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**Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006**

# Potential Impacts of Golden Rice on Public Health in India

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**Abstract**: Vitamin A deficiency (VAD) affects millions of people world-wide, causing serious health problems. Golden Rice (GR), which has been genetically engineered to produce beta-carotene, is being proposed as a remedy. While this new technology has aroused controversial debates, its nutritional impact and cost-effectiveness remain unclear. We determine the current burden of VAD in India from a public health perspective, and simulate the potential alleviating impact of GR using representative household food consumption data. Given broad public support, GR could more than halve the overall burden of VAD. Juxtaposing health benefits and overall costs suggests that GR is very cost-effective.

**JEL classifications**: I0, I3, Q16, Q18.

**Keywords**: Golden Rice, vitamin A deficiency, biofortification, genetic engineering, DALYs, cost-effectiveness analysis, India.

## Introduction

Globally, 140 million pre-school children and 7 million pregnant women suffer from vitamin A deficiency (VAD). Of these, up to 3 million children die every year (SCN 2004). Apart from increasing child mortality, VAD can lead to visual problems, including blindness, and it increases the incidence of measles (Sommer and West, 1996)[1]. This affects public health, economic productivity, and individual well-being. Income growth alone is not expected to reduce micronutrient malnutrition in the short to medium term (Haddad et al. 2003). Pharmaceutical supplementation with vitamin A (VA) is commonly practiced but has its shortcomings: those children that are least likely to receive supplements tend to be most at risk of VAD, and extending coverage is becoming increasingly difficult (Adamson, 2004). Golden Rice (GR), which has been genetically engineered to produce beta-carotene, a precursor of VA, has been proposed as an intervention for VAD (Ye et al., 2000). The technology's potential for deficient populations has been shown in preliminary studies (Dawe et al., 2002; Zimmermann and Qaim, 2004). Nonetheless, the usefulness of GR is questioned by some, and the technology has become the centerpiece in the public controversy over genetically engineered crops (Shiva, 2000; Greenpeace, 2005). Since GR is still at the stage of research and development (R&D), its actual effectiveness remains unknown (Grusak, 2005; Nuffield, 2003).

Recently, a second generation of GR has been developed, with a beta-carotene content up to 20 times higher than in the initial lines (Paine et al., 2005). To take account of these

[1] Individual studies suggest that further health outcomes are associated with VAD, but causality has not been shown. For an overview of the recent literature see Stein et al. (2005).

new developments, we determine the current public health burden of VAD in a rice-eating population, and simulate to what extent this burden could be reduced through GR. Furthermore, we juxtapose these health benefits and overall costs of developing and disseminating the technology, to establish its cost-effectiveness. We use comprehensive food consumption data and take into account more nutrition and epidemiological details than previous studies (Dawe et al., 2002; Zimmermann and Qaim, 2004). Hence, our results add precision to the ongoing debate. The study is carried out for India, where GR lines are currently adjusted to local conditions and are likely to be released in 5-7 years. Of the 140 million pre-school children suffering from VAD world-wide, more than 35 million live in India (SCN, 2004). Coverage levels of the existing VA supplementation program are low (Planning Commission, 2002). Since rice is widely consumed in the country,[2] introducing GR may reduce the prevalence of VAD and free scarce resources in the health sector.

## Method and material used

Although the extent of VAD in a country is generally captured by prevalence rates, merely counting the number of people below a certain threshold for VA sufficiency fails to take account of the problem's depth. Disability-adjusted life years (DALYs) provide a means to measure the total health burden in one single index (Murray and Lopez, 1996). This is done by weighting different health conditions (including premature death) according to their

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[2] For instance, the average monthly per capita consumption of rice in rural India is 6.8 kg (NSSO, 2000). This masks regional and socioeconomic differences. In the analysis this is taken care of through the use of nationally representative household data: GR has no impact on the VA status of people who do not eat rice. Hence, if only predominantly rice-eating states within India are included in the analysis, the relative impact of GR improves.

severity and adding up their duration. To quantify the burden of VAD, we use a refined DALYs method to explicitly capture related health outcomes (Stein et al., 2005). The public health burden is expressed in "DALYs lost".

