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Projecting the Benefits of Golden Rice in the Philippines

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List of Abbreviations and Acronyms

DALYs	Disability-Adjusted Life Years
FNRI	Food and Nutrition Research Institute of the Philippines
GM	Genetically Modified
GNP	Gross National Product
GR	Golden Rice
IRR	Internal Rate of Return
IRRI	International Rice Research Institute
Philrice	National Rice Research Institute of the Philippines
R&D	Research and Development
RDA	Recommended Dietary Allowance
VA	Vitamin A
VAD	Vitamin A Deficiency
WHO	World Health Organisation

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Abstract

Golden Rice has been genetically engineered to produce beta-carotene in the endosperm of the grain. It could improve the vitamin A status of deficient food consumers, especially women and children in the developing world. This paper analyses the potential impacts in a Philippine context. Since the technology is still at the stage of R&D, benefits are simulated within a scenario approach. The health effects are quantified using the methodology of disability-adjusted life years (DALYs). Golden Rice will not completely eliminate the problems of vitamin A deficiency, such as blindness or increased mortality rates. So it should be seen as a complement rather than a substitute for alternative interventions. Yet, the technology will reduce related health costs significantly. In monetary terms, annual gains will lie between $23 million and $137 million, depending on the underlying assumptions. A preliminary cost-benefit analysis shows high returns on R&D investments. Micronutrient-enriched crops are an efficient way to reduce deficiency problems among the poor, and related research projects should receive higher political priority.

Kurzfassung

“Golden Rice” ist Reis, der gentechnisch verändert wurde, um Beta-Carotin im Endosperm des Korns zu produzieren. Diese Technologie könnte die Vitamin A Versorgung armer Bevölkerungsschichten erheblich verbessern. Insbesondere Frauen und Kinder in Entwicklungsländern leiden vielfach an Vitamin A Mangel mit schwerwiegenden Gesundheitsfolgen wie Erblindung oder Tod. Die vorliegende Studie analysiert die erwarteten Auswirkungen von “Golden Rice” im Rahmen einer Fallstudie in den Philippinen. Da entsprechende Reissorten sich noch im Stadium der Entwicklung befinden, werden Nutzenwirkungen durch einen Szenarioansatz simuliert. Zur Quantifizierung von Gesundheitseffekten kommt eine Methode zum Einsatz, die die Kosten von Krankheits- und Sterbefällen in einem gemeinsamen Index zusammenfasst. Die Technologie wird die Probleme von Vitamin A Mangel nicht vollständig beheben können, so dass sie nicht als Ersatz, sondern als komplementäres Instrument zu anderen Maßnahmen betrachtet werden sollte. Dennoch wird “Golden Rice” die auftretenden Gesundheitskosten in den Philippinen erheblich reduzieren. In monetären Einheiten ausgedrückt wird der jährliche Nutzen je nach Annahmen zwischen 23 Millionen und 137 Millionen US Dollar liegen. Eine vorläufige Kosten-Nutzen-Analyse zeigt eine sehr hohe soziale Verzinsung der Forschungsinvestitionen. Züchterische Ansätze sind eine effiziente Strategie zur Bekämpfung von ernährungsbedingtem Mikronährstoffmangel, so dass entsprechenden Forschungsprojekten eine höhere politische Priorität eingeräumt werden sollte.

1 Introduction

Vitamin A deficiency (VAD) is a major problem in large parts of the developing world. An estimated 250,000 to 500,000 VA-deficient children go blind every year. Apart from acute eye symptoms, VAD also weakens the immune system, thus increasing the incidence and severity of infectious diseases and infant mortality rates. For adults, the implications can be serious, too, especially for pregnant and lactating women. Nearly 600,000 women die from childbirth-related causes each year, many of them from complications which could be reduced through better provision of vitamin A (Sommer and West, 1996). The most affected population groups are the poor, whose diets are predominated by less nutritious staple foods on account of lacking purchasing power and limited awareness.

During the last decade, a lot of efforts have been made to reduce VAD in developing countries. Food fortification, supplementation, and dietary education programmes have been undertaken. A complementary approach is to enrich major staple foods with provitamin A through plant breeding. For some crop species, such as maize and sweet potato, cultivars or landraces with high beta-carotene contents were identified, which can be used in traditional breeding programmes. However, beta-carotene does not occur naturally in the endosperm of rice – the major staple food in large parts of Asia. Hence, for rice, use of biotechnology is required (Bouis, 2000). Recently, so-called Golden Rice (GR) has been developed through genetic engineering to produce beta-carotene in the endosperm of the grain (Ye et al., 2000; Beyer et al., 2002). This technology could contribute to improving the VA status of the poor. Although GR is still at the stage of research and development (R&D), it is already surrounded by a lot of public controversy. Some optimists praise it as the solution to overcome malnutrition and VAD. Others denounce it as a mere child of the biotech lobby and consider it a useless and rather harmful innovation for the developing world.

The aim of this study is to analyse the potential benefits of GR in the Philippines. VAD constitutes a serious problem in this country. Moreover, the technology was recently transferred to the Philippine-based International Rice Research Institute (IRRI), where adaptive research is now being carried out. GR has not yet been released for commercial application, so the study takes an *ex ante* perspective. Since the main merit of GR is its potential to improve the health and nutrition status of rice consumers, the methodological challenge is to appropriately combine issues of agricultural and health economics. At first, an analytical framework is developed to conceptualise the study and identify key issues that might affect the impact of the innovation. Apart from technological features, the adoption by farmers and acceptance by consumers will play an important role. Then, health problems resulting from VAD in the Philippines are described and classified. The social costs associated with these health problems are quantified using the methodology of disability-adjusted life years (DALYs). These costs are expressed in DALYs lost. In a further step, DALYs to be gained through GR are calculated, and a preliminary cost-benefit analysis of the R&D

project is provided. This is among the first studies to quantify the health benefits from micronutrient-enriched crops.[1]

Many of the parameters needed for the analysis are not yet known in our *ex ante* framework. Therefore, the calculations have to be built on scenarios and assumptions. To use the best information available at this stage, our assumptions are based on interviews and intensive discussions with researchers, health and nutrition specialists, as well as farmers and consumers in the Philippines. Of course, the exact numerical results should be interpreted with some caution. Nonetheless, the study might help to rationalise the controversy surrounding GR technology. More generally, it will also contribute to a better understanding of the ramifications of genetically modified (GM) food crops with enhanced nutritive values in developing countries. Biotechnology is increasingly seen as a powerful tool to fight micronutrient deficiencies, but empirical evidence is still lacking.

[1] Based on detailed food intake data from one region in the Philippines, Robertson et al. (2001) analysed the role GR could play for the VA status of children. However, they do not explicitly consider the health effects and economic benefits resulting from an improvement in VA status.

