-carotene (pro–vitamin A)	0

Adapted from Bouis et al.[6]

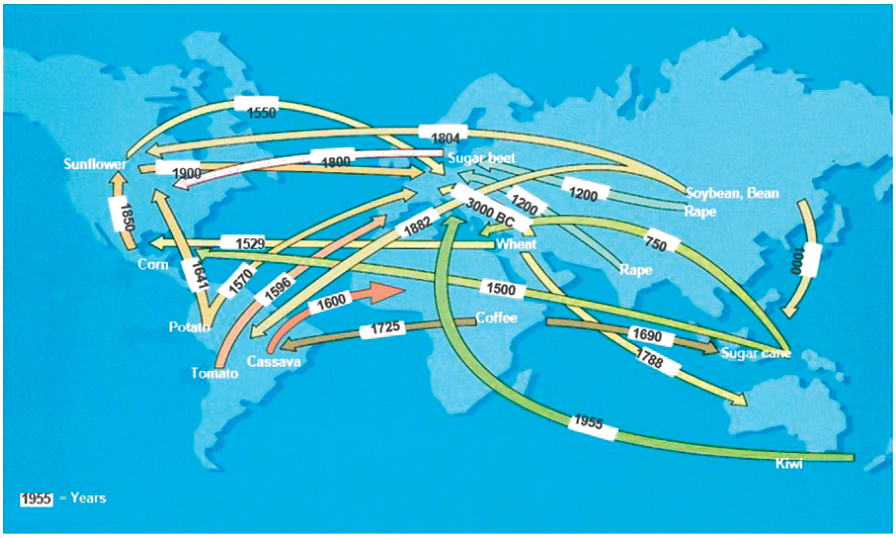

FIGURE 1. New food crops have a 5000-year movement history.[14]

been introduced as crops in new regions far beyond their places of origin. For millennia, crop improvement depended solely on selecting and replanting the highest-yielding seeds, gradually enhancing macronutrient output—carbohydrates, proteins, and fats.

Since the 1940s, plant breeders have used chemicals or irradiation to induce random genetic mutations in crops, without the technology available to seek, understand, or measure the specific genetic changes involved. Instead, they selected beneficial phenotypes for further breeding. More than 1500 mutant cereal varieties are now in use worldwide, contributing significantly to global food security and climate-resilient crops.[12]

In the 1960s, American plant breeder Norman Borlaug introduced high-yield, disease-resistant wheat varieties from Mexico to India. This "Green Revolution" boosted agricultural yields across all continents, except Africa (Table 5). These innovations earned Borlaug the Nobel Peace Prize in 1970.

A series of technological advances have been embraced to enhance crop yields (Figure 2).

In 1961, when this author began secondary school, the global population was 3 billion. By 2025, the world's population had grown to 8.2 billion—nearly tripling within a single lifetime, highlighting the need for more food.

Governments must invest in sustainable food systems to feed the world in a warming climate, particularly as only 13% to 18% of global land area has naturally fertile soils for growing crops.[17]

TABLE 5

Per-Capita Food Production as a Share of Per-Capita All Food Production in 1961 to 2001, to Various Years Before and After the "Green Revolution"[15]

Continents	1961–1965	1971	1981	1991	2001
Africa	100	103	94	90	90
Asia	100	104	114	134	174
South America	100	100	115	118	144
World	100	107	112	115	126

Food production has outpaced global population growth by leveraging technology to prevent malnutrition, and it can continue to do so if given the chance.

TECHNOLOGY DRIVES IMPROVEMENTS IN MICRONUTRIENT NUTRITION

However, despite sufficient global food production, hunger remains widespread. This includes not only hunger due to lack of macronutrients providing food energy that causes protein calorie malnutrition and physically visible and felt hunger, but also "hidden hunger" that is not so evident and is caused by inadequate micronutrients—vitamins and minerals—all of which are also essential for health and development. It is likely that more people suffer from micronutrient deficiencies than even the 750 million experiencing daily macronutrient hunger.[13]

Supplementation

For the past 35 years, local governments and the Helen Keller International Foundation have distributed vitamin A capsules to combat VAD. Although the capsules are inexpensive (5% of costs), distribution accounts for 70%, bringing the total cost to about $1.00 per capsule.[12] Over 20 years, 10 billions of these vitamin A capsules have been distributed to preschool children, costing $10 billion to $15 billion and reducing preschool mortality by 12%, along with decreasing diarrhea and measles cases.[12]

Chemical Fortification. For the last 20 years, chemical fortification of staple foods by adding synthetic micronutrient premixes during their processing has also been used to address micronutrient deficiencies. Dr Semba outlined the ideal characteristics of a food fortificant in his book titled, *The Vitamin A Story: Lifting the Shadow of Death*.[18]