To determine the potential impact of GR, we used a nationally representative dataset of 120,000 households (NSSO, 2000). Based on household food consumption data and food composition tables we derived VA intakes[3] at the individual level by using internally generated adult equivalent weights.[4] These VA intakes represent the status quo without GR. In a further step, we carried out the same calculations assuming that a certain share of the rice consumed is replaced by GR. (Because of the use of adult equivalent weights, our results take into account that children eat less rice than grown-ups.) Knowing individuals' current VA intakes, their potential additional intake through GR, and their estimated average requirements (EARs) (IOM, 2002), we determined the relative success of GR in closing the gap between intakes and requirements based on a "dose-response" function (Stein et al., 2005). Improved VA status will reduce the incidence of adverse health outcomes. Based on these lower incidence rates, we calculated a new, reduced burden of VAD. Subtracting this reduced burden from the current one results in the number of "DALYS saved" through GR, which is our measure of the technology's impact. Finally, we considered the cost of devel-

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[3] Plant food does not contain any VA but only VA precursors, mainly beta-carotene; whenever we talk about "VA intake" we mean the actual VA intake from animal source foods and the beta-carotene intake from all foods, which we converted into units of VA at a rate of 12:1 (IOM 2002).

[4] Adult equivalents were generated from within the dataset by regressing the households' composition (i.e. age and gender groups) on the households' VA intakes.

oping and disseminating GR to calculate the cost per DALY saved as a measure for its cost-effectiveness.

To take account of uncertainty in this ex-ante analysis, we simulated a low impact and a high impact scenario in which GR is consumed. Both scenarios were projected over a period of 30 years. Our low impact scenario assumes that GR will experience only limited scientific success and weak political support. Our high impact scenario, in contrast, reflects what the scientists involved deem possible, and what broad political support could accomplish (Table 1). In any case, GR varieties are developed jointly by the private and public sector and, in the framework of a humanitarian mandate, they will be handed over to small-scale farmers who can reproduce the seeds themselves (Potrykus, 2001). The cost estimates for GR are shown in Table 2. Owing to the yellow color of the grain, consumers will note the difference to conventional rice. Therefore, social marketing activities will be necessary to facilitate adoption amongst farmers and acceptance amongst consumers. The base year for our analysis is 2001, when the development of GR as a crop started. All costs were discounted to this year at a rate of 3%; analyses with different discount rates do not fundamentally change the overall findings.

## Results

According to our calculations, the current burden of VAD in India amounts to 2.3 million DALYs lost each year[5], of which 2.0 million DALYs are lost due to child mortality alone. In terms of incidence numbers, 71,625 children under the age of six die each year because

[5] This estimate is based on the most recent data available. Because we only considered health consequences of VAD for which there is broad scientific consensus, this may be a conservative estimate of the true burden.

of VAD, and 3,663 pre-school children go blind; 2.6 million pregnant and lactating women and 1.6 million children suffer from nightblindness, and 0.8 million children succumb to measles. In this context, wide-spread consumption of GR with a high beta-carotene content (high impact scenario) can reduce the burden of VAD by 59% and save thousands of lives (Table 3). The positive effects are more pronounced in the poorer income groups that also tend to suffer more from VAD. Less frequent consumption of GR with a lower beta-carotene content (low impact scenario) would only have a smaller impact. These results demonstrate the potential of the technology to deliver pro-poor nutrition and health benefits, but they also emphasize the importance of public support for this potential to materialize. Evidently, delays in bringing GR to the farmers can be very costly in terms of DALYs that could otherwise be saved.

