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Rice Biotechnology and Its Potential to Combat Vitamin A Deficiency: A Case Study of Golden Rice in Bangladesh

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List of Abbreviations and Acronyms

µg	Microgram
BR29	Rice variety Brridham29
BRRI	Bangladesh Rice Research Institute
BSCIC	Bangladesh Small and Cottage Industries Corporation
DALYs	Disability Adjusted Life Years
dL	Decilitre
FAO	Food and Agriculture Organization of the United Nations
GBD	Global Burden of Disease
GR	Golden Rice
HKI	Helen Keller International
ICCIDD	International Council for Control of Iodine Deficiency Disorders
INFS	Institute of Nutrition and Food Science
IPHN	Institute of Public Health Nutrition
IRRI	International Rice Research Institute, Los Baños, The Philippines
IVACG	International Vitamin A Consultative Group
Kg	Kilogram
L	Litre
NGO	Non Governmental Organisation
NIPORT	National Institute of Population Research and Training
NPB	National Programme for Biotechnology
R&D	Research and Development
ßC	Beta-carotene
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Emergency Fund
USA	United States of America
VA	Vitamin A
VAC	Vitamin A Capsule
VAD	Vitamin A Deficiency
WHO	World Health Organization
YLD	Years Lived with Disability
YLL	Years of Life Lost due to Mortality

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Abstract

Vitamin A deficiency (VAD) remains a public health problem in many developing countries. Thousands of preschool children go blind every year, and many of them die due to VAD. Also VAD weakens the immune system, making children to be prey to infection diseases. Adults are also affected by VAD, and the most affected population groups are pregnant and lactating women. Fortunately, there are many ways to tackle this problem, including pharmaceutical supplementation, food fortification, dietary education, and breeding food crops rich in micronutrient. One of the famous examples of crops rich in micronutrient is Golden Rice (GR). Golden Rice has been genetically engineered to produce beta-carotene in the grain endosperm. Beta-carotene is a precursor of vitamin A (VA). This study analyses the potential health impacts of this rice on VA deficient consumers in Bangladesh. We have calculated the current burden of VAD in the country by using the methodology of disability-adjusted life years (DALYs), then simulated the future benefits by using 24 hours recall data for individual food intake of household members. Finally, we have juxtaposed the health benefits and overall cost of Research and Development (R&D) of GR in Bangladesh to assess its cost-effectiveness. Since GR is still in the stage of R&D, our calculations are of *ex ante* nature. Therefore, we have used scenarios for our calculations. To test the robustness of parameters used, we have conducted a sensitivity analysis. The results of our study show that GR has a potential to reduce significantly the burden of VAD in Bangladesh and the technology is cost-effective. However, the same results show also that GR alone will not completely eliminate the problems of VAD; therefore GR should be seen as a complementary intervention to the existing ones.

Kurzfassung

Vitamin A Mangel (VAM) bleibt ein schwerwiegendes Gesundheitsproblem in vielen Entwicklungsländern. Jedes Jahr erblinden tausende Kinder im Vorschulalter, und viele von ihnen sterben infolge von VAM. Die Mangelkrankheit schwächt das Immunsystem und macht Kinder anfällig für Infektionskrankheiten. Auch Erwachsene sind betroffen, insbesondere schwangere Frauen und stillende Mütter. Erfreulichweise gibt es Behandlungsmethoden, wie z.B. pharmazeutische Mittel, Nahrungsmittelergänzungen, Aufklärung zu einer ausgewogenen Ernährung und Grundnahrungsmittelpflanzen, die durch züchterische Eingriffe einen höheren Gehalt an Mikronährstoffen enthalten. Eines der bekanntesten Beispiele ist Golden Rice (GR). Dies ist ein Reis, der gentechnisch verändert wurde, um Betakarotin im Endosperm zu produzieren, welches der menschliche Körper in Vitamin A umwandeln kann. Die vorliegende Studie analysiert den potentiellen Einfluss des GR auf die von VAM Betroffenen in Bangladesh. Wir haben die aktuellen gesundheitlichen Schäden durch VAM in Bangladesh mit Hilfe der DALY (Disability-Adjusted Life Years) Methode berechnet und dann den zukünftigen Nutzen simuliert. Schließlich haben wir den so berechneten potentiellen gesundheitlichen Nutzen den Gesamtkosten aus Forschung und Entwicklung (F&E) gegenübergestellt, um die Kostenwirksamkeit von GR zu bewerten. Da sich der GR immer noch im F&E Stadium befindet, ist dies eine ex-ante Studie, bei der wir verschiedene Szenarien für unsere Berechnungen eingesetzt haben und durch eine Sensitivitätsanalyse die Robustheit der Parameter getestet haben. Das Ergebnis zeigt, dass GR das Potential hat, die Auswirkungen von VAM in Bangladesh signifikant und kosteneffektiv zu reduzieren. Es ist aber auch klar, dass GR die Probleme von VAM nicht vollständig beheben kann, sondern als komplementäres Instrument zu anderen Maßnahmen betrachtet werden sollte.

1 Introduction

Vitamin A deficiency (VAD) continues to be a major public health problem in many developing countries. It occurs where diets contain insufficient vitamin A (VA) for meeting the needs of the human body. Although VAD is largely preventable, an estimated 100 to 140 million children are VA deficient, of whom at least 2.8 to 3 million are clinically deficient (WHO, 2003). Every year, 250,000 to 500,000 children go blind as a result of VAD (West and Darnton-Hill, 2001), half of them dying within twelve months by losing their sight (WHO, 2003). Infections such as measles may precipitate a child into clinical VAD (WHO, 2003). In VAD areas, women of childbearing age are at high risk of VAD and its consequences because of increased VA requirements during pregnancy and lactation. Their newborns having been VA depleted require VA supplements. Otherwise, following their initial 4 to 6 months of nursing they are likely to develop VAD (WHO, 2003).