2 Analytical Framework

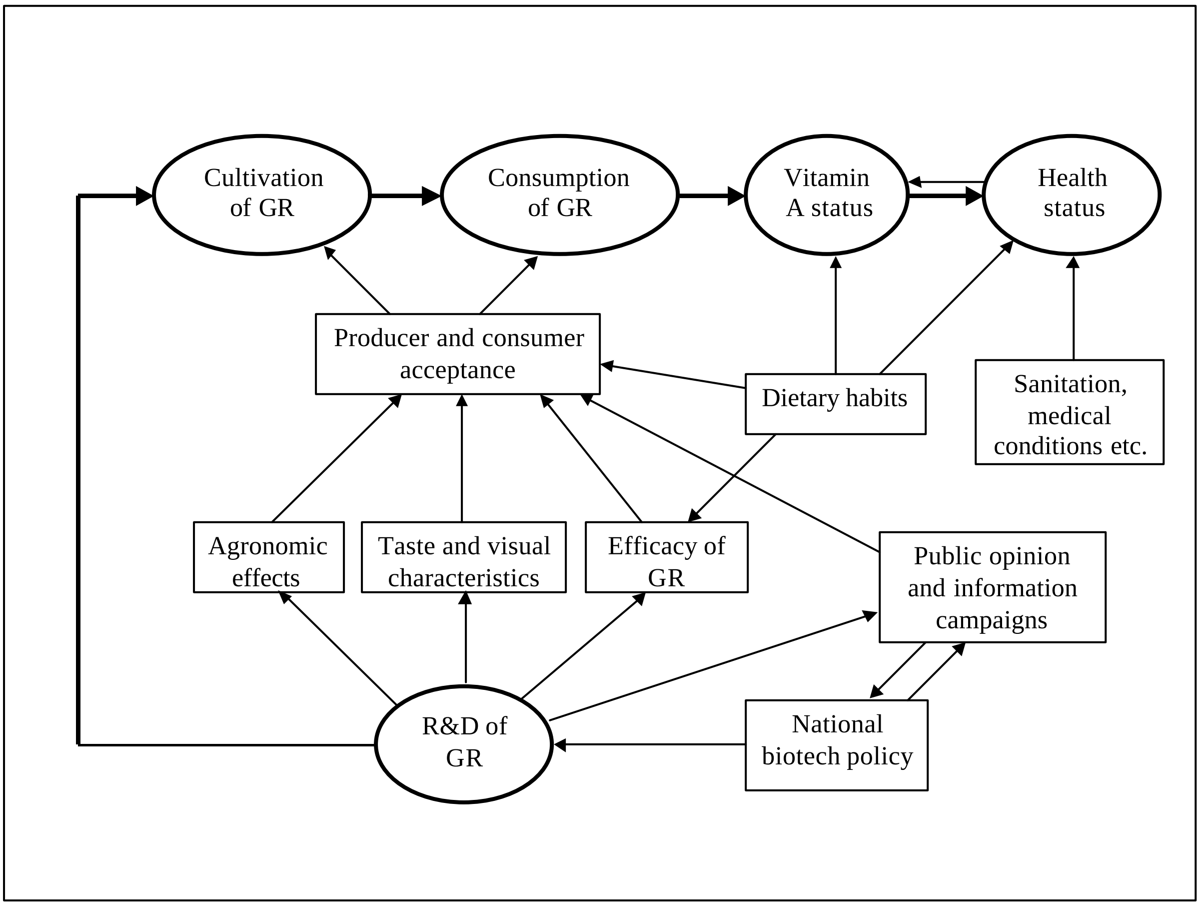
New agricultural crop technologies are usually evaluated by looking at changes in yield or cost of production. With the help of fitting data, aggregate benefits can then be calculated by modelling a shift in the commodity supply curve. However, this approach is only suitable when the technology involves improved agronomic traits, that is, when the advantage unfolds at the level of agricultural production. Technologies that enhance the quality of commodities are rather associated with benefits at the level of consumption. The primary goal of GR is to improve the health and nutrition status of rice consumers. Generally, quality improvements would increase the consumers' willingness to pay, entailing an upward shift in the commodity demand curve. This was modelled, for instance, by Unnevehr (1986). An increase in willingness to pay, however, presupposes that consumers recognise and appreciate the quality improvement. It is questionable whether this will be the case for GR, because awareness of VAD among poor population segments is generally low. And, even if awareness is existent, poverty often prevents that nutritional needs are translated into effective market demand. Therefore, modelling the benefits of GR in a market model does not appear appropriate. Instead, we have to identify and measure the health effects associated with the technology.

2.1 Conceptual Issues

VAD leads to increased morbidity and mortality. The most affected population groups are children, and pregnant and lactating women. VAD causes xerophthalmia, which is a term used to describe the entire eye signs resulting from the deficiency (see next section for details). But diseases such as diarrhoea, measles, and respiratory infection are also related to VAD. The potential benefit of GR is to reduce these health problems through improving VA status of affected individuals. Before these advantages can materialize, though, farmers have to grow and consumers have to eat GR. These relationships are visualized in Figure 1.

The ellipses and bold arrows indicate the way which GR has to take from the stage of R&D over agricultural production to the level of consumption. How fast the technology will leave the stage of R&D depends on progress within the research process itself. Yet, also the biotechnology policy, including the handling of bio- and food safety issues at the national level, will play an important role. Then, there is uncertainty related to the question as to how effective GR will eventually be. On the one hand, this depends on the technology's efficacy, that is, the amount of beta-carotene contained in the rice as well as its absorption and bioconversion by the human body. On the other hand, the coverage rate of GR will be a crucial factor, that is, consumer and producer acceptance. Consumers that are aware of VAD problems will assess in how far normal levels of GR consumption could improve their VA status. But also taste and visual characteristics, as well as general dietary habits, will have an effect on consumer decisions. Producers will additionally be interested in possible agronomic consequences associated with the technology (e.g., yield, susceptibility to stress). Finally, acceptance will be influenced by the general public opinion about biotechnology and, related to this, education and information campaigns for GR.

Figure 1: Factors influencing the impact of Golden Rice



2.2 Methodology

The main benefit of GR will be to reduce the health costs associated with VAD. We only consider the direct costs. Indirect costs, such as caring for a blind family member or pain associated with certain ailments, are disregarded. Health costs are quantified by using the disability-adjusted life years (DALYs) approach. First, the number of years lost due to mortality and disability caused by VAD without GR are evaluated. Second, the same calculations are carried out assuming the introduction of GR. The difference in years lost represents the impact of the innovation. To our knowledge, the DALYs approach has not been used previously for the evaluation of micronutrient-enriched staple foods.

DALYs lost without Golden Rice

The DALYs approach was developed by Murray and Lopez (1996). It is a relatively new metric, which is promulgated by the World Health Organisation (WHO) and the World Bank as a means of combining information about mortality and morbidity within a single index. It expresses years of "healthy" life lost due to mortality (YLL) and years of life with disability (YLD) of specific severity and duration. The formula as defined by Murray and Lopez has been modified and adapted to our study:

(1) $$DALYs_{Lost} = YLL + YLD_{temp} + YLD_{perm}$$

where YLD_{temp} are years with temporal disability, and YLD_{perm} are years with permanent disability. We will concentrate on three target groups – children under the age of six, pregnant women, and lactating women. Furthermore, we take into account different diseases or disease levels, which are explained in the following section. DALYs lost are calculated on an annual basis. This means that only deaths and new cases of disease occurring in the reference year are considered, whereby the health costs are accumulated over the entire life of the people affected. Thus, the DALYs formula becomes:

(2) $$DALYs_{Lost} = \sum_j T_j M_j \left[\frac{1}{r}\left(1 - e^{-rL_j}\right) \right] + \sum_i \sum_j T_j I_{ij} D_{ij} \left(\frac{1 - e^{-rd_{ij}}}{r} \right) + \sum_k \sum_j T_j I_{kj} D_{kj} \left(\frac{1 - e^{-rL_j}}{r} \right)$$

where T_j is the total number of people in target group j, M_j is the mortality rate associated with VAD, and L_j is the average remaining life expectancy in the same group. I_{ij} is the incidence rate of temporary disease i in group j, D_{ij} is the corresponding disability weight, and d_{ij} is the duration of the temporary disease. k, in turn, denotes permanent diseases, and r is the rate at which future costs are discounted.

Murray and Lopez use an age weighting function such that deaths or disabilities occurring in childhood or old age cause fewer DALYs lost than when occurring in the middle years of life. Age weighting is intended to reflect the greater social responsibility of individuals at middle age. It is, however, relatively controversial in terms of equity implications (Anand and Hanson, 1998) and, in many cases, does not essentially change the overall burden estimates (Mathers et al., 1999). We do not use age weighting, because children are among the most affected by VAD-related diseases.

Often, health statistics provide prevalence rather than incidence rates of particular diseases. Without adjustment, this would certainly overestimate the annual burden of disease. Different authors argued that when using prevalence rates instead of incidence rates, the duration of disease should be taken as one year in the calculation (e.g., Brenzel, 1993; Murray and Lopez, 1996). We follow this suggestion for temporary diseases in equation (2). For permanent diseases, a somewhat different approach is taken: in the case of VAD, permanent diseases can be reduced to blindness.

Unfortunately, neither prevalence nor incidence rates for blindness are available for the Philippines. However, as is elaborated in the next section, VAD-related blindness is always preceded by certain levels of temporary disease, which, without immediate treatment, will rapidly lead to complete loss of eyesight. Therefore, we assume that the prevalence rates of these particular temporary diseases added up will constitute a good approximation for the incidence rate of VAD-related blindness.