1. The fortified food must be a staple eaten daily with little variation.
2. It should reach the entire population.

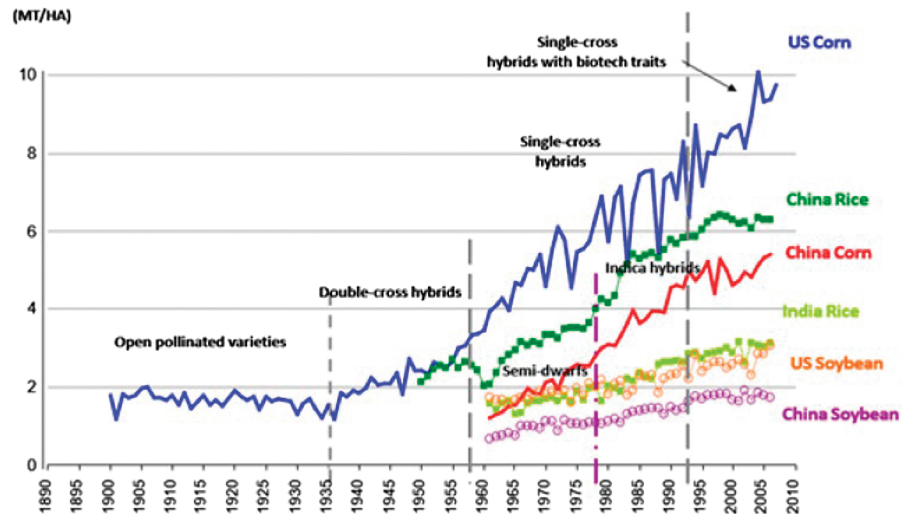

FIGURE 2. Science and innovation drive yield improvements.[16]

3. The process must be cost-effective with minimal impact on food price.
4. The micronutrient must be chemically stable.
5. The fortificant should be undetectable by consumers.

Private sector involvement in chemical fortification enhances efficiency. However, costs of fortification can limit access by the poorest in LMICs, including when foreign exchange to import premixes is scarce.[12] Consumption of locally grown unfortified rice is unaffected by the private sector's chemical fortification activities.

A hugely significant issue with both supplementation and micronutrient fortification of staple foods with chemicals is product cost and the cost of industrial processing, packaging, and distribution of packaged goods and sale through shops or markets.

As an example, adding chemical micronutrients to rice in Bangladesh increases the cost by 6%, making financially impossible the government's aim of fortifying 100% of the countries rice crop of approximately 25 million tons. Using chemical fortificants to treat the whole crop would cost approximately US $1.6 billion annually, without impacting the underlying cause.[19]

Biofortification. Biofortification is the process whereby plants are bred, through any means, to accumulate micronutrients essential for human nutrition in the edible part of the plant. Biofortified crop plants organically synthesize vitamins. Plants may also be bred with the capacity to accumulate important micronutrient minerals, such as iron and zinc. It is important to recognize that plants do not synthesize minerals: they are dependent on mineral absorption from the soil through the roots or, in the case of foliar fertilizers, through the leaves and other above-ground plant parts.

Addressing micronutrient deficiency through biofortification delivers impressive economic returns—for each US $1.00 invested US $17.00 is generated in decreasing nutrition-related disease burden. "Consistently, cost-effectiveness analyses show biofortification outperforming alternative interventions like supplementation and fortification in most scenarios."[20]

Biofortification Using Bioengineering

A quarter of a century ago, advancements in genetic knowledge enabled purposeful improvements to a crop's nutritional profile for the first time.[21] Today, continuing to embrace advanced technologies to improve crops is essential. Genetic engineering is one such technology.

Golden Rice is one biofortified crop plant created in part with the use of genetic engineering, as a source of beta-carotene to combat VAD.[22]

Golden Rice fulfills all the criteria for a food fortificant outlined by Dr Semba. Its agronomy, storage, cooking quality, taste, and texture are identical to white rice, apart from the golden hue from beta-carotene—as a human source of vitamin A—and (by design of the technology donors, Professors Potrykus and Beyer) it costs no more than white rice.[12]

Biofortification Using Conventional Plant Breeding

The announcement of the creation of what came to be called Golden Rice in 2000[21] stimulated the International Food Policy Institute and the International Centre for Tropical Agriculture, public sector research centers focused on pro-poor agriculture, to create Harvest Plus in 2003, to breed crops with increased micronutrients in the harvested and consumed parts. They have been very successful; during the past 2 decades, Harvest Plus has developed many biofortified crop varieties through cross-breeding and selection for increased micronutrient retention.[12]