The problem of VAD has been recognized, and over the past two decades, a large number of countries have embraced VA control programs in order to reduce VAD in their countries. The large majority of VA-deficient people live in developing countries. To fight this problem, many approaches have been used: VA-supplementation, food fortification, dietary diversification or food based-strategies such as breeding new staple crops varieties that contain high concentration of beta-carotene. Hence, there are a lot of food crops that contain naturally a high amount of beta-carotene. Examples include fruits, leafy vegetables, and some roots crops like sweet potatoes and carrots. Although a diversified diet with high amount of beta-carotene can provide enough of VA, many poor people in developing countries can not afford such balanced diet. Therefore, fortification of staple crops becomes necessary. Rice - which is a staple food in a large part of Asia - does not contain beta-carotene in the endosperm. To fortify rice with provitamin A, the use of biotechnology is required (Bayer et al. 2002). The so-called Golden Rice (GR) was developed through genetic engineering at Swiss and German universities to fight against VAD (Ye et al., 2000; Beyer et al., 2002). Although preliminary studies have shown the potential of GR to reduce VAD (Dawe et al., 2002; Zimmermann and Qaim, 2004), it remains a subject of controversial debate. Some people consider it to be a solution to overcome malnutrition and VAD, with the potential to save thousands of VA-deficient children from going blind every year (Potrykus, 2001). Other people consider it to be a mere child of the biotech lobby, which wants to sell the idea that genetically engineered crops will solve the problem of malnutrition (Koechlin, 2000).

Recently, a second generation of GR with higher beta-carotene content has been developed (Paine et al. 2005). Considering this improved variety, we analyze the potential health benefits of GR to reduce VAD among rice consumers, by using the disability-adjusted life years

(DALYs) methodology. Commonly used assessment approaches, e.g. contingent valuation or cost-of illness, seek to quantify the impact of illness and injury on individuals and society only in economic terms. The DALY approach, on the contrary, addresses this problem in depth. It is a metric that combines mortality and disability information into a single summary health-outcome. The different health outcomes attributable to VAD are night blindness, corneal scarring, blindness, measles and increased child mortality. To determine the potential health benefits associated to GR, we assess the current burden of disease related to VAD, i.e. the VAD status quo; then we calculate the new burden of disease by considering the introduction of GR. The difference between the two is the potential health benefit. Furthermore, we juxtapose the potential benefits and costs of the development and dissemination of GR to simulate its cost-effectiveness. Since GR has not yet been disseminated, and the actual impacts are not observable at this stage, the study takes an *ex ante* perspective.

Bangladesh has been chosen as example to carry out this study. Although the magnitude of clinically evident VAD has dropped significantly in the past two decades, recent studies have shown that VAD still remain a problem in different population groups (HKI/IPHN, 2005). IRRI has been working together with BRRI on the breeding of the GR trait into some rice varieties from Bangladesh. As soon as Bangladesh will receive the approval of breeding genetically modified crops, GR will be transferred to Bangladesh Rice Research Institute (BRRI), where further adaptive research on local varieties will be carried out. After that, a testing phase will follow. GR is expected to become commercially available in 2012.

2 Analytical Framework

2.1 Conceptual Issues

The concept of evaluating the potential health benefits of bio-fortified crops by using the DALY approach was developed for the first time by Zimmermann and Qaim (2004). This concept combined parameters from agriculture, nutrition and health economics within a single formula. Agricultural economics, because the desirable traits are introduced into the crops which farmers grow, and finally commercialise or consume. And finally, nutrition and health economics, because crops are used for production of substances with nutritional or/and health benefits, including prevention (and treatment) of diseases. This methodology has been discussed in an interdisciplinary group of economists, nutritionists, and health experts, whereby, the assumptions have been revised. The revised methodology has been published as a handbook for analyzing health benefits of bio-fortified crops using the DALY approach (c.f. Stein et al., 2005). Meanwhile the revised methodology has been used by HarvestPlus[1] for evaluating the potential health benefits of biofortified crops. We also use the revised methodology for our case study in Bangladesh.

2.2 Methodology

The DALY approach expresses years of "healthy" life lost due to mortality (YLL) and years of life with disability (YLD) of specific severity and duration. Thus, the DALYs formula becomes:

$$DALYs_{Lost} = YLL + YLD \tag{1}$$

Taking into account different levels of disease, different functional outcomes, and different target groups, Zimmermann and Qaim (2004) represent the formula as follows:

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

where T_j is the total number of people in target group j, M_j is the mortality rate associated with VAD-related functional outcomes, and L_j is the average remaining life expectancy. I_{ij} is the

[1] The biofortification initiative of the CGIAR.

incidence rate of temporary disease *i*, D_{ij} is the corresponding disability weight, and d_{ij} is the duration of the disease. I_{ij} is the incidence rate of permanent disease *k*, while *r* is the rate at which future costs are discounted. The parameters used in this formula are described in detail in Stein et al., 2005.

For our calculation, we concentrated on three target groups; children under five, pregnant women and lactating women because these groups are the most affected by VAD. Furthermore, we have taken into account different functional outcomes related to VAD. DALYs lost are calculated on an annual basis. This means that only new VAD-related functional outcomes occurring in the reference year are considered, whereby the health costs are accumulated over the entire life of the people affected.