As the name indicates, DALYs are measured in disability-adjusted life years. However, when attributing a monetary value for each year, DALYs can also be expressed in dollar terms. In a study on different micronutrient deficiencies in developing countries, the World Bank (1994) used an amount of US $1,000 per DALY lost. We will use the same figure for our calculations. For industrialized countries, assumed values are often much higher than this (e.g., Tolley et al., 1994). Generally, a suitable value in a particular context is derived as a function of per capita incomes and willingness to pay for health services. So, by using a monetary figure it is not claimed to quantify the intrinsic value of life, which would certainly be associated with serious ethical concerns.

DALYs lost with Golden Rice

VAD-related diseases and thus costs will be reduced if people eat GR on a regular basis. The reduction of diseases in each target group is expressed by a decline in prevalence rates. To calculate the reduced prevalence rates, we adopt a model used by Brenzel (1993). The new prevalence rate of disease i (or incidence rate of disease k) in group j (Pn_{ij}) is a function of the initial prevalence rate (P_{ij}), the group-specific efficacy rate (E_j), and the coverage rate (C) of the GR intervention, according to the following formula:

$$Pn_{ij} = \left[1 - \left(E_j \times C\right)\right] \times P_{ij}. \tag{3}$$

The new mortality rates (Mn_j) are calculated in the same way. E_j is mainly a function of technological characteristics, and C depends on accessibility and acceptance of GR, aspects which are dealt with in later sections. An implicit assumption behind this formula is that GR will reduce the prevalence rates of all diseases to equal proportions within a particular target group. Whether this is realistic cannot be established at this stage. However, based on the information presently available, it is the only reasonable conjecture we can make. Inserting the new prevalence rates in equation (2) will result in the number of DALYs lost with GR.

2.3 Data

The use of the DALYs approach presupposes the availability of different types of data and information. To a great extent, these data were not easily available for our study in the Philippines, either because they are not yet observable in the *ex ante* framework, or because existing statistics do not cover certain variables. The concrete values used for the calculations will be explained in later sections. This sub-section, however, gives a brief overview of data sources and collection procedures. Often, expert estimates had to be elicited in order to complement secondary data. In these cases, great care was taken to obtain statements from a variety of persons, in order to minimize a possible bias due to personal incentive structures or lack of farsightedness. Specific data requirements and sources are summarized in Table 1.

Table 1: Data categories and sources

Category	Information required	Source
Technology-related data	• Amount of beta-carotene • Agronomic effects • Time path and cost of R&D project	• IRRI and Philrice researchers • Independent researchers
Nutrition-related data	• Bioconversion of beta-carotene in GR • Efficacy of GR • Nutrition situation • Food consumption data	• Nutritionists • Medical experts • Secondary sources
Epidemiology-related data	• Prevalence/incidence rates of VAD • VAD-related mortality rates • Disability weights	• Secondary sources • Epidemiologists • Medical experts • Health economists
Demographic data	• Number of people in target groups • Life expectancy	• Secondary sources
Acceptance-related data	• Coverage rate	• Focus group discussions • Nutritionists • Social scientists • Extensionists

Technology-related data – such as the amount of provitamin A in GR and possible agronomic effects – are mainly based on interviews with researchers at IRRI and the National Rice Research Institute in the Philippines (Philrice). Since feeding tests with GR have not been carried out so far, questions concerning bioconversion and the technology’s potential efficacy in improving the health status of consumers were discussed with a number of nutritionists and health experts in the Philippines and other countries. Epidemiology-related and demographic data were partly taken from national statistics. The Food and Nutrition Research Institute of the Philippines (FNRI), for instance, is conducting nutrition and health surveys every five years. Missing data were assembled through interviews with health specialists, as were estimates on disability weights associated with different disease levels. Food consumption data are partly based on FNRI surveys, supplemented by discussions with local nutritionists. Information on GR acceptance was obtained through focus group discussions with rice producers and consumers and interviews with local experts.

3 Vitamin A Deficiency and Related Health Costs in the Philippines

In order to assess the costs of VAD and the potential impact of GR, it is essential to understand the linkages between nutrition, VAD, and related levels of disease. This section gives a brief overview and analyses the problem in a Philippine context.

3.1 Vitamin A Deficiency and Related Diseases

VA is a fat-soluble vitamin. It helps in the formation and maintenance of healthy teeth, skeletal and soft tissue, mucous membranes, and skin. It promotes good vision, and is also required for reproduction and lactation (Sommer and West, 1996). VA occurs in two forms: the active (preformed) and the precursor form. Preformed VA is found only in animal products; the most frequent active VA is retinol. Precursor forms, in turn, are common in many fruits and vegetables, as well as in yeast and some species of bacteria and fungi. The precursors of VA are known as carotenoids. However, less than 10% of all carotenoids serve as precursors for VA. The most well-known carotenoid is beta-carotene, which the human body can convert to the active form of VA. Excessive dietary intake of preformed VA can be toxic, an effect which does not occur with the precursor forms. When VA intake is lower than the recommended dietary allowance (RDA), the individual will suffer acute and chronic health impairments.[2] VAD usually results from malnutrition but can also be due to abnormalities in the intestinal absorption of retinol or carotenoids.

VAD is subdivided into two categories – sub-clinical and clinical VAD. Sub-clinical VAD is usually not associated with immediate symptoms, but it can cause high morbidity and mortality, among children in particular. Clinical VAD involves the characteristic ocular manifestations, usually referred to as "xerophthalmia". Xerophthalmia can be subdivided into the following levels according to degree of VAD and medical severity (WHO, 1982):

- *Night blindness (XN).* Night blindness is the earliest, specific clinical manifestation of VAD and is usually the most prevalent stage of xerophthalmia. In this stage, the patient is not able to see in dim light. Night blindness is not always recognised, especially among infants and children.

[2] The RDA is the average daily dietary intake level that is sufficient to meet the nutrient requirement of healthy individuals in a particular life stage and gender group (IOM, 2002). It has been established to give approximately three months of body stores, so that temporary undersupply can be compensated. However, insufficient VA intake over an extended period of time will lead to the health problems described.

- *Bitot's spot (X1B).* Bitot's spots are irregular shaped foam-plaques on the underside of the eyelid. Often, they are associated with a dryness of the white of the eye.
- *Corneal ulceration (X2, X3A, X3B).* Corneal ulceration indicates destruction of a part or all of the cornea, the outermost layer of the eye. It is associated with relatively high VAD over an extended period of time.
- *Corneal scars (XS).* As the name indicates, Corneal scars are scars on the cornea, resulting from previous destructions through earlier stages of xerophthalmia.

Night blindness and Bitot's spot can develop into more severe manifestations when they are not medicated in due time. When they are treated with high-potency VA, however, the eye usually fully recovers in a matter of weeks. Recommended treatment and prevention schedules are shown in Table 2. While Corneal ulceration and Corneal scars can also heal with only minimal structural damage when treated with high-potency VA, they rapidly lead to irreversible blindness when not treated on time (Sommer, 1995).

Table 2: Xerophthalmia treatment and prevention schedules

	Treatment at diagnosis		Prevention	
Population group	VA dosage (IU) [a]	Frequency	VA dosage (IU) [a]	Frequency
Children				
Below 6 months	50,000	on two consecutive days, again after 1-4 weeks	50,000	At 6, 10, 14 weeks
6-11 months	100,000		100,000	Every 4-6 months
Above 11 months	200,000		200,000	
Women	200,000 [b]		400,000	8 weeks after delivery

[a] 1 international unit (IU) is equivalent to 0.3 µg of retinol.
[b] Only for corneal xerophthalmia; for milder eye signs, women are treated with 25,000 IU per week for up to 4 weeks.
Source: West and Darnton-Hill (2001).