Our cost-effectiveness analysis indicates that in the high impact scenario, one healthy life year is saved at a cost of U.S.$ 3.06, while in the low impact scenario, one DALY saved costs U.S.$ 19.40 (Table 3). Cost-effectiveness is a relative measure that requires reference values for its assessment. One possible base for comparisons are international standards. We used standards given by the World Bank and the World Health Organization to establish that GR is highly cost-effective (Table 3). Another possibility for assessing the results is to compare them with the cost-effectiveness of the current alternative. In the case of India, this is VA supplementation – and also in this context GR proves to be very cost-effective (Table 3).

### Sensitivity analyses

To test the robustness of our results we carried out sensitivity analyses (Fig. 1). We found that a high amount of (bioavailable) beta-carotene in GR is paramount for reducing the burden of VAD. Increasing the coverage of GR with lower beta-carotene content can improve its impact, but it remains relatively small. We also found that the public distribution system, through ration shops or school feeding programs, has a relatively small influence on the overall impact. Public support is important, but rather in the form of broader social marketing strategies: GR needs to be consumed on a larger scale to have a major impact.

An alternative proposition to fight VAD is to promote (low yielding) red and black landraces of rice for consumption and further breeding. These varieties, *if unmilled*, contain up to 0.38 μg/g beta-carotene (Frei and Becker, 2004). Our calculations show that this beta-carotene content is too low to have a considerable impact. Even the widespread consumption of such unmilled rice would reduce the burden of VAD by only 3%.[6] Finally, critics of GR often suggest that the right way to combat VAD would be to increase dietary diversity and rely on food that is already rich in VA or beta-carotene (Shiva, 2000; Greenpeace, 2005). In the long run, the solution to overcome malnutrition and VAD is certainly to ensure general access to diverse and nutritious foods, but this comes with problems of its own. And one major weakness of many of these propositions is to neglect the cost side (Ruel, 2001), but effectiveness on its own is a poor guide when resources are limited (World Bank, 1993).

[6] The general proposition of using crop varieties with sufficiently high concentrations of essential micronutrients as basis for breeding is valid, though. Such a strategy is followed in the HarvestPlus program of the Consultative Group on International Agricultural Research (www.harvestplus.org).

## Conclusion

We have shown the potential positive impact and cost-effectiveness of GR. Yet, this technology is no panacea in the fight against malnutrition. Neither GR nor any other intervention alone will eliminate VAD. While VA supplementation can address more severe and acute cases of VAD and serve as a preventive measure in the short run, it is costly and less sustainable over longer periods of time. Poverty reduction can sustainably reduce not only VAD but also other forms of malnutrition, but this will only happen in the long run. Dietary diversification, breeding food crops for higher micronutrient content (such as GR), other food-based approaches, and nutrition education are all interventions that have their own strengths and weaknesses. Here we have shown that GR has the potential to reduce the public health burden of VAD in India substantially and at low costs. Therefore, GR promises to be an effective and efficient pro-poor intervention to combat VAD. Its inclusion into strategies that aim at the elimination of VAD in rice-eating populations should be considered seriously.

Our analysis is ex-ante in nature. Future research will have to determine the exact size of crucial parameters, like the beta-carotene content in the rice grain that can be realized under field conditions, the magnitude of post-harvest losses of beta-carotene, or its bioavailability. Another important question is to what extent high levels of beta-carotene in rice are compatible with agronomic properties or with characteristics that are important to consumers. Beside sufficient support for social marketing activities, this will influence technology acceptance. Finally, the safety of GR for human consumption and the environment will have to be tested, and possible risks be managed in biotechnology regulatory processes.