However, most of these biofortified varieties are visually identical to their nonbiofortified counterparts. As a result of their similar appearance to unfortified commodities, until these varieties become widespread, for the consumer to identify them they require separate packaging and marketing, imposing the same cost and distribution limitations that hinder distribution and consumption of food from chemically fortified crops.[12]

Initially, Harvest Plus eschewed bioengineering to avoid any entanglement with associated controversy and especially to avoid any deleterious impact on fund raising to pursue their biofortification objectives. However, rice conventional breeding could not achieve target levels of iron and zinc in biofortified rice, whereas bioengineering achieved the target levels of both minerals.[12]

New Bioengineering Advances

The founding director of Harvest Plus, now hosted solely by International Food Policy Institute, recognizes that "To reach a higher trajectory, the impacts of biofortification can be multiplied several-fold using genetic engineering and other advanced crop development techniques to combine multiple-nutrient densities with climate-smart traits."[23]

Super-biofortified "Golden Rice + 3." Biotechnology has also been used to develop super-biofortified "Golden Rice + 3," enriched with higher levels of beta-carotene, iron, and zinc. The plants are undergoing field trials in the Philippines.[12]

Super-biofortified "Golden Rice + 5." Similarly, genetic bioengineering has been used to introduce thiamine (vitamin B_1) and folate (the natural form of folic acid) into rice. Although super-biofortified "Golden Rice + 5," including beta-carotene, iron, zinc, folate, and thiamine, has not yet been produced, it is anticipated to be available soon. Like Golden Rice and "Golden Rice + 3," it is expected to be made available to governments, growers, and consumers at no more than the cost of white rice.[12]

GOLDEN RICE: THE GOOD, THE BAD, AND THE UGLY

The Good

Golden Rice is the first biofortified crop. Proof of concept was achieved in 1999,[21] before the term "biofortified" was first used in 2002.[12] Golden Rice is specifically designed to combat VAD in LMICs where rice is a staple, dietary variety is limited, and alternatives such as vitamin supplements or palm oil or chemically fortified foods are inaccessible to the most needy, due to cost or subsistence farming practices. Golden Rice was bioengineered to introduce genes, one from maize and one from a commonly ingested soil bacterium,[22] to the rice genome, resulting in beta-carotene production in the endosperm—the usually white part of rice that humans consume.[22] The beta-carotene gives the color to Golden Rice (Figure 3) as the beta-carotene in carrots gives the carrots their orange color.

All green leaves of all rice plants, including those in the background of Figure 3, contain beta-carotene. Only animal dietary sources contain vitamin A itself and are often too expensive for poor people in LMICs.

Using bioengineering was the only way to develop Golden Rice, because white rice lacks beta-carotene entirely (Table 4), ruling out traditional breeding. By 2004, the biotechnology had progressed to the point that enhancements had permitted increased beta-carotene levels in Golden Rice.[22] The bioengineering task is illustrated in Figure 4.

Beta-carotene is present in all green and colored plant parts—leaves and fruits and vegetables. However, the efficiency with which the human body converts beta-carotene to circulating retinol—vitamin A—varies according to the source.

Dr Semba again said, "A young child between ages 1 and 3 years would need to eat 8 servings of dark green leafy vegetables per day in order to meet the Recommended Dietary Allowance for vitamin A. The problem of the low bioavailability of vitamin A in plant foods has brought the sobering reality of "the virtual impossibility for most poor, young children to meet their vitamin A requirements through vegetable and fruit intake alone." The low bioavailability of vitamin A from plant foods explains, in part, the presence of VAD among children living amid ample supplies of dark green leafy vegetables and other plant sources of vitamin A.[18]

This is one of the reasons home gardens have limited success in combatting VAD.

Conversely, the bioavailability of Golden Rice's beta-carotene is very favorable in comparison with other plant sources of beta-carotene (Table 6).

In the Philippines, Golden Rice was approved for consumption in 2018 and cultivation in 2020. In 2022, the first 100 tons were harvested—a milestone recognized as one of *Time Magazine*'s "10 Good News Stories" of the year.[12]

Golden Rice has been declared safe for consumption by regulatory authorities in the United States, Canada, Australia, and New Zealand. However, there are no plans to introduce it in these countries, where VAD is rare due to varied diets and rice consumption is low[12] (eg, see the US consumption, shown in Table 3).