These four levels of xerophthalmia are considered as temporary diseases in our study, whereby Corneal ulceration and Corneal scars are assumed to result in permanent blindness. In a Philippine context, this assumption appears realistic, because only in very rare cases will eye symptoms among the poor be diagnosed and treated promptly. It should be mentioned, though, that dietary VAD is not the only cause of xerophthalmia. Night blindness and eye dryness, for instance, can also be symptoms of several rare degenerative disorders of the eye (e.g., Zeiss et al., 2000). Such symptoms do not respond to changes in VA intake, which could be a cause of inaccuracy in our approach to evaluate GR. Yet we expect this inaccuracy to be small, because VAD is by far the most important cause of xerophthalmia in developing countries.

3.2 Nutrition and Vitamin A Deficiency in the Philippines

In the Philippines, FNRI carries out nutrition and health surveys every five years with varying regional and thematic focuses. Results from the 1993 survey showed that the typical Filipino diet was rice, boiled fish with relatively little vegetables.[3] On average, this diet only meets 88% of the RDA for energy and even less for other nutrients (FNRI, 1993). Vulnerable groups, such as pre-school children, and pregnant and lactating women, usually achieve less than 70% of their energy requirements. The present economic situation in the Philippines further aggravates the problem of malnutrition. The effects of the 1997 Asian financial crisis and the El Niño phenomenon were manifested in an increased prevalence of malnutrition in the nutrition survey of 1998 (FNRI, 1998).

Micronutrient deficiencies in the Philippines are widespread. Besides iron and iodine deficiencies, VAD is considered a major health problem, with prevalence rates exceeding the WHO cut-off points. As a signatory to the World Summit for Children (1990), the Conference on Ending Hidden Hunger (1991), and the International Conference on Nutrition (1992), the Government of the Philippines is committed to reducing micronutrient deficiencies in the country. Public initiatives include the distribution of VA capsules to children between one and six years of age and iodised oil capsules to pregnant women. Another programme encourages private food manufacturers to fortify their products with micronutrients at levels approved by the Department of Health. So far, a handful of manufacturers were authorised to fortify wheat flour, margarine, instant fruit drinks, and canned sardines with VA (Solon et al., 2000). A recent evaluation showed that these supplementation and fortification programmes are successful in improving VA status of the Philippine population (Fiedler et al., 2000). However, due to institutional problems, coverage rates of both programmes are incomplete; in particular, they are less effective for the poor in remote rural areas. GR could overcome some of these institutional drawbacks.

3.3 Costs of Vitamin A Deficiency in the Philippines

In this sub-section, we calculate the costs of VAD in the Philippines without GR. The costs are expressed in DALYs lost, based on the methodology outlined above. Before presenting the results of these calculations, we briefly describe the individual parameters used.

[3] Regional differences occur. For instance, in the Visayas and Mindanao, more corn than rice is consumed. In Luzon regions, fish is often supplemented with meat. In general, urban dwellers tend to consume more animal products, whereas people in rural areas show a significantly higher consumption of staple foods and vegetables.

Parameters used for the calculations

Prevalence rates for different levels of VAD and associated diseases are based on the FNRI nutrition and health surveys. Unfortunately, the most recent survey of 1998 did not look into clinical levels of VAD; data collection was confined to sub-clinical levels by measuring plasma retinol concentrations of randomly selected individuals. As the 1993 survey was more comprehensive with respect to VAD, we use these earlier values for the prevalence of clinical manifestations. Based on sub-clinical VAD alone, prevalence rates among the three target groups were higher in 1998 than in 1993. For children, the value increased from 35.3% to 38.0%. For pregnant women, the increase was from 16.4% to 22.2%, and for lactating women, the values were 16.4% and 16.5% in 1993 and 1998, respectively. Table 3 shows the prevalence rates for sub-clinical levels and temporary diseases used in our calculations. Missing values were replaced by estimates of local epidemiologists. Incidence rates for VAD-related blindness are not shown in the Table; they are assumed to equal the sum of prevalence rates for Corneal ulceration and Corneal scars in each individual target group.

Table 3: Prevalence rates and number of people affected by VAD-related diseases

	Children (0-6 years)		Pregnant women		Lactating women	
	Prevalence rate (%)	Number of affected (thousand)	Prevalence rate (%)	Number of affected (thousand)	Prevalence rate (%)	Number of affected (thousand)
Sub-clinical VAD	38.00 [a]	5,082.81	22.20 [a]	359.23	16.50 [a]	260.36
Night blindness	0.40 [b]	53.50	0.60 [b]	9.71	0.90 [b]	14.20
Bitot's 's spot	0.10 [b]	13.38	0.40 [c]	6.47	0.70 [c]	11.05
Corneal ulceration	0.05 [c]	6.69	0.30 [c]	4.85	0.50 [c]	7.89
Corneal scars	0.00 [b]	0.00	0.15 [c]	2.43	0.30 [b]	4.73

[a] These values are based on FNRI (1998).
[b] These values are based on FNRI (1993).
[c] These values are based on expert estimates.

The total number of children is based on data from the Philippines Census Bureau. For pregnant and lactating women, published statistics do not provide data. The number of pregnant women is assumed to equal the sum of life births and foetal deaths, whereas the number of lactating women is assumed to equal the sum of life births minus the deaths of infants. These values were taken from the Philippine Statistical Yearbook (NSCB, 2000). Multiplying the total number of individuals in each target group by the prevalence rates, results in the number of people affected by VAD-related diseases also shown in Table 3. Around 6,700 children, 7,300 pregnant women, and 12,600 lactating women go blind every year in the Philippines. It is assumed that the average age at onset is 0.5 for children, and 20 for pregnant and lactating women, respectively.

Disability weights for different diseases were specified together with the interviewed health experts in the Philippines. For night blindness, the disability weight is 0.15, for Bitot's spot, it is 0.25, and for Corneal ulceration, Corneal scars, and blindness, it is 0.5, equal across the three target groups. These figures are consistent with values used in other studies in a similar context (e.g., World Bank, 1994). Sub-clinical levels of VAD have a disability weight of zero, because there are no immediate symptoms. However, since they are associated with increased mortality rates, their costs are at least partially considered in the DALYs calculations.

In countries where VAD presents a risk for the population, 10% of all deaths from tuberculosis, measles, pertussis, malaria, diarrhoeal, and respiratory diseases among children under five are attributable to VAD (World Bank, 1993). According to our expert interviews, 6% of all female deaths in the Philippines between the age of 15 and 49 are of pregnant women caused by VAD, and 4% of all maternal deaths are of VA-deficient lactating women. Figures on overall death rates were taken from recent official statistics (NSCB, 2000). The average age at death for children is assumed to be one, and for pregnant and lactating women, it is assumed to be 35. Following international standards for the discounting of future health costs and benefits (e.g., Gold et al., 1996), a discount rate of 3% is used in our DALYs calculations.

DALYs lost due to VAD

By using equation (2) and the parameters specified above, DALYs lost without GR were calculated. The results are shown in Table 4. In total, about 432 thousand years of "healthy" life are lost in the Philippines annually due to VAD-related mortality and disability conditions. As can be seen, the highest cost occurs among children. Losses due to increased mortality are much higher in this target group than in the other two groups. This underlines that blindness and visual problems are only part of the overall social costs caused by VAD. Also, the total number of children affected by xerophthalmia is higher than the number of affected pregnant and lactating women. Still, disability costs for lactating women exceed those for children because of higher prevalence rates for Corneal ulceration and Corneal scars. In fact, the incidence of blindness among children is fairly low in the Philippines; much lower than in other countries of Southeast Asia. In part, this might be due to the VA supplementation programme targeted at children, which the Philippine Government started in the early 1990s.

Table 4: DALYs lost due to VAD without Golden Rice

	Children	Pregnant women	Lactating women	Total
Loss due to mortality	88,811	2,093	1,334	92,238
Loss due to disability	108,411	84,610	146,246	339,267
Total loss	197,222	86,704	147,579	431,505
In monetary terms (million US$)	197.22	86.70	147.58	431.51

According to the World Bank (1993), the total DALYs lost due to VAD in Asia (China and India excluded) were about 9.5 million in 1990. Assuming that this figure remained constant until the late 1990s, which is our reference period, would mean that the Philippines accounted for 4.5% of the total DALYs lost in the region. Such a comparison, however, should be treated with caution. In the World Bank publication, a very rough approach is used, and VAD is evaluated among many other health problems. We are not aware of any study that uses DALYs for VAD with a degree of detail similar to ours. Converting the total DALYs in Table 4 into monetary terms, we result in a pecuniary loss of about $432 million per year. This is equivalent to 0.54% of the Philippine gross national product (GNP) in the late 1990s.