Since the main benefit of GR will be to reduce the burden of disease caused by VAD, the incidence of VAD-related functional outcomes can be reduced if GR rice is eaten regularly by the people. Reduction of incidence rate leads to a reduction in costs associated with VAD-related diseases. In this context, we have drawn two different scenarios. In the first, pessimistic scenario, we assumed that GR is not eaten regularly; this lowers beta-carotene consumption, thereby affecting VA intake. In the second, optimistic scenario, we assume that GR is frequently eaten, thus increasing VA intake.

In order to calculate the reduced incidence rate due to consumption of GR, we apply the following formula used by Zimmermann and Qaim (2004).

$$I_{ij}^{new} = \left[1 - \left(E_j C\right)\right] I_{ij} \tag{3}$$

The new incidence rate of disease *i* in group *j* (I_{ij}^{new}) is a function of the group-specific efficacy rate of GR (E_j), and the technology's coverage rate (C). Efficacy and coverage are discussed in section 0.

We use the new incidence rate to calculate the potential health benefits. DALYs gained are calculated as a difference between DALYs lost in the *status quo*, i.e. DALYs lost without the introduction of GR in Bangladesh, and DALYs lost with the introduction of GR in the country. We juxtapose the potential health benefits and the costs of development and dissemination of GR to simulate its cost-effectiveness. To carry out the cost-benefit analysis we give a monetary value to a DALY. However, attaching a monetary value to one DALY saved does not mean to value life as such, it is only a convenient device for comparative economic analysis. Finally, we conduct a sensitivity analysis to test the robustness of our results.

3 Vitamin A Deficiency and Its Costs in Bangladesh

Macro- and micronutrient deficiency constitute a serious problem in Bangladesh. In Appendix A, we have presented an overview of these deficiencies. The next section gives brief information on VAD and the costs it attracts.

3.1 Vitamin A Deficiency in Bangladesh

Over the past two decades, the burden of VAD has decreased significantly in Bangladesh. For example in 1982-83, the prevalence rate of night blindness among preschool children in rural Bangladesh was 3.6 percent (HKI/IPHN, 1985); in 2004 this prevalence rate had decreased to 0.07 percent (HKI/IPHN, 2005), this rate is lower than in many other countries in South and Southeast Asia. The VA survey of 1997-98 showed that the prevalence rates of night blindness among pregnant and lactating women in rural Bangladesh were 2.7 and 2.4 percent respectively (HKI/IPHN, 1999b). In 2004, these prevalence rates decreased to 0.71 and 0.54 respectively (HKI/IPHN, 2005). These figures are below the levels used by the World Health Organisation to define a public health problem. However, a recent study has shown that VA capsule coverage, particularly among lactating women, is still very low. The coverage rate in rural Bangladesh amounts to 3.1 percent (HKI/IPHN, 2005). Pregnant women are not covered at all. The low coverage rate of VA capsules, particularly among adults has many reasons; for example, there are no organised structures for the delivery of the supplements to pregnant and lactating mothers. On the other hand, infrastructure in the rural areas is not good enough so that these areas are very often neglected. Therefore, the existing programs to combat VAD are not sufficient to eradicate VAD-related functional outcomes among the population in Bangladesh. GR has been proposed as a complementary approach, because it does not need special infrastructures, the rice can be reproduced by the growers themselves, so that it could potentially be swiftly disseminated through farmer-to-farmer exchange of seeds. Thus, also, subsistence farmers and poor consumers in remote rural areas could be reached with GR.

3.2 Cost of VAD in Bangladesh

We have used the equation (2) above to calculate DALYs loss without GR, each parameter use is explained in Appendix B. According to our calculation, about 9 thousand children under the age of six die every year due to VAD, 254 preschool children go blind, and the same number suffer from permanent eye damage, about 102 thousand children are affected

by measles and about 15 thousand are night blind. In addition, about 68 thousand pregnant women and 40 thousand lactating women are night blind. In terms of “healthy” life, VAD causes an annual loss of about 262 thousand DALYs in Bangladesh. The highest cost occurs among preschool children, where over 95 percent of them are due to child mortality. In monetary terms, VAD causes annual losses between US$104.8 and US$261.9 million dollars per year. This is equivalent to 0.2 and 0.5 percent of the gross domestic product (GDP) of Bangladesh.

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 and hence 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 South-East Asia. In 2001, the technology was transferred to IRRI for adaptive research, where the gene constructs have been improved and incorporated into various indica varieties. IRRI and BRRI scientists have recently introduced the GR trait into *Brridham29* (BR29), which is the most widely grown *boro* rice variety in Bangladesh, into GR. This work will continue to breed the trait into other Bangladeshi varieties. After that, the Bangladeshi varieties carrying the novel trait will be transferred to BRRI where further research will take place as soon as the country has developed its national biosafety guidelines and regulations.

Moreover, GR continues to be improved in Europe, in the USA and in Japan. Successful field tests on three GR rice varieties - Cocodrie (North-American long grain javanica rice); TP309 (japonica); and IR64 (indica) - has been carried out in Crowley, LSU Experimental Station in Louisiana (USA). Field tests are now planned in the Philippines, and India. After completion of the field tests, feeding trials will follow as well as biosafety and food safety tests. It is expected that GR could become commercially available in 2012. 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, 2001).[2] However, the effectiveness of GR is still unknown. In order to simulate the future benefits of GR, we have identified two key parameters associated to its effectiveness: efficacy and coverage rate. These parameters are explained in the next sections.