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## Tables and figures

**Table 1.** Assumptions used to simulate two scenarios in which GR is consumed in India.

| Scenario | Low impact | High impact |
|---|---|---|
| Beta-carotene ($\beta$C) content in GR (µg/g)[a] | 14 | 31 |
| Post-harvest loss of $\beta$C (%)[b] | 80 | 35 |
| Conversion of the $\beta$C in GR into VA[c] | 6:1 | 3:1 |
| Coverage rate of GR 15 years after release (%)[d] | | |
| - in government shops[e] | 20 | 100 |
| - in school meals[f] | 20 | 100 |
| - on the free market[e] | 14.3 | 50 |
| - in rice products | 10 | 50 |

[a]Based on the average and maximum beta-carotene ($\beta$C) content in the second generation of GR (Paine et al., 2005). [b]Losses due to storage and cooking are based on estimates by G. Barry (International Rice Research Institute), A. Dubock (Syngenta), P. Beyer (University. of Freiburg) and H. Bouis (International Food Policy Institute). [c]These values are based on Zimmermann and Qaim (2004) and re-confirmed by R.M. Russell (Human Nutrition Research Center on Aging, USDA ARS and Tufts University). [d]It is assumed that the “golden” trait will be incorporated in at least four relevant and popular rice varieties with superior agronomic traits. [e]While the government can influence what is sold in its ration shops that cater for the poor, the free market follows actual consumer demand. For the free market, we assume that in the low impact scenario people eat GR only one day a week, while in the high impact scenario people eat GR every other day. [f]NSSO (2000) also recorded the number of meals received at schools and similar institutions by each household member over the last 30 days; we assume that *outside* the predominantly wheat-eating states (Haryana, Punjab, Rajasthan, Uttar Pradesh, Uttaranchal, Chandigarh and Delhi) these meals include 100 grams of GR.

**Table 2.** Time frame and cost estimates for R&D and dissemination of GR in India.

| | Low impact scenario | | High impact scenario | |
|---|---|---|---|---|
| | Years | Undiscounted cost (U.S.$) | Years | Undiscounted cost (U.S.$) |
| International R&D | 2001-2007 | 7,462,000 [a,b] | 2001-2007 | 3,262,000 [a,b] |
| R&D within India | 2002-2011 | 1,158,000 [a,c] | 2002-2009 | 780,000 [a,c] |
| Regulatory process | 2003-2012 | 2,515,000 [a,d] | 2003-2010 | 2,213,000 [a,d] |
| Release of GR | 2012-2013 | | 2010-2011 | |
| Social marketing | 2013-2015 | 15,570,000 [a,e] | 2011-2015 | 30,710,000 [a,e] |
| Maintenance breeding | 2013-2029 | 2,125,000 [f] | 2011-2029 | 1,900,000 [f] |
| Total cost (discounted at 3%) | 2001-2030 | 21,384,000 | 2001-2030 | 27,937,000 |

[a]In the low impact scenario, we increased past costs (before 2005) by 10% to account for possible underreporting, while we increased the more uncertain future costs by 25%. In the high impact scenario, we only increased future costs by 10%. [b]R&D costs at the University. of Freiburg, Syngenta, and the International Rice Research Institute (IRRI) as reported by J. Mayer, A. Dubock and G. Barry, respectively. To attribute a share of these overall costs to India, in the low impact scenario we used India's share of 70.5% in the total rice production of India, Bangladesh, and the Philippines, which are the core beneficiary countries suggested by the GR Humanitarian Board. In the high impact scenario, we used India's share of 34.2% in the total rice production of these countries and China, another potential beneficiary country (production data from FAO (2004)). [c]R&D costs at the Indian Agricultural Research Institute (IARI), the Directorate for Rice Research, and the Tamil Nadu Agricultural University, as reported by A. K. Singh of the IARI. [d]Costs that need to be incurred in the framework of the institutional biosafety committees, the Review Committee on Genetic Manipulation, the Genetic Engineering Approval Committee, and the Seed Act, based on estimates by S. R. Rao of the Indian Department of Biotechnology. [e]Based on the costs for different combinations of awareness program and campaigns in the framework of India's Integrated Child Development Services (ICDS) centers, including nation-wide campaigns in the electronic media, as obtained in expert interviews. In the high impact scenario, we assume a stronger political support, i.e. more activities are carried out over a longer period of time; this also justifies the assumption of higher coverage rates of GR in Table 1. [f]Based on estimates by G. Barry (IRRI).