4 Golden Rice and Factors Influencing Its Effectiveness

GR was invented to provide a new intervention to combat VAD. It was developed through genetic engineering to produce beta-carotene in its endosperm, giving it the distinct yellow colour that affords it the name Golden Rice. Three gene constructs were inserted into the rice genome, which complete the biochemical pathway needed for beta-carotene production in the grain (Ye et al., 2000). Conventional rice produces carotenoids in other parts of the plant but not in the endosperm. The research was performed at Swiss and German universities, and was funded by the Rockefeller Foundation, the Swiss Government, and the European Union. The concept was initially proved with japonica rice varieties, which are not commonly consumed in Asia. In 2001, the technology was transferred to IRRI for adaptive research. IRRI researchers are currently working on verifying and improving the gene constructs and incorporating them into various indica varieties. After the adaptive phase, feeding trials as well as bio- and food safety tests will need to be carried out. It is expected that GR could become commercially available in 2007. Private companies, holding patents over different technology components used in the research process, have agreed that GR may be distributed free of charge to resource-poor farmers in developing countries (Potrykus, 2000).[4]

In section 2, it was pointed out that the main effect of GR will be to lower mortality and prevalence rates of VAD-related diseases. Equation (3) showed that this is a function of the technology's efficacy and coverage. This section explains the factors influencing these variables. As there is uncertainty related to key parameters, we use two scenarios for calculating the potential impact of GR – one more pessimistic scenario and one which is rather optimistic. The assumptions underlying these scenarios are also outlined in this section.

4.1 Efficacy

The efficacy of GR is its capacity to improve the health status of the VA-deficient population, that is, its potential clinical outcome. Primarily, efficacy depends on the actual amount of VA obtained through GR and the degree of VAD in the target groups. The amount of VA obtained, in turn, depends on the amount of beta-carotene in the rice as well as its bioconversion to VA. Because these are crucial factors for the analysis, we will explain them one by one, before proceeding to the actual efficacy calculations.

[4] For humanitarian purposes, the technology may be distributed free of charge to farmers who earn an income of less than $10,000 per year from GR.

Amount of beta-carotene

The current amount of beta-carotene that researchers managed to get into GR is 1.6 micrograms per gram. Ye et al. (2000) argued that the same technology could yield 2.0 micrograms per gram, if a homogenous line with uniformly coloured grains were produced. With slight modifications in the gene constructs, such as using more efficient promoters, the amount could be further increased. According to Datta (2001), it could be possible to achieve 3.0 micrograms per gram within the adaptive research phase. Even much higher amounts are theoretically possible (Beyer et al., 2002). This, however, could possibly have an undesirable influence on yield performance and taste characteristics of rice varieties. Therefore, in the pessimistic scenario, we assume a beta-carotene content of 1.6 micrograms per gram of GR, whereas in the optimistic scenario, we assume 3.0 micrograms per gram.

Post-harvest treatment, storage and processing of GR might also influence its beta-carotene content at the time of consumption. For leafy vegetables, for instance, it has been reported that exposure to sunlight after harvesting can result in a considerable loss of beta-carotene (Boileau et al., 1996). The same study found that losses are negligible for carrots, which is probably due to their more compact structure and smaller surface area. Given these results, it is likely that post-harvest losses of beta-carotene in GR can be kept relatively low. Still, some losses might occur with improper storage. In terms of processing, prolonged exposure to extreme heat often reduces the bioavailable portion of beta-carotene, while cooking at temperatures up to 100°C can even increase the extractable amount of carotenoids (Dietz et al., 1988). The fact that rice in the Philippines is usually steamed or boiled at moderate temperatures suggests that processing will not lead to significant additional losses. Against this background, we assume that total post-harvest losses are 25% in the pessimistic scenario, while they are zero in the optimistic alternative.

Bioconversion

Bioconversion is defined as the process of beta-carotene absorption by the human body and its transformation to retinol. After absorption, the transformation of beta-carotene to retinol takes place with a factor of approximately 2:1 (IOM, 2002). However, variation in terms of absorbability occurs between different types of food. Absorption is most efficient when physiological amounts of beta-carotene are dissolved in oil. For spinach, an absorption efficiency of only 7% has been reported (Castenmiller et al., 1999). Other authors reported values of 11-12% for broccoli, and of 18-26% for carrots (Micozzi et al., 1992; Törrönen et al., 1996). In a study with schoolchildren in Indonesia, de Pee et al. (1998) found that the VA activity of beta-carotene in fruits and yellow tubers was more than double the activity for dark, green leafy vegetables. Generally, absorbability depends on the state of beta-carotene and its association with plant matrix materials in the food source (Parker, 2000). Also, it is correlated with the intake of complimentary ingredients in the diet.

Low fat consumption, for instance, reduces the absorption of beta-carotene significantly (Jalal et al., 1998). The same holds true for alcohol, smoking and other drugs (e.g., Albanes et al., 1997).

Given these findings, the retinol equivalency ratio (bioconversion) for beta-carotene from food in a mixed diet, which includes fruits and vegetables, is estimated to be 12:1 (IOM, 2002).[5] For GR, feeding tests will only be carried out over the next few years, so that specific data and information are not available. We take the 12:1 bioconversion rate as our negative assumption. However, since rice has a simple food matrix with totally digestible carbohydrates, beta-carotene absorption might be higher than when obtained from fruits and vegetables. If taken along with some fat in the diet, the retinol equivalency ratio for beta-carotene in GR could even be as high as for beta-carotene dissolved in oil, that is, 2:1 (Russell, 2002). Taking this as an average value might be exaggerated for our projections. But, taking account of the simple food matrix, we increase the bioconversion rate and use a value of 6:1 in the optimistic scenario.

Efficacy calculation

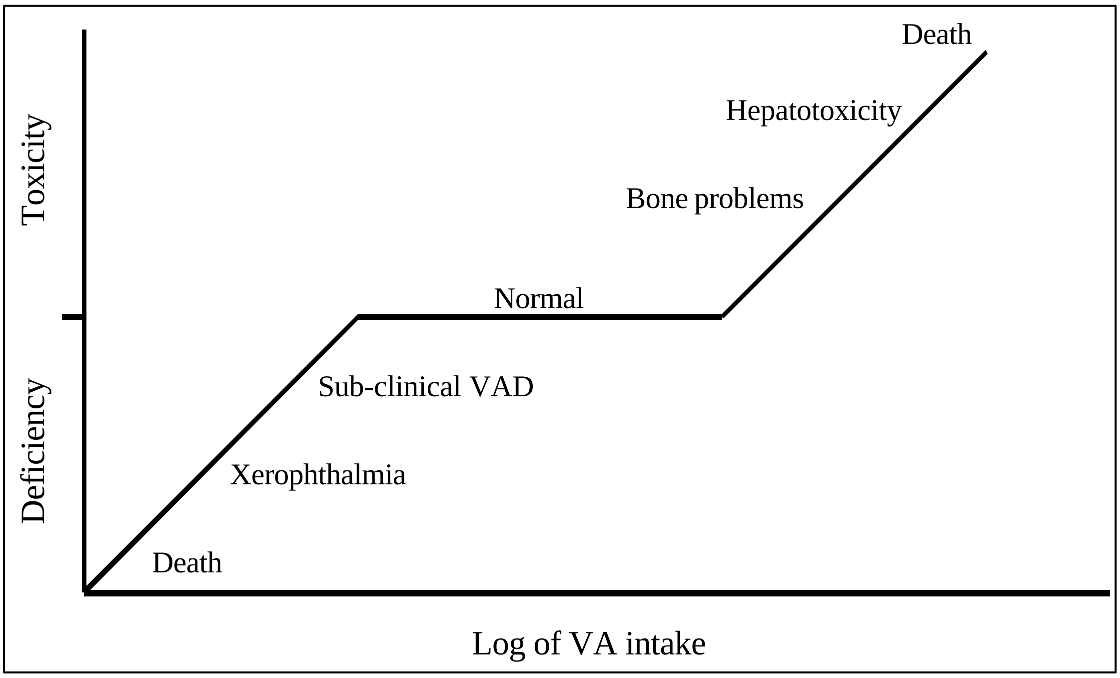
A straightforward way of calculating the efficacy of GR would be to assume a linear relationship between VA intake and the level of deficiency-related diseases. This would mean that each percent reduction of a person's VA gap would result in an equally high efficacy, regardless of the degree of VAD. This is too simplistic, however, because it is widely acknowledged that the biological response to VA intake strongly depends on the body stores of VA. Bauernfeind (1980) and Olson (1994) describe the occurrence of health problems as a logarithmic function of VA intake, as illustrated in Figure 2. The implication is that the health response to VA intake is more pronounced at higher levels of deficiency than it is at lower levels.