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

4.1 Efficacy

The efficacy of GR is its capacity to improve the nutritional intake of beta-carotene, and therefore to reduce the prevalence of VAD-related diseases. Efficacy depends on the actual amount of VA obtained through GR and the levels of VAD in the target groups. The amount of VA obtained in turn depends on the amount of beta-carotene in the rice, its bioavailability, and its bioconversion to VA by the human body. Because these are crucial factors for the analysis, we will explain them one by one, before proceeding to the actual efficacy calculations.

4.1.1 Amount of the Beta-carotene

The amount of beta-carotene initially obtained in a GR prototype version was 1.6 micrograms per gram (Ye et al. 2000). This amount has been increased to 31 micrograms per gram in the latest version of GR, where tissue-specific promoters and a gene from maize instead of daffodil were used (Paine et al., 2005). Much higher amounts have been observed in experimental versions of GR but the goal is to produce rice lines delivering only the recommended amounts of beta-carotene (Mayer, 2005). Two different GR products are now available, Golden Rice 1 and 2 (GR1 and GR2). GR1 contains in average 6 µg/g of beta-carotene, whereas GR2 contains 31 µg/g. For our calculation we take the average and maximum content of beta-carotene of GR2, assuming that Bangladesh will apply the newest technology in the future.

Post-harvest treatment, storage and processing of GR affect its beta-carotene content at the time of consumption. Losses might occur during normal storage, exacerbated by improper storage conditions. Prolonged exposure to extreme heat during processing might reduce the bioavailable portion of beta-carotene, while normal cooking at boiling temperature generally increases the extractable amount of carotenoids (Dietz et al., 1988). In Bangladesh, rice is usually washed and than boiled. Therefore, minerals and vitamins (especially water soluble vitamins B and C) are lost (40 percent of thiamine and niacin) even during the washing of rice, before the actual cooking (Gopalan et al.; 1993).[3] Considering these factors we assumed the total post-harvest losses at 80 percent in the pessimistic scenario, and 35 percent in the optimistic scenario.

4.1.2 Bioavailability and Bioconversion of Beta-carotene

Bioavailability is the fraction of an indigested nutrient that is available for utilization in normal physiological functions or for storage (Jackson, 1997). Bioconversion is defined as the process of beta-carotene absorption by the human body and its transformation to retinol. After

absorption, transformation takes place with a factor of approximately 2:1. 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 percent has been reported (Castenmiller et al., 1999). Other authors reported values of 11-12 percent for broccoli, and of 18-26 percent for carrots (Micozzi et al., 1992; Törrönen et al., 1996). In a study with school children 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 of the same carotenoid in dark-green leafy vegetables. Generally, absorbability depends on the state of beta-carotene and its association with plant matrix materials in the food source. Also, it is correlated with the intake of complimentary ingredients in the diet. Low fat consumption reduces the absorption of beta-carotene significantly.

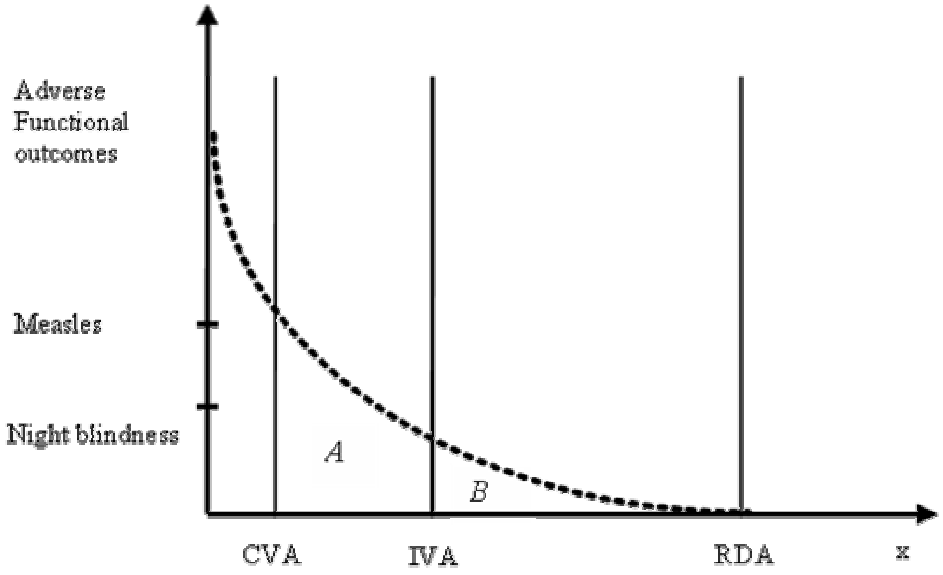
Using these findings, IOM (2002) estimated the retinol equivalency ratio for beta-carotene from food in a mixed diet, which includes fruits and vegetables, to be 12:1.[4] For GR, feeding tests have not been carried out yet, so that specific data and information are presently not available. However, since rice has a simple food matrix with totally digestible carbohydrates, we assumed that the bioconversion factor in a pessimistic scenario is 12:1 and in optimistic scenario 6:1. In the next sub-section, the relationship between beta-carotene consumed and the changes in health are described.

4.1.3 The Concept of Dose-response and the Impact of Golden Rice

As already mentioned in sub-section 0 above, the main merit of GR will be to reduce VAD-related functional outcomes. To determine the relationship between the amount of beta-carotene consumed by the target groups and the resulting changes in health, a graphic representation is used (c.f. Figure 4-1). This relation is also called dose-response assessment. The dose-response curve is semi-logarithmic, i.e., the amount of beta-carotene consumed is plotted as the log of adverse functional outcomes. This is because the dose-response for an individual with higher level of deficiency is bigger than an individual with a lower level of deficiency. Although this general relationship is widely accepted in the literature, concrete evidence on the exact numerical association between VA supply and adverse health outcomes is lacking (Underwood, 1998; Sommer and West, 1996).