In the Philippines, specially selected taste panels have participated in scientifically conducted taste tests of cooked

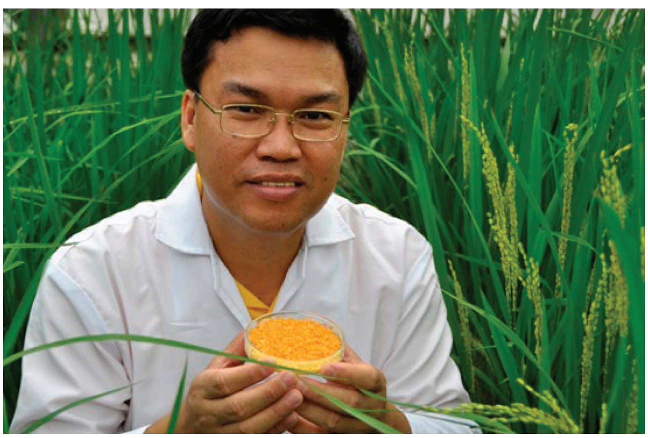

FIGURE 3. The beta-carotene in Golden Rice, shown in the Petri dish, imparts the golden color. Golden Rice was specifically developed to combat vitamin A deficiency (VAD) in communities where rice is a staple. Its only difference from white rice is the addition of beta-carotene.[12]

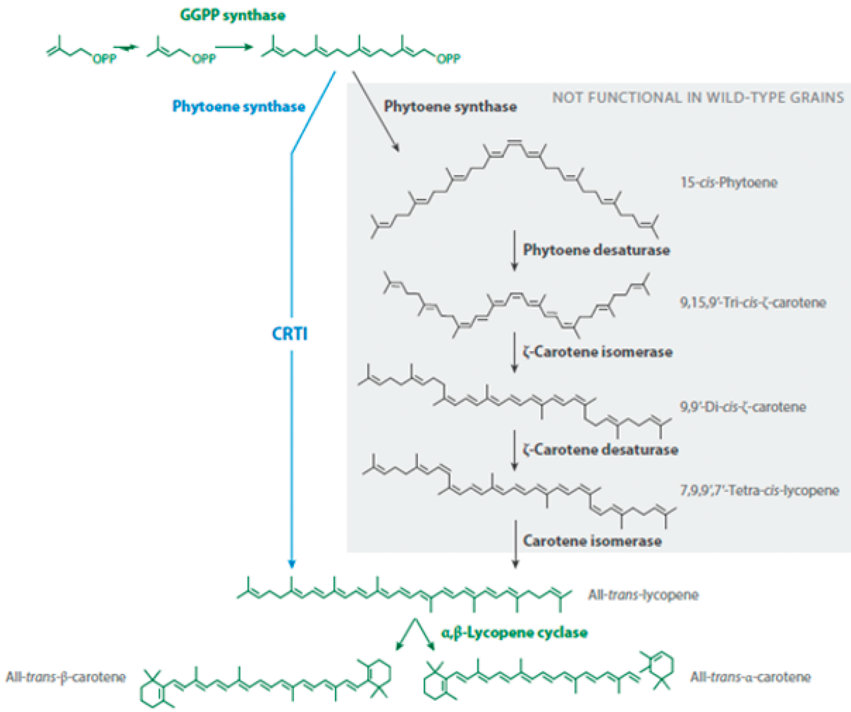

FIGURE 4. The latest precursor available in the rice genome is geranylgeranyl diphosphate synthase. Two transgene proteins phytoene synthase and CRT1 (from maize and a commonly ingested soil bacterium) allow the conversion of geranylgeranyl diphosphate synthase to beta-carotene in the rice endosperm. Two synthetic steps achieve in the endosperm of the grain the same result as 5 steps in the green leaves of the rice plant.[24]

Golden Rice and cooked isogenic white rice (eg the same rice variety without the beta-carotene genetics). The lighting was adjusted so that the color could not be discerned by the professional tasters. No differences in taste or odor or mouth feel were discernible between the samples.

Successful adoption of biofortified crops such as Golden Rice in LMICs requires addressing both sociocultural barriers and practical constraints through well-designed delivery programs that engage local communities and respect traditional food preferences, eliminating the need for significant behavioral changes.[20] The excellent acceptance of Golden Rice has been proven with growers and consumers in the Philippines between 2020 and 2024.[26]

Golden Rice, with its natural color, is ideal for self-sustaining rural communities in Asia and increasingly in Africa, where people grow, mill, store, and consume their own rice; its distinct

TABLE 6

Vitamin A Equivalence of Dietary Plant Beta-carotene to Retinol (Vitamin A) in Human Studies of Bioavailability