Building on this relationship, we develop a non-linear model of efficacy which is shown in Figure 3. VA intake is depicted on the horizontal axis, whereas disease levels are shown on the vertical axis. The current VA intake (CVA) is below the RDA, a situation which we actually observe for our target groups in the Philippines. The improved VA intake (IVA) represents the current intake plus the increment from GR consumption. This level might still be lower than the RDA. However, it can be seen that the lower the initial level of VA intake is, the higher is the positive health effect of the technology. Beyond the point of RDA, no further health improvement is possible. Algebraically, the relationship between VA intake (x) and disease levels (DL) can be written as

(4) $$DL(x) = \frac{1}{x} - \frac{1}{RDA} .$$

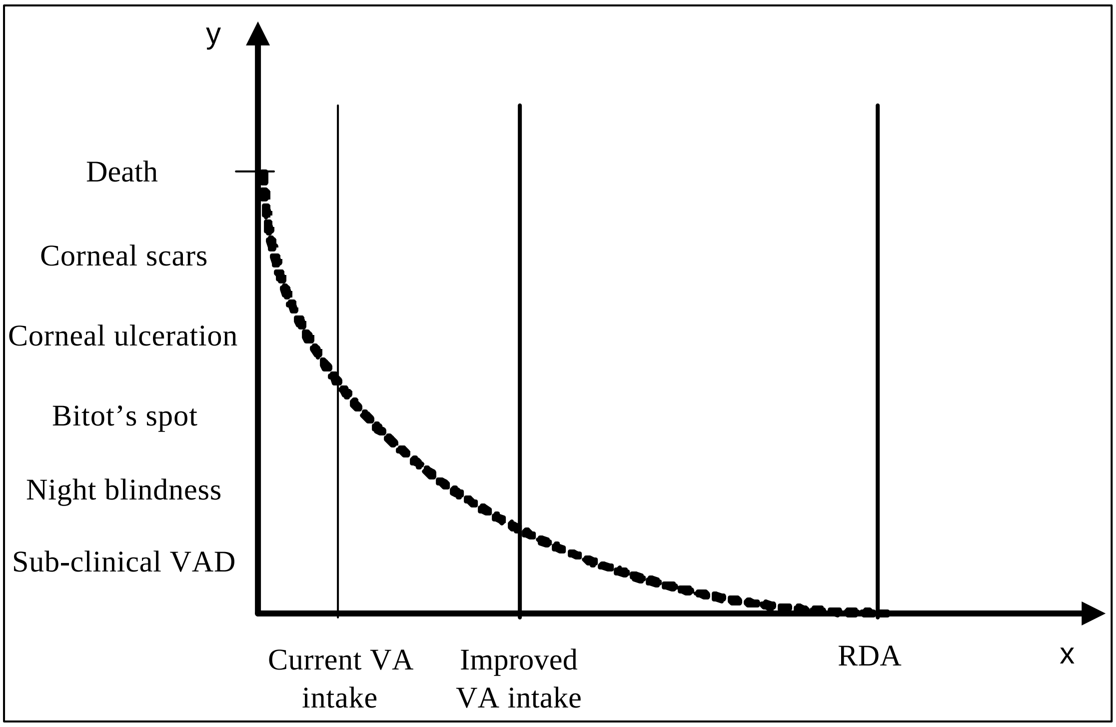
[5] This is only half the value of 6:1, which was assumed for a long time in the nutrition community (e.g., FAO, 1988; Underwood, 2000).

Figure 2: Relationship between VA intake and clinical manifestations



Source: Schematic adaptation from Bauernfeind (1980).

Figure 3: Efficacy model



The efficacy of GR (E) as a function of x is then defined as the proportion of two areas under the function in equation (4), that is

(5)
$$E(x)=\frac{\int_{CVA}^{IVA}\left(\frac{1}{x}-\frac{1}{RDA}\right)dx}{\int_{CVA}^{RDA}\left(\frac{1}{x}-\frac{1}{RDA}\right)dx}.$$

Evaluating the integrals we obtain

(6)
$$E(x)=\frac{\log\left(\frac{IVA}{CVA}\right)-\left(\frac{IVA-CVA}{RDA}\right)}{\log\left(\frac{RDA}{CVA}\right)-\left(\frac{RDA-CVA}{RDA}\right)}.$$

Based on equation (6), we calculate the efficacy for our two scenarios. Because efficacy should represent the technological potential of the innovation, at this point we assume that GR will completely substitute for the conventional rice that a deficient individual eats. To what extent substitution might take place in reality is a question which is discussed in the following sub-section. The results of the efficacy calculations are shown in Table 5.

Table 5: VA intake and efficacy of Golden Rice

	Pessimistic scenario			Optimistic scenario		
	Children	Pregnant women	Lactating women	Children	Pregnant women	Lactating women
Rice consumed (g/day) [a]	121.00	245.00	274.00	121.00	245.00	274.00
Current VA intake (µg/day) [a]	234.30	597.10	404.10	234.30	597.10	404.10
RDA for VA (µg/day) [b]	500.00	800.00	1,250.00	500.00	800.00	1,250.00
VA deficit (µg/day)	265.70	202.90	845.90	265.70	202.90	845.90
Beta-carotene intake through GR (µg/day)	145.20	294.00	328.80	363.00	735.00	822.00
VA from GR after bioconversion (µg)	12.10	24.50	27.40	60.50	122.50	137.00
Improved VA intake (µg/day)	246.40	621.60	431.50	294.80	719.60	541.10
Contribution of GR to reduce VA deficit (%)	4.55	12.07	3.24	22.77	60.37	16.20
Efficacy (%)	11.54	24.64	9.65	47.97	86.08	40.30

[a] These figures are based on FNRI (1993).
[b] These figures represent internationally used RDAs (IOM, 2002).

The efficacy in the optimistic scenario is significantly higher than in the pessimistic scenario. Given the higher assumptions on beta-carotene content and bioconversion, this should not come as a surprise. Noteworthy, however, is that even in the optimistic scenario the efficacy is significantly lower than 100% for all three target groups. This means that GR alone will not completely eliminate VAD and associated health problems.[6] But, as can be seen, its potential to improve VA status of the target groups is significant. Interestingly, the efficacy is highest for the group of pregnant women in both scenarios. As the VA deficit in this group is comparatively low, the relative contribution of GR in closing this gap is bigger than for the other two groups. On the other hand, the efficacy-to-contribution ratio is lower than for the more deficient groups, as we would expect given the non-linearity in the efficacy model.

4.2 Coverage Rate

The coverage rate of GR is its capacity to reach the VA-deficient population. Coverage depends on accessibility on the one hand, and on producer and consumer acceptance on the other.

Accessibility

Access to GR by consumers will primarily depend on the extent to which this technology is going to be used by Philippine farmers in rice production, and, hence, its availability on local food markets. The first precondition certainly is that the technology will receive commercial approval by the government. Although the biotechnology debate in the Philippines was fairly controversial in the last few years, the National Committee on Biosafety has recently given green light for the first GM field trials in the country.[7] We take this as an indication that biosafety procedures for GR will be handled efficiently by national authorities, once the technology enters the testing phase.