[3] Rice is mainly used as parboiled rice. 90 percent of the total rice produced in the country is parboiled.
[4] This is only half the value of 6:1, which had been assumed for a long time in the nutrition community. The established assumption was mainly challenged through the work of de Pee et al. (1998) in Indonesia.

Figure 4-1: Relationship between Beta-carotene Intake and Health Outcome



In Figure 4-1 VA supply is depicted on the horizontal x-axis, whereas adverse health outcomes *(H)* are shown on the vertical axis. Current VA intake (*CVA*) is below the recommended dietary allowances *(RDA)*,[5] a situation which we actually observe for the target groups in Bangladesh. Improved VA supply (IVA) represents current supply plus the increment from GR consumption. This level might be lower or higher than the RDA. However, the lower the initial supply, the larger the dose-response. Beyond the point of RDA, no further improvement is possible. Therefore, if *IVA* is higher than *RDA*, we use the value of *RDA* to calculate the efficacy.[6] That means H = 0 at $x = RDA$.[7]

Without having to specify units of measurement for *H*, efficacy (*E*) can be calculated as the ratio of two areas, namely area *A* divided by area *A+B*. Thus, *E* can take any value between zero and one, whereby it is positively correlated with the convexity of the curve (c.f. Zimmermann and Qaim; 2004). The result of the calculation is presented in Table 4-1.

$$H(x) = \frac{1}{x} - \frac{1}{RDA} \tag{4}$$

5 RDA is the average daily dietary intake level that is sufficient to meet the nutrient requirement of nearly all (97 to 98 percent) healthy individuals in a particular life stage and gender group (IOM, 2002).

6 The human body converts only the amount of beta-carotene it needs into VA, even if a large amount is consumed, there is no evidence of toxicity (Heywood et al., 1985; Olson, 1987; Bendich, 1988; Hathcock, 1990; Diplock, 1995). The only documented biological effect of high beta-carotene intake has been discoloration of the skin.

7 RDA is used instead of Estimated Average Requirement (EAR) because our consumption data refer to averages for the entire population. EAR is a daily nutrient intake value that is estimated to meet the requirement of half of the healthy individuals in a life stage and gender group (IOM, 2002).

Using equation (5), E can be calculated as:

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

Table 4-1: Contribution of Golden Rice to reduce VAD in Bangladesh

	Pessimistic scenario			Optimistic scenario		
	Children	Pregnant women	Lactating women	Children	Pregnant women	Lactating women
Rice intake (g/day)[a]	168	478	527	168	478	527
Current VA intake from all food sources (µg/day)[a]	178	478	588	178	478	588
RDA for VA (µg/day)[b]	350	770	1,300	350	770	1,300
VA deficit (µg/day)	172	292	712	172	292	712
VA intake through GR (µg/day)	217	590	711	742	2,083	2,358
Contribution of GR to reduce VA deficit (µg/day)[c]	39	112	123	564	1,605	1,770
Contribution of GR to reduce VA deficit (percent)	18.0	18.9	17.3	76.0	77.1	75.1

[a] Figures based on 24 hours recall data for individual food intake of household members.

[b] Figures based on international RDA (IOM, 2002).

[c] Contribution is the difference between VA intake through GR and current intake.

The current VA intake of the three target groups from all food sources is lower than the international RDA. The deficit, which is the difference between the international intake and the current intake, is very high for lactating women. Consequently, VA intake through GR is higher by lactating women. This result confirms our theory of dose-response assessment introduced above.

4.2 Coverage Rate

4.2.1 Accessibility

Access to GR by consumers will primarily depend on the extent to which the new rice varieties will be used in agricultural production, and hence their availability in local food

markets and for home consumption. The first precondition is that the technology will receive commercial approval. This will be the role of the Bangladeshi government.

In 2002, FAO and the United Nations Development Programme (UNDP) conducted an assessment of the status of biotechnology application in Bangladesh (FAO, 2004a). Based on this assessment, the Government of Bangladesh formulated a National Programme for Biotechnology (NPB), which aims to utilize biotechnology as an important complementary route to fight food insecurity and poverty, two pressing problems of the nation. The NPB will promote awareness at all levels; establish and implement appropriate policies, strategies and partnerships; strengthen investment, institutional and market support; and undertake focused and integrated biotechnological research and development. To reach this goal, Bangladesh has created for the first time a budget line for biotechnology in its national budget (FAO, 2004a). For example, the Government is supporting the effort of scientists to incorporate the genes controlling beta-carotene production in BR29.[8] After proper evaluation of the food safety and environmental effects and economic validity, the rice will be handed over to farmers free of charge.[9]

4.2.2 Acceptance

Acceptance of GR in Bangladesh will depend on many factors. For example, the public perception of biotechnology will play an important role for the adoption of the technology. Because the civil society groups mould the public opinion and any negative opinion may stand in the way of releasing the products however beneficial they might be to rice producers and consumers. Therefore, education and information campaigns will be necessary to improve awareness of biotechnology among the population. On the other hand, political support will play a significant role for the adoption of the technology, because the political stakeholders[10] are assumed to be better informed about the risk and benefits of agricultural biotechnology and have a significant influence on the formation of public opinion.