**Table 3.** The annual burden of VAD in India and the cost-effectiveness of GR.

| Scenario | Low impact | High impact |
|---|---|---|
| *Current annual burden of VAD* | | |
| DALYs lost (x $10^3$) | -2,328 | |
| Lives lost (x $10^3$) | -71.6 | |
| *Potential impact of rice rich in beta-carotene* | | |
| Annual gain through GR (DALYs x $10^3$) | 204 | 1,382 |
| Annual gain through GR (lives x $10^3$) | 5.5 | 39.7 |
| Reduction of the DALYs burden of VAD through GR (%)[a] | -8.8 | -59.4 |
| Reduction of the DALYs burden of VAD through the consumption of (unmilled) colored rice landraces (%)[b] | -0.1 | -3.3 |
| *Cost-effectiveness of VA and health interventions* | | |
| Cost per DALY saved through GR (U.S.$) | 19.40 | 3.06 |
| World Bank benchmark for DALYs saved (U.S.$)[c] | 200 | |
| WHO standard for valuing DALYs (U.S.$)[d] | 620-1,860 | |
| Cost per DALY saved through supplementation (U.S.$)[e] | 134-599 | |

[a]This refers to the reduction in all regions, rice eating or not. In the predominantly rice eating regions, GR is much more effective in closing the VA intake gap. [b]An alternative proposition to fight VAD is to promote red and black landraces of rice for consumption and further breeding. These (low yielding) varieties, *if unmilled*, contain 0.22-0.38 µg/g beta-carotene (c.f. Frei and Becker, 2004). [c]The costs per DALY of U.S.$ 150 given by the World Bank (1993) rise above U.S.$ 200 in current terms. [d]The WHO (2001) suggests to value one DALY at the single to triple per capita income; for India the per capita income was U.S.$ 620 in 2004 (World Bank, 2005). [e]Supplementation is the prevailing VA intervention in India; figures for South Asia from Tan-Torres et al. (2005) were weighted for India and converted into 2004 U.S.$.

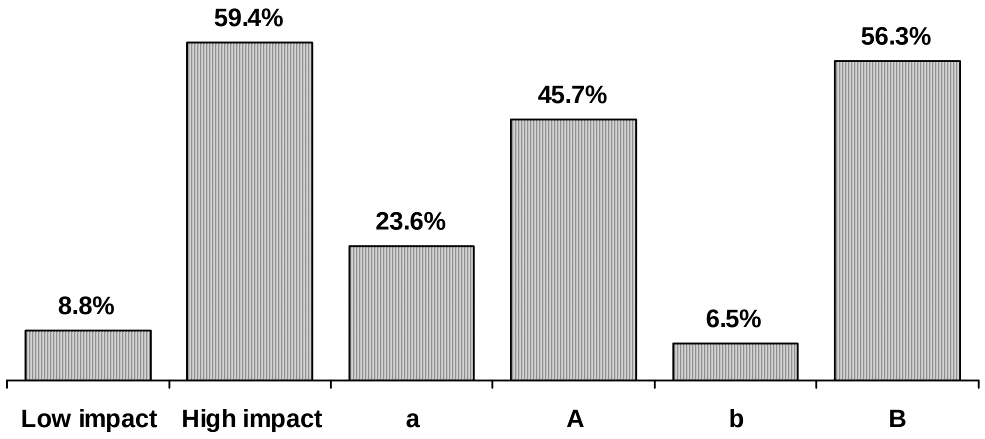


**Fig. 1.** Reduction of the public health burden of VAD through GR for different scenarios. "Low impact" and "High impact" are the initial scenarios as described in the main text; "a" is a scenario where GR has the assumed low level of bioavailable beta-carotene, but high coverage rates; "A" assumes a high beta-carotene content, but low coverage rates; "b" and "B" are the low and high impact scenarios but in the calculation of the dose-response "recommended dietary allowances" (RDAs) are used instead of EARs.