Currently, researchers are incorporating GR technology into high-yielding varieties that are already established in the market, are consumed by the poor, and are easily crossable with other breeding lines. Apart from distribution in the Philippines, these varieties will also be transferred to other countries in Asia.[8] As was mentioned above, these GM varieties will be handed over to resource-poor farmers free of charge. They can be reproduced by the growers themselves so that

[6] The same conclusion is drawn by Robertson et al. (2001). Their study looks in greater detail at food intake data of children in one region in the Philippines and does not derive a clinical efficacy of GR. Yet their results on technology contribution to overall VA requirements are similar to ours.

[7] The Philippines had designed national biosafety guidelines already in 1991. But GM field trials were not permitted prior to 2001, due to controversies between researchers, the government and non-governmental organisations (Aerni, 2001).

[8] In a participatory approach, six varieties from different countries were chosen for the adaptive research phase. These are IR64 and IR72 from the Philippines, BR28, BR29 and BIR from Bangladesh, and Nang Huong Cho Dao from China. It is also planned to incorporate the technology into varieties with other interesting quality traits, such as IR68144 with high iron contents.

there could be a rapid dissemination of the technology through a farmer-to-farmer exchange of seeds. Experience from the green revolution shows that new acceptable germplasm is generally diffusing very rapidly in the country (Hayami and Kikuchi, 2000). Although GR has not yet been field-tested, breeders do not expect that reasonable levels of beta-carotene would have any influence on the agronomic performance of the varieties in terms of yield or susceptibility to pests. Therefore, the marginal cost of rice production at the farm level is likely to remain unaffected through adoption of GR. However, as many farm households in the Philippines produce rice semi-subsistently, they will benefit from the technology on the consumption side. Of course, farmers who sell a significant portion of their rice will only adopt if GR is acceptable to market consumers.

Producer and consumer acceptance

Technology acceptance by rice producers and consumers depends on attitudes towards GM crops in general, and features of GR in particular. Although the biotechnology opposition in the Philippines was fairly strong in the past, there are signs that public attitudes are gradually becoming more positive (e.g., The Philippine Star, 2002). With respect to acceptability of GR itself, very little is known so far. It is not expected that the technology will cause a change in taste and cooking characteristics of rice varieties. Yet the colour of GR is yellowish, which has often been stated as a possible constraint. Most of the rice consumed in the Philippines is polished and white.

In order to get a better understanding of acceptance issues, we carried out focus group discussions with Philippine rice producers and consumers in two villages in 2001. The first village was Gabaldon, located in Nuevo Ecija Province in Central Luzon, and the second village was Tuban, located in Laguna Province in Southern Tagalog. In both villages, rice production is the major economic activity. To facilitate communication, the village heads were asked for collaboration. They organised homogenous groups of men and women to participate in the discussion. Homogenous samples are generally preferred, because mixing age and gender groups may inhibit some people from expressing their views (e.g., Templeton, 1994). In total, 66 villagers participated, of which 34 were women and 32 men. 80% of them had their own rice fields; the others were landless.

All interviewed women were aware of VAD, whereas only 35% of the men knew about it. After explaining features of GR, male and female farmers were asked whether they would adopt these varieties. All of them affirmed this question. Many said that they would start using GR on part of their area in order to observe its performance. But over one-fourth of the participants stated that they would completely switch to GR right away. In general, farmers were less concerned about yields than about pollination characteristics and the fertility of harvested seeds. The yellow colour did not seem to be a problem: all participants articulated that they would substitute GR for other rice so long as it does not have any negative health effects. Yet, the price is an issue for market consumers. Only 5% said that they would be willing to pay more for GR than for other varieties. This is a reflection of the limited purchasing power in rural areas of the Philippines. Finally, participants were asked whether they would eat GR even if it had a different taste than ordinary rice. All of them said that they would, but around 16% stated that they would either mix it with other rice or consume it only every second day.

Although participants in these discussions are not a representative sample of the Philippine population, the results are quite interesting and useful for our assumptions on coverage rates. As changes in taste, agronomic effects, or the reproductive capacity of seeds are not expected, farmer adoption and consumer acceptance of GR varieties could potentially be very high. Nonetheless, experience in different countries with the adoption of other value-enhanced crops, such as quality protein maize, shows that education and information can be crucial determinants (Lauderdale, 2000). Therefore, public campaigns to further increase the awareness of VAD and to explain the merits and limitations of GR will be essential for widespread technology use. Against this background we make rather cautious assumptions for our simulations. We assume medium-term coverage rates of 40% in the pessimistic and 60% in the optimistic scenario. This does not mean that 40% or 60% of the total rice available in the Philippines will be GR. For instance, around 25% of the rice consumed in the country is imported. Our assumptions merely refer to rice that is eaten by poor population segments affected by VAD, many of which depend on the local rice economies in rural areas. Coverage may increase over time, but, especially in the early phase, rice producers and consumers are likely to experiment by only substituting partially.

5 Potential Benefits of Golden Rice

Based on the insights from previous sections, this section analyses the potential benefits of GR in the Philippines for the pessimistic and optimistic scenarios. For easy reference, the assumptions underlying the two scenarios are summarized in the following.

- *Pessimistic scenario.* The amount of beta-carotene is 1.6 micrograms per gram of GR. Post-harvest losses of beta-carotene are 25%. The bioconversion rate to VA is 12:1, and the technology coverage rate is 40%.
- *Optimistic scenario.* The amount of beta-carotene is 3.0 micrograms per gram of GR. There are no significant post-harvest losses. The bioconversion rate is 6:1, and the technology coverage rate is 60%.

5.1 DALYs Gained

Inserting the values for the technology's efficacy and coverage into equation (3), new prevalence rates were calculated. These are shown in Table 6 for the pessimistic and optimistic scenarios. New mortality rates were derived accordingly. Based on these values, DALYs lost due to VAD with GR were computed (Table 7).

Table 6: New prevalence rates of VAD-related diseases

	Pessimistic scenario			Optimistic scenario		
	Children	Pregnant women	Lactating women	Children	Pregnant women	Lactating women
Sub-clinical VAD	36.25	20.01	15.86	27.06	10.73	12.51
Night blindness	0.38	0.54	0.87	0.28	0.29	0.68
Bitot's spot	0.10	0.36	0.67	0.07	0.19	0.53
Corneal ulceration	0.05	0.27	0.48	0.04	0.15	0.38
Corneal scars	0.0	0.14	0.29	0.00	0.07	0.23

As expected, mortality and disability-related losses are still sizable, but with a significant difference between the two scenarios. In monetary terms, remaining health costs in the pessimistic scenario account for 0.51% of the Philippine GNP, while in the optimistic scenario, they account for 0.37% of GNP.

Table 7: DALYs lost due to VAD with Golden Rice

	Children	Pregnant women	Lactating women	Total
		Pessimistic scenario		
Loss due to mortality	84,711	1,887	1,282	87,880
Loss due to disability	103,406	76,270	140,598	320,275
Total loss	188,117	78,157	141,881	408,154
In monetary terms (million US$)	188.12	78.16	141.88	408.15
		Optimistic scenario		
Loss due to mortality	63,251	1,012	1,011	65,274
Loss due to disability	77,211	40,912	110,888	229,011
Total loss	140,462	41,924	111,899	294,285
In monetary terms (million US$)	140.46	41.92	111.90	294.29

Table 8: Number of disease and death cases averted through Golden Rice

	Pessimistic scenario			Optimistic scenario		
	Children	Pregnant women	Lactating women	Children	Pregnant women	Lactating women
Sub-clinical VAD	234,655	35,412	10,054	1,462,827	185,530	62,946
Night blindness	2,470	957	548	15,398	5,014	3,433
Bitot's spot	618	638	427	3,850	3,343	2,670
Corneal ulceration	309	479	305	1,925	2,507	1,907
Corneal scars	0	239	183	0	1,254	1,144
Blindness	309	718	487	1,925	3,761	3,052
Deaths	141	9	2	879	48	14

More interesting than the remaining health costs of VAD with GR, however, is the difference that the technology is likely to make. Table 8 shows the difference between the number of people affected by certain health conditions with and without technology, and thus the number of cases averted through GR. The positive health effects are large. In the pessimistic scenario, a total of 1,514 cases of blindness and 152 premature deaths can be averted annually. In the optimistic scenario, the numbers are 8,738 and 941 for cases of averted blindness and deaths, respectively. The reduction in the cases of blindness is higher for pregnant and lactating women than for children. This is due to the lower incidence rate of blindness for children in the Philippines. For cases of death, however, the opposite holds true. Especially among infants, even moderate levels of VAD can have fatal consequences, so that an improvement in VA status can lower the death toll significantly. Even if infants do not eat rice themselves, the better VA status of their mothers during pregnancy and lactation will have a positive impact on them.