In Bangladesh consumers prefer eating white rice, whereas GR has a yellow colour. Owing to this difference in colour, consumers could hesitate to buy the new rice. Therefore, social marketing activities will be necessary to facilitate the adoption of the product by the farmers and its acceptance by the consumers. Taste has not been affected in GR but negative effects on agronomic characteristics will be ruled out before release of commercial varieties by extensive field testing (Mayer, 2005). Hence, undesirable effects cannot be ruled out with certainty. Therefore, it is very difficult to assess the future coverage rate of GR. However, the variable is not completely random; researchers and policymakers can influence its outcome.

[8] Three other popular rice varieties are also targeted.
[9] Private companies, holding patents over certain technology components, agreed to waive royalty payments when GR is used by resource-poor producers. Most of the rice in Bangladesh is produced by small-scale, semi-subsistence farmers.

Since there are no functioning government shops in Bangladesh, we have considered only the free market. In this context, the coverage rate will depend on the consumers' demand. We assume that in a pessimistic scenario, people will eat GR only once a week and in optimistic scenario every other day. Therefore, we use the values of 14.3 and 60 percent for pessimistic and optimistic scenarios respectively. All coverage rates are supposed to be reached 15 years after the release of GR. This time period is a relatively short adoption period, but we have considered not only the extension services, information and education campaigns of GR, we have also considered that beside *BR29* three other popular rice varieties with better agronomical traits will be introduced. This number will increase with time if the programme proves successful. Table 4-2 summarizes all the assumptions used to simulate the potential benefit of GR.

Table 4-2: Assumptions Used to Simulate the Potential Benefits of GR

Scenario[11]	**Pessimistic**	**Optimistic**
Beta-carotene (ßC) content in GR (µg/g)	14	31
Post-harvest losses of ßC (percent)	80	35
Conversion of the ßC in GR into VA	12:1	6:1
Coverage rate of GR 15 years after release (percent)	14.3	60

[10] Stakeholder is another word for all the persons, groups, organizations and institutions which are directly or indirectly involved are affected by the biotechnology debate.
[11] Both scenarios were projected over a period of 30 years.

5 Potential Benefits of Golden Rice

According to our calculation, the annual benefits of GR are about 12.1 thousand DALYs in a pessimistic scenario and 107.3 thousand DALYs in an optimistic scenario. Preschool children account for 95.4 percent of the total gain. The overall reduction of VAD functional outcomes are about 4.6 percent in a pessimistic scenario and 41.0 percent in an optimistic scenario. This result shows that GR could bring a significant contribution to reduce VAD in Bangladesh.

We juxtapose DALYs gained and the costs of R&D of GR to calculate its cost-effectiveness. First, we estimate the overall costs of R&D for Bangladesh. This cost estimates are based on the budget used to develop GR by the University of Freiburg, IRRI and Syngenta. To attribute a share to the overall costs to Bangladesh, in the pessimistic scenario we used a share of 21.5 percent of the total rice production of Bangladesh, India and the Philippines to Bangladesh, as these countries are the main GR beneficiaries targeted by the Golden Rice Humanitarian Board. In the optimistic scenario, we assigned 10.4 percent of the total rice production of Bangladesh, China, India and the Philippines to Bangladesh, because China is also a potential beneficiary of GR (c.f. Appendix C). Both scenarios are projected over a period of 30 years, which is a reasonable time horizon to carry out R&D, testing and dissemination, and to account for a life cycle of the biofortified varieties (c.f. Table 5).

Our cost-effectiveness analysis shows that one life saved costs US$1,673 in the pessimistic scenario, while in the optimistic scenario it costs only $US123. In term of DALYs, one DALY saved costs US$ 54 in pessimistic scenario, and US$4 in the optimistic scenario. We have compared this cost calculation with the next best VA intervention program in Bangladesh, which is VA supplementation program. Although the cost of VA Capsule in Bangladesh is the lowest in the World, our calculation shows that one DALY is saved at a cost of US$171 and US$156 in pessimistic and optimistic scenario, respectively (c.f. Appendix D). This result shows that GR is the cost effective program even under pessimistic scenario. We have summarized the annual burden of VAD in Bangladesh and the cost effectiveness of GR in Table 5.

Table 5-1: Cost Estimates for R&D and Dissemination of GR in Bangladesh

Undiscounted costs (US$)	Time frame	Pessimistic scenario	Time frame	Optimistic scenario
International R&D costs[a]	2000-2007	2,304,531	2000-2007	1,005,247
R&D costs within Bangladesh[ab]	2007-2011	1,062,500	2006-2009	935,000
Regulatory costs[ac]	2008-2012	2,250,000	2007-2010	1,980,000
Release of GR	2012-2013		2011-2012	
Social marketing costs[ad]	2013-2016	6,250,000	2012-2014	5,500,000
Maintenance cost[abe]	2013-2030	2,187,500	2012-2030	1,925,000
Total (discounted at 3%)		9,564,885		7,775,139

[a]To build our pessimistic scenario, we have increased past costs reported, i.e. costs incurred before the year 2005, by 10% to account for possible underreporting or omissions, while we increased the more uncertain future costs by 25%. In the optimistic scenario, we only increased future costs by 10%.

[b]R&D costs at the Bangladesh Rice Research Institute (BRRI) include breeding of GR into popular varieties, gene improvement, field trials, feeding experiments. These costs are based on estimates by Nilufer Hye Karim (BRRI).

[c]The regulatory costs include variety registration, biosafety and food safety evaluation. The costs are based on estimates by M. Imdadul Hoque (Biosafety Program South Asia).

[d]Social marketing costs include the costs of information and dissemination campaign and the first delivery of seeds to farmers; based on estimates by Noel Magor and M. A. Hamid Miah from IRRI Bangladesh.