Crop or Food	Subjects	n	Conversion Factor Plant Beta-carotene to Retinol (Vitamin A)
Spinach	US adults	14	21:1
Carrots cooked	US adults	7	15:1
Carrots raw	US adults	1	13:1
Orange fleshed sweet potato	Adults, men		13:1
Indian spinach	Bangladesh men	14	10:1
Spinach in oil	**Chinese children 6–8 y**	**22**	**7.5:1**
Yellow maize + beta-carotene	US adults	6	6.5:1
Golden Rice cooked	**US adults**	**5**	**3.6:1**
Yellow maize with high beta-carotene	Zimbabwean men	8	3.2:1
Biofortified yellow cassava	US adults	8	2.8:1
Golden Rice cooked	**Chinese children 6–8 y**	**23**	**2.3:1**
White maize + beta-carotene	US adults	6	2.3:1
Biofortified cassava porridge + 1 mg beta-carotene	US adults	8	2.1:1
Pure beta-carotene in oil	**Chinese children 6–8 y**	**23**	**2.0:1**

The crops with **"Chinese children 6–8 years old"** subjects were part of the same research. The 2.3:1 bioconversion ratio of cooked Golden Rice was not different statistically than the 2.0:1 bioconversion ratio of pure beta-carotene in oil.[25]

TABLE 7

The Potential for Golden Rice to Deliver the Estimated Average Requirement of Beta-carotene, as a Source of Vitamin A to 1- to 3-Year-Old Children and Adults[13]

Amount of Beta-carotene in Golden Rice, μg/g	Rice Consumption per Day (g of Dry Rice Before Cooking)	Percentage of EAR Provided
Beta-carotene to circulating retinol bioconversion rate 2.2:1 (eg, children) to a child [a]		
4.0	40	36%
4.0	100	91%
6.0	40	54%
6.0	100	136%
11.2	40	102%
11.2	100	254%
Beta-carotene to circulating retinol bioconversion rate 3.8:1 (eg, adults) to an adult		
4.0	40	20%
4.0	100	50%
6.0	40	30%
6.0	100	75%
11.2	40	56%
11.2	100	140%

Abbreviation: EAR, Estimated Average Requirement.

[a]For 1- to 3-year-old children, 100% of EAR is 210 μg retinol activity equivalents per day. An EAR that does not ensure adequate stores but is enough because normal dark adaption is set at 112 μg ~ 50% EAR.

color also eliminates the need for special packaging, labeling, or marketing while supporting consumer choice.[12]

This does not mean that dishes that require white rice cannot be made using white rice when consumers wish to use it.

Many nutritionists consider that supply of 30% to 40% of the Estimated Average Requirement will be sufficient to combat VAD because the biofortified staple crop is seldom the only source of beta-carotene. (The recommended daily allowance—RDA—which implies maintenance of 3-month liver stores of vitamin A, is not required to combat VAD.)[13]

In the last 2 decades, traditional cross-breeding has created new Golden Rice varieties adapted to the climates and consumer preferences in different countries, all retaining the original genetic improvements GR2E from 2 decades ago.[22] Two months after harvest, beta-carotene levels in Golden Rice GR2E stabilize after initial degradation, and stabilized levels measured in different Golden Rice varieties have been used in Table 7. (A 6% loss of beta-carotene in cooking Golden Rice, or 25% loss of beta-carotene when a Golden Rice meal is parboiled first, and then reheated, has not been accounted for.)

Consider per capita, daily rice consumption for different countries (Table 2) in examining the Table 7 data, which are based on only 40 or 100 g daily consumption. "Beta-carotene is a safe source of vitamin A and the pro–vitamin A function of beta-carotene contributes to vitamin A intake."[27] Excess beta-carotene is excreted unchanged: there is no possibility of overdosing, thus avoiding toxicity risks associated with vitamin A overdose.

Only small amounts of Golden Rice are sufficient to significantly impact VAD. The highly bioavailable beta-carotene in Golden Rice meets 89% to 113% and 57% to 99% of the estimated vitamin A needs for preschool children in Bangladesh and the Philippines, respectively.[12]

Compared with the World Bank standard, or the cost of provision of vitamin A capsules, the cost of Golden Rice, to save each disability-adjusted life-year is very low: US $0.5/ disability-adjusted life-year at the highest efficiency (Table 8).