The difference in DALYs lost with and without GR is shown in Table 9. Because this is the technology's projected impact, the unit of measurement is years of "healthy" life gained. The total gain in the pessimistic scenario is 23,351 DALYs, while in the optimistic scenario, it is 137,220 DALYs. Compared to the total cost of VAD in the Philippines without GR, the cost reduction is 5.4% in the pessimistic scenario; in the optimistic scenario, costs are even reduced by 31.8%. DALYs gained are also shown in monetary terms: around $23 million and $137 million per year in the pessimistic and optimistic scenario, respectively. Although we use a comparatively low value of $1,000 per DALY, these benefits are huge, especially when compared to the R&D investments. A preliminary cost-benefit analysis is provided in the next sub-section.

Table 9: Potential benefit of Golden Rice (DALYs gained)

	Children	Pregnant women	Lactating women	Total
		Pessimistic scenario		
Gain due to reduced mortality	4,100	206	52	4,358
Gain due to reduced disability	5,005	8,341	5,647	18,993
Total gain	9,105	8,547	5,699	23,351
In monetary terms (million US$)	9.11	8.55	5.70	23.35
		Optimistic scenario		
Gain due to reduced mortality	25,560	1,081	322	26,963
Gain due to reduced disability	31,201	43,698	35,358	110,257
Total gain	56,760	44,779	35,680	137,220
In monetary terms (million US$)	56.76	44.78	35.68	137.22

5.2 Cost-Benefit Analysis

This sub-section puts the projected monetary benefits of GR in relation to the R&D investments. The project was started in 1992 at Swiss and German universities, with basic research on how to induce the production of beta-carotene in the endosperm, identification of suitable genes, and the development of gene constructs and transformation protocols. The basic concept was successfully proved in 1999 (Ye et al., 2000). The research cost during this phase in Europe was estimated at $3 million. This cost is not considered in our analysis in the Philippines, because the knowledge and technology generated is likely to produce much wider international benefits.

A breakdown of the estimated cost of R&D at IRRI and technology testing in the Philippines is given in Table 10. The three-year adaptive research phase includes the verification and improvement of available gene constructs and their incorporation into popular indica varieties. After this, a three-year testing phase is foreseen for field trials, feeding experiments, and bio- and food safety evaluation. The budget also includes outlays for variety registration and commercialisation. The total cost for the six years of R&D and testing in the Philippines is estimated to be around $3.7 million. IRRI has an international mandate, and the GR varieties developed will be transferred to a number of other countries. But, to remain on the conservative side, we disregard such spillovers and consider the full cost in the Philippine context. Furthermore, we take into account expenditures of $7 million towards the end of the testing phase for a broad information campaign, including efforts like printing promotional leaflets, radio and TV broadcasts, and training rural extension staff. This value is based on a cost estimate of similar activities for the VA supplementation programme in the Philippines (Fiedler et al., 2000).

Table 10: Estimated cost of R&D and information campaigns

Phase	Cost (US$)
Adaptive research phase (3 years)	
Infrastructure and operating expenditure	1,000,000
Personnel	423,000
Testing phase (3 years)	
Infrastructure and operating expenditure	2,000,000
Personnel	300,000
Information campaigns (towards the end of testing phase)	7,000,000
Total cost	10,723,000

Using these cost figures, we calculated returns on project investments, assuming a benefit stream of 10 years after commercial release of GR technology. In the pessimistic scenario, the internal rate of return (IRR) is 81%, while it is 152% in the optimistic scenario. In spite of conservative cost estimates, these values are remarkably higher than for most R&D projects focusing on improvements of agronomic traits in agricultural crops (e.g., Alston et al., 2000). Thus, the cost-benefit analysis confirms that breeding for micronutrient-dense staple foods can be an investment with very high social returns.

It would certainly be interesting to compare these results for GR with other alternatives to reduce VAD. Unfortunately, we could not find analogous cost-benefit studies for VA interventions in the Philippines or other countries. Fiedler et al. (2000) carried out a cost-effectiveness analysis for the Philippines's supplementation and fortification programmes. However, as is common in cost-effectiveness studies of nutrition interventions, their measure of effectiveness is the number of people in the target population being lifted from deficient to non-deficient levels. Thus, a comparison with our results is difficult. Collecting further data to use the DALYs approach for those alternative interventions proved problematic, as well. Both programmes are already being carried out simultaneously, so that one would need to establish without-programme benchmarks, and disentangle the individual effects. Nonetheless, a simple comparison of costs might be instructive. The annual cost of the food supplementation programme in the Philippines is estimated at $21 million, whereas the fortification of wheat flour with VA costs $4-6 million per year (Fiedler et al., 2000). This has to be compared with zero recurrent cost for GR, or only a minimal expenditure for maintenance breeding. Hence, GR is definitely a sustainable and low-cost alternative.

6 Conclusions

This paper has analysed the potential benefits of Golden Rice in the Philippines. VAD is a severe problem in this country, causing increased morbidity and mortality, especially among children and pregnant and lactating women. The analysis showed that the annual VAD-related health costs are in a magnitude of 0.5% of the Philippine GNP. GR has the potential to reduce these costs.

There are numerous factors influencing the impact of GR. The amount of beta-carotene in the grain, post-harvest losses as well as bioconversion to VA affect the technology's efficacy. Producer and consumer acceptance are crucial for the coverage rate of the innovation. Since GR is still at the stage of R&D, we used different data collection techniques to come up with realistic assumptions on key parameters. We delineate a pessimistic and an optimistic scenario for the simulation of future effects, supposing that the true benefits will lie somewhere in-between.

In the pessimistic (optimistic) scenario, 1,514 (8,738) cases of blindness and 152 (941) premature deaths per year can be averted. In monetary terms, the annual gain is around $23 million and $137 million in the pessimistic and optimistic scenario, respectively. Although these are very significant benefits, it must be stated clearly that GR alone will not completely eliminate VAD. Micronutrient deficiencies are caused by a complex set of economic, social, and cultural factors, so that a technological approach cannot be considered a magic bullet. The purpose of developing GR is not to substitute for other interventions such as food fortification, supplementation, or dietary education programmes. Rather, the technology should be seen as a complementary tool in the fight against VAD. GR is particularly promising for remote rural areas, because, after the initial R&D investment, the cost and institutional effort to reach the target population is much lower than for other interventions.

A preliminary cost-benefit analysis shows that R&D expenditures for GR are a highly profitable investment. Depending on the assumptions made, the internal rate of return lies between 81% and 152%. These returns are higher than for many crop breeding projects focusing on the improvement of agronomic traits. Of course, the benefits of agronomically improved crops and micronutrient-dense staple foods are different in nature. While the former show up in terms of increased real incomes for agricultural producers and consumers, the latter consist primarily in a reduced burden of disease for society in general and for affected population groups in particular. These benefits might be less visible, but our analysis demonstrates their high economic significance. Micronutrient-dense crops are an efficient way to reduce deficiency problems among the poor, and related research projects should receive higher political priority.

The scenario results presented in this paper are based on *ex ante* assumptions, which might have to be revised when better data on efficacy and coverage of GR become available over the next couple of years. Also, it should be pointed out that our analysis is only a first attempt to quantify the health impacts of micronutrient-enriched food crops within an economic framework. There is certainly scope for extending the methodology employed. In principle, our approach could also prove useful for the evaluation of other value-enhanced crops with positive health effects in developing countries, such as nutraceuticals or edible vaccines.

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