[e]The maintenance costs includes the costs of germplasm maintenance and monitoring by Nilufer Hye Karim (BRRI).

Table 5-2: Annual Burden of VAD in Bangladesh and the Cost-effectiveness of GR

Scenario	**Pessimistic**	**Optimistic**
Current annual burden of VAD (DALYs)	-262,000	-262,000
Annual burden of VAD with GR (DALYs)	-249,788	-154,554
Absolute annual gain through GR (DALYs)	12,105	107,338
Reduction of the burden of VAD (%)	-4.6	-41.0
Cost per DALY saved through GR (US$)	54.0	4.0
Cost per DALY saved through supplementation (US$)	171	156
Current annual burden of VAD (lives)	-8,780	-8,780
Annual burden of VAD with GR (lives)	-8,386	-5,268
Absolute annual gain through GR (lives)	394	3,512
Cost per live saved through GR (US$)	1,673	123

6 Sensitivity Analysis

Since this study is an *ex-ante* study, some parameters are still associated with uncertainty. Therefore we have carried out a number of sensitivity analyses to test the robustness of the parameters used (c.f. Table 6). We found that the higher the amount of beta-carotene in GR the higher its effectiveness. However, if we lower the amount of beta-carotene to 10µg/g the reduction of burden of VAD is still significant even in pessimistic scenario. The coverage rate is another important factor for the effectiveness of GR. The higher the coverage rate the higher the effectiveness. Even with a low coverage rate, the benefit is sizable. High post-harvest losses have no impact on our optimistic scenario, because the amount of beta-carotene in the rice is relatively high. These results show that the parameters we have used are very robust.

Table 6-1: Reduction of VAD-functional Outcomes in Different Scenarios

Scenarios[12]	**Pessimistic**	**Optimistic**
Original assumption: percentage of the reduction of the burden of VAD	**-4.6**	**-41.0**
Amount of beta-carotene (ßC) in GR: 10 µg/g	-3.5	-41.0
Coverage rate: 10%	-3.2	-6.8
Coverage rate: 70%	-22.6	-47.8
Post-harvest losses of ßC: 90%	-2.6	-41.0

[12] Both scenarios were projected over a period of 30 years.

7 Conclusion

This study analysed the potential benefits of GR technology in Bangladesh. Although the burden of VAD has diminished over the last two decades, our calculation shows that VA problem remains significant in the country. About 262 thousand DALYs are lost every year due to VAD-related functional outcomes, around nine thousand children under age of six die every year due to VAD, 254 preschool children go blind, and the same number suffer from permanent eye damage. About 102 thousand children are affected by measles and about 15 thousand become night blind. In addition, 68 thousand pregnant women and 40 thousand lactating women become night blind. The total burden of VAD causes an annual lost of about 0.2 to 0.5 percent of the Bangladesh GDP. This loss could be reduced if GR were introduced in the country. Our scenario calculations show that the total reduction of DALYs lost is about 4.6 and 41.0 percent in the pessimistic and optimistic scenarios, respectively. In monetary terms this reduction is between 0.01 and 0.2 percent of the GDP. The cost effectiveness analysis shows that one life could be saved at a cost of US$1,673 in the pessimistic scenario and US$123 in the optimistic scenario. In terms of DALYs, one DALY could be saved at a cost of US$54 and US$4 in the pessimistic and optimistic scenarios respectively. If we compare these costs with the costs of the next best VA intervention, which is the supplementation, one DALY is saved at a cost of US$171 and US$156 in the pessimistic and optimistic scenarios, respectively. This implies that GR could be highly cost-effective program. Although our analysis was of *ex-ante* nature, the sensitivity analysis has shown that the parameters used for the calculation are very robust. This study has shown remarkable gains which could be realized by the introduction of GR in Bangladesh. However, it must be clearly stated that GR alone will not eliminate VAD. Therefore this intervention should be seen as a complementary program to the existing ones, such as supplementation, food fortification, dietary education and breeding for micronutrient rich food. On the other hand, these benefits can only be realized if GR receives a political support in Bangladesh. In terms of safety, GR will be released for commercialisation after proper evaluation of food safety and environmental effects.

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Appendix

Appendix A

Nutritional Situation in Bangladesh

The rate of malnutrition in Bangladesh, although declining over the past few decades, is still very high. The proportion of low birth weight babies is estimated at 30 to 50 percent of live births. About 70 percent of these babies are the result of intrauterine growth retardation or they are small for their age (Arifeen et al, 2000). Thirteen percent of pre-school children are severely underweight (lower body weight for their age) and about 50 percent are moderately underweight. Some 10 percent are suffering from moderate to severe wasting (lower body weight for their height-reflects acute or short term malnutrition) and nearly half (45 percent) are moderately to severely stunted (lower height for their age-reflects chronic malnutrition). The rates are significantly higher for girls compared to boys and higher for rural compared to urban areas (UNICEF, 2004).

Nearly half (45 percent) of the women who had given a birth in the three years prior to survey have a body mass index of less than 18.5 kg/m^2, indicating the presence of malnutrition. Further, the prevalence of malnutrition was much higher among women in rural areas (NIPORT/MA/ORCM, 2001).

A recent survey in rural areas found that 53 percent of Bangladeshi children aged 6–59 months were anaemic, with the rates even higher among the younger children in this group. The prevalence of anaemia among women of reproductive age was 45-50 percent. About 38 percent of the school-age children and 43 percent of adolescent girls were also found to be anaemic. It is likely that a significant proportion of this anaemia is due to iron deficiency; however data on true prevalence of iron deficiency is limited (HKI/IPHN, 1999a). A few studies on adolescent girls in Bangladesh have shown that a significant proportion of anaemia in these girls was due to iron deficiency (Ahmed et al., 2000; Ahmed et al., 2001).