In 2017, the World Bank recommended that biofortified crops—including all production methods and specifically mentioning Golden Rice—should become standard in crop breeding.[12] The World Bank calculates that achieving the nutritional targets of Sustainable Development Goal 2 ("zero hunger") offers a cost-benefit ratio of 1:23.[12]

Red palm oil is sometimes proposed as an alternative source of pro–vitamin A carotenoids. However, Golden Rice contains higher levels of beta-carotene.[13,28] It is designed as a staple food consumed daily, independent of industrial processing and markets. Palm oil requires refining, the cost of which compares unfavorably with producing vitamin A capsules.[28])

The Bad

Bangladesh has a significant micronutrient malnutrition problem, and chemical fortificants are sold there. The Bangladesh Rice Research Institute (BRRI) submitted its application for cultivation approval, including food use, for locally developed Golden Rice varieties at the end of November 2017. In the 8 years since then, the National Committee on Biosafety, under the Ministry of Environment, Forest, and Climate Change, and its technical core committee have only met very infrequently. BRRI has fully responded to any and all questions raised to date. The lack of a truly operational regulatory system and the absence of a predictable process for National Committee on Biosafety meetings are major impediments to progress. As of March 2025, no regulatory decision has been taken concerning BRRI's November 2017 application.

Philippines: In April 2024, and reinforced in most respects by the Philippine Appeal Court on August 15, 2024, the Philippine Courts found in favor of Greenpeace's assertion that Golden Rice posed a risk to the ecology of the Philippines. The Philippine Government is taking that decision to the Philippine Supreme Court with the intent of overturning the Appeal Courts decision.[28] The timing of this is unclear.

In the meantime, some of the Golden Rice adoption work in the Philippines[26] is paused.

The Ugly

One might ask why it is that Golden Rice has not been more widely adopted for micronutrient deficiency alleviation. That is a peculiar story and involves more about politics than about nutrition or health.

TABLE 8

Relative Costs of Saving 1 DALY Using Difference Sources of Vitamin A

	Costs (US $ of 2006)	
	Highest Efficiency	Lowest Efficiency
Word Bank cost-effective standard	200	200
Providing vitamin A capsules	134	599
Vitamin A fortification of food	84	98
Golden Rice	0.5–1.4	3.4–9.5

Abbreviation: DALY, disability-adjusted life-year.

Adapted from Table 3 in Dubock.[13]

It is often forgotten that the sole genetic engineering step in Golden Rice's creation occurred 2 decades ago,[22] with all subsequent development relying on "conventional" rice breeding.[12]

Genetic engineering is routinely used in producing enzymes for bread, cheese, beer, and wine. It is also used in lifesaving "humanized" bioengineered insulin for persons suffering from diabetes—a major advantage because the previous source of insulin was from pigs, and porcine insulin stimulates the body to produce antibodies causing immune responses and allergies in some individuals. Genetic engineering is widely used in the pharmaceutical industry, including vaccine production, especially because the COVID-19 epidemic overtook the world.

However, some activist organizations such as Greenpeace uniquely oppose use of bioengineering/genetic engineering in agriculture, despite their objections lacking scientific support. "Many people do have an ethical problem with genetically modified organisms but it's not related to science."[17] Greenpeace originally objected to the commercial licenses put in place for value extraction from the first GMO traits designed to combat pests and diseases in agricultural crops. The licenses were necessary to recover research expenses because crops naturally reproduce. Objections then multiplied.[12] (A similar system charging license fees is also used by companies developing and selling computer software. Software does not naturally reproduce and is anyway a less emotive subject than food for generating donations to activist causes.)

One of Greenpeace's early actions was influencing the creation of the Cartagena Protocol, which underpins restrictive regulations for genetically engineered crops in much of the world. (Sensibly, the United States is not a party to the protocol.)[29]

These regulations impose lengthy delays—exacerbated by seasonal crop cycles—and high compliance costs, limiting participation to large companies, and for some, "Even big companies are no longer able to afford it."[17] For public sector not-for-profit initiatives such as Golden Rice, these barriers severely restrict the geographical scope of projects (eg, Bangladesh and the Philippines are the only 2 countries where Golden Rice cultivation has been sought[12]), increasing their vulnerability to opposition and efforts aimed at halting their progress (eg, as in the Philippines' outstanding legal case[29]).

The Golden Rice project was designed for humanitarian purposes initiated by and conducted solely by public sector scientists and institutions for over 2 decades. If it is successful, it will refute the longstanding anti–genetic engineering claims and campaigns by Greenpeace and similar activists, which began in the late 1990s against genetically engineered crops and specifically Golden Rice.

"If we lose the Golden Rice battle, we lose the GMO war"[12]: this is why Greenpeace opposes Golden Rice.

Opposition to Golden Rice, biofortified crops, or GMO crops is effectively an attack on public health. Development, public health, and nutrition professionals need to broaden their vision to enable effective implementation of this critical intervention.[1]

The World Bank recommends considering the effects of climate shocks and rising temperatures on food supply and nutrition.[12] Conventional plant breeding is much slower than utilizing genetic knowledge to adapt crops. And it is imperative to win the race against time.

In 2016, 179 Nobel Laureates issued an open letter to the UN, world governments, and to Greenpeace, urging an end to opposition driven by "emotion and dogma contradicted by data." Indeed, more than nearly 30 years of genetically engineered crop use, no evidence of human or environmental harm has ever been documented.[30]

Dr Henry Miller, founding director of the US Food and Drug Administration's Office of Biotechnology, in 2024 summarized frustration at the irrationality of opposition to Golden Rice:

> "Over the years, partly under the guidance of the United Nations, various stop-gap efforts have been instituted to try to slow the scourge, including distributing vitamin A supplements and trying to educate desperately poor villagers about diet changes. They've all failed…
>
> There is one, and only one, solution that could work on a global scale: vitamin A–enhanced rice, known as Golden Rice. The only thing blocking this global treatment is a coalition of advocacy groups, led by Greenpeace International, that has intimidated the public and manipulated some regulators and courts into believing that obstructing the genetic engineering revolution is a more important cause than preserving the lives of vulnerable children."[31]

CONCLUSIONS

Rice is a staple crop in many LMICs, but white rice lacks beta-carotene and contains only minimal amounts of other essential vitamins and minerals. Although micronutrient supplements, chemical fortification, and nutrition education help address deficiencies, these measures alone have proven insufficient.

Golden Rice, a bioengineered variety enriched with beta-carotene, offers a practical and cost-effective solution to VAD. As an agricultural intervention, it complements existing strategies and supports the development of multivitamin Golden Rice, which is in early stages of development to further improve public health.

Public health authorities should strategically adopt Golden Rice and other uncolored biofortified crops to help meet Sustainable Development Goal 2 (zero hunger) by 2030, as current efforts may fall short without this shift.[12]

REFERENCES

[1] Khush GS. IRRI and the Green Revolution in India April 2015. Published online 2013:3740480. http://irri.org/rice-today/india/revisiting-50-years-of-indian-rice-research/irri-and-the-green-revolution-in-india?tmpl=component&print=1&page=. Accessed May 3, 2025.
[2] https://worldpopulationreview.com/country-rankings/rice-consumption-by-country; https://www.helgilibrary.com/indicators/rice-consumption-per-capita. Accessed May 3, 2025.
[3] New Scientist Leader. November 13, 2024. We must use genetic technologies now to avert the coming food crisis. https://www.

newscientist.com/article/mg26435173-000-we-must-use-genetic-technologies-now-to-avert-the-coming-food-crisis/. Accessed May 3, 2025.

[4] Savaiano D. America needs a food is medicine revolution. *Nutrition Today*. doi:10.1097/NT.0000000000000714 October 16, 2024.

[5] Lamberts L, Delcour JA. Carotenoids in raw and parboiled brown and milled rice. *J Agric Food Chem*. 2008;56(24):11914–11919. doi:10.1021/jf802613c.

[6] Bouis H, Slamet-Loedin I, Trijatmiko K, et al, December 10, 2022, 'Multiplying the efficiency and impact of biofortification through metabolic engineering of rice for the Philippines.' A presentation made in Tokyo. 22nd IUNS-International Congress of Nutrition, Submission No.:C001200 [Track 8] Agriculture, Food Science and Safety keywords: micronutrients, provitamin A, iron, zinc, biofortification. oral

[7] World Health Organization. Global prevalence of vitamin A deficiency in populations at risk 1995–2005. Geneva, Switzerland: WHO; Published online 2009.

[8] Wu F, Wesseler J, Zilberman D, et al. Opinion: allow Golden Rice to save lives. *Proc Natl Acad Sci U S A*. 2021;118(51):e2120901118. doi:https://doi.org/10.1073/pnas.2120901118.

[9] Song P, Adeloye D, Li S, et al. The prevalence of vitamin A deficiency and its public health significance in children in low- and middle-income countries: a systematic review and modelling analysis. *J Glob Health*. 2023;13:04084. doi:10.7189/jogh.13.04084.

[10] Stevens GA, Beal T, Mbuya MNN, et al. Micronutrient deficiencies among preschool-aged children and women of reproductive age worldwide: a pooled analysis of individual-level data from population-representative surveys. *Lancet Glob Health*. 2022;10(11):e1590–e1599. doi:10.1016/S2214-109X(22)00367-9.

[11] World Health Organization. Micronutrient deficiencies: vitamin A deficiency. Published 2013. http://www.who.int/nutrition/topics/vad/en/. Accessed September 26, 2013.

[12] Dubock A. The sustainable development goals are unattainable without a change of nutritional strategy. *Med Res Arch*. 2024;12(10). doi:10.18103/mra.v12i10.5818.

[13] Dubock A. Golden Rice: to combat vitamin A deficiency for public health. In: Queiroz ZL, de Rosso VV, Eduardo J-L, eds. *Vitamin A*. IntechOpen; 2019:1–21. doi:10.5772/intechopen.84445

[14] Dubock A. Crop conundrum. *Nutr Rev*. 2009;1(67):17–20. doi:10.1111/j.1753-4887.2008.00137.x.

[15] Southgate D and Graham D Growing Green. *The Challenge of Sustainable Agricultural Development in Sub-Saharan Africa*. University of Ohio, USA; International Policy Press; 2006: Published on behalf of the Sustainable Development Network. https://www.cbd.int/doc/meetings/suse/rwsuafr-01/other/rwsuafr-01-oth-growing-green-en.pdf. Accessed May 6, 2025.

[16] Dubock AC. Chapter 12: Nutritional enhancement by biofortification of staple crops. Successful Agricultural Innovation in Emerging Economies: New Genetic Technologies for Global Food Production. Bennett D J and Jennings R C, eds. 2013;67(112):119–220. Cambridge, England: Cambridge University Press.

[17] Glover A, European Commisssion. Agricultural biotechnology in Europe and Africa. Network of African Science Academies meeting Addis Abbaba: February 2014. https://nasaconline.org/ and https://www.yumpu.com/en/document/read/45930208/agricultural-biotechnology-in-europe-and-africa-anne-glover. Accessed May 3, 2025.

[18] Semba RD. The vitamin A story: lifting the shadow of death. *World Rev Nutr Diet*. 2012;104:VII–X. doi:10.1159/e-ISBN.978-3-318-02189-9 Koletzko C, ed.

[19] Dubock A, Wesseler J M, Russell R, et al. Golden Rice, VAD, COVID and public health: saving lives and money. In: *Integrative Advances in Rice Research*. *IntechOpen*; 2022. doi:10.5772/intechopen.101535

[20] Shohael AM, Kelly J, Venkataraman S, Hefferon K. Unlocking opportunities and overcoming challenges in genetically engineered biofortification. *Nutrients*. 2025;17(3):518. doi:10.3390/nu17030518.

[21] Ye X, Al-babili S, Klöti A, et al. Engineering the provitamin A (beta-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. *Science*. 2000;287(5451):303–305.

[22] Paine JA, Shipton CA, Chaggar S, et al. Improving the nutritional value of Golden Rice through increased pro–vitamin A content. *Nat Biotechnol*. 2005;23(4):482–487. doi:10.1038/nbt1082.

[23] Bouis H, Foley J, Lividini K, et al. Biofortification: future challenges for a newly emerging technology to improve nutrition security sustainably. *Curr Dev Nutr*. 2024;8(12):104478. doi:10.1016/j.cdnut.2024.104478.

[24] Potrykus I. From the concept of totipotency to biofortified cereals. *Annu Rev Plant Biol*. 2015;66:1–22. doi:10.1146/annurev-arplant-043014-114734.

[25] Tang G. Using plant foods rich in β-carotene to combat vitamin A deficiency. *Sight Life* 2013;27(1). http://www.sightandlife.org/fileadmin/data/Magazine/2013/27_1_2013/using_plant_ foods_rich_in_beta_carotene_to_combat_VAD.pdf. Accessed May 3, 2025.

[26] Philippine Rice Research Institute. Monthly E Newsletters. October 2020–December 2024 https://www.philrice.gov.ph/golden-rice/golden-rice-e-newsletter/. Accessed May 3, 2025.

[27] Grune T, Lietz G, Palou A, et al. β-Carotene is an important vitamin A source for humans. *J Nutr*. 2010;140(12):2268S–2285S. doi:10.3945/jn.109.119024.

[28] Loganathan R, Subramaniam KM, Radhakrishnan AK, Choo YM, Teng KT. Health-promoting effects of red palm oil: evidence from animal and human studies. *Nutr Rev*. 2017;75(2):98–113. doi:10.1093/nutrit/nuw054.

[29] Dubock A. Golden Rice. Some considerations for Philippine pending legal decisions and expected local and global implications. *Med Res Arch* Published online 2024. 12. doi:10.18103/mra.v12i8.5884.

[30] Roberts R. Support precision agriculture. 2016. Nobel laureates June 2016. http://supportprecisionagriculture.org/. Accessed March 3, 2017.

[31] Miller H and Hefferon K., Greenpeace's cruel war on genetically engineered crops grinds on. Published online 2024. https://www.acsh.org/news/2024/08/20/greenpeaces-cruel-war-genetically-engineered-crops-grinds-48914. Accessed May 3, 2025.

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