Iodine deficiency remains a serious problem, despite a universal salt iodisation programme. Although the situation has improved since the early 1990s, a 1999 survey (IPHN/BSCIC/UNICEF/ICCIDD, 1999) showed that 43 percent of the population were still iodine deficient, compared to 69 percent in a 1993 survey. The corresponding numbers for children aged 5-11 years were 42.5 percent and 71 percent, respectively. The prevalence varied by gender and by region with the highest rates among women and in the hilly areas of the country.

Vitamin A Deficiency in Bangladesh

In 1982-83, the first population-based assessment of the magnitude of VAD in Bangladesh was conducted by Helen Keller International (HKI)[13] and the Institute of Public Health Nutrition (IPHN) (HKI/IPHN, 1985). The survey revealed provided insights on severe VAD symptoms, for rural children aged 6-59 months: 3.6 percent had night blindness, 0.9 percent had Bitot's spot and 20 percent had corneal xerosis. Fortunately, clinical VAD among children in Bangladesh is now below the levels used by the World Health Organisation to define a public health problem. Among children 12-59 months old, night blindness has been reduced from 3.5 percent in 1982/83 to 0.07 percent in 2004 (HKI/IPHN, 2005).

The nutrition survey of 1981-82 showed that the prevalence of conjunctival xerosis among non-pregnant and pregnant women in rural Bangladesh 2.6 percent and 1.6 percent, respectively, but none was found with night blindness (INFS, 1983). However, most recent VAD survey showed that about 0.71 and 0.54 percent of pregnant and lactating women, respectively, were night blind (HKI/IPHN, 2005).

Sub-clinical VAD in preschool children is defined as a serum retinol level <0.7µmol/L (20µg/dL), and is associated with lower rates of child survival. The National VA Survey 1997-98 showed the prevalence of sub-clinical VAD among preschool children and school age children in rural Bangladesh was 22 percent (HKI/IPHN, 1999b). Sub-clinical VAD among women was also very high. About 45-50 percent of pregnant and lactating women had serum retinol values below 30 µg/dL (HKI/IPHN, 1999b). Nearly half of rural adolescent girls were reported to have poor VA status (<1.05 µg/dL), with about 12 percent having sub-clinical VAD (HKI/IPHN, 1999b). In a study among adolescent female factory workers in Bangladesh, 56 percent had serum retinol levels <1.05 µg/dL, and 14 percent had sub-clinical VAD (Ahmed et al., 1997). In summary, although the prevalence of clinically evident VAD among preschool children has decreased significantly, sub-clinical VAD is still a significant public health problem.

Appendix B: Parameters Used for Calculation

The following lines explain briefly the parameters used for the calculation; all these parameters are described in detail in Stein et al. (2005).

- Five adverse functional outcomes have been identified to be attributable to VAD: night blindness, corneal scars, blindness, measles, and increase mortality. All these adverse functional outcomes affect children under five. However, night blindness affects also pregnant and lactating women.

[13] Founded in 1915, Helen Keller International is among the oldest international non-profit organizations devoted to fighting and treating preventable blindness worldwide. HKI is headquartered in New York City, and has offices in 24 countries around the world. HKI builds local capacity and provides technical and scientific assistance to governments, international, national and local organizations, and individuals around the world. HKI does this by establishing sustainable programs and providing other groups working towards the same goal with data about needs as well as impacts of programs and policies.

- To estimate the size of each target group, we have used data from the *U.S. Bureau of the Census*[14] (2003 and 2004). For children, we have used the data of 2004; for pregnant and lactating women, published statistics do not provide data; therefore we assumed that 10 percent of women in 2003 were pregnant, and 10 percent of women in 2004 were lactating.

- In the case of mortality rates, we took the under-five mortality rate from the *U.S. Bureau of the Census* (2004). Since the under-five mortality rate is given in 1,000 life births, the rate has not been applied to the size of the actual target group, but to the number of life births.

- It is assumed that the average age at death for VAD-related under-five mortality is one year. To calculate the remaining life expectancy, we used the national life tables of Bangladesh. For children under five years of age, the remaining life expectancy is 63.4 year for both sexes.

- The rate of VAD is always given as prevalence rate. However, DALY is an incident-based measure; therefore, we have used the relationship between the two rates to calculate the incidence rate. The relationship is defined as follows:

  Prevalence rate[15] *= incidence rate*[16] *x duration*[17]

  Prevalence rates of night blindness for children under-five, pregnant and lactating women are 0.07; 0.71; 0.54, respectively (HKI/IPHN, 2005). The incidence rate of measles among children under five years is 4.72 percent (Lutfor; 2005). It was assumed that all night blindness among pregnant and lactating women and all children was due to VAD, and 10 percent of all measles cases are due to VAD, and complications can be expected in 50 percent of these cases.

- The disability weights for functional outcomes related to VAD are deemed universally applicable; for night blindness the disability weight is 0.1 and 0.05 for women and children respectively; for children, the disability weight for measles and for measles with complications is 0.35 and 0.7, respectively.

- The duration of night blindness is expected to be five months for pregnant women and six months for lactating women. For children it is assumed to be one year after birth. Children are assumed to acquire corneal scars at the age of one. For those 50 percent of children who go blind due to corneal scars, this is assumed to happen at the same time. Both corneal scars and blindness are permanent conditions, i.e. the duration of these two functional outcomes corresponds to the remaining life expectancy. Measles is a temporary disease and its duration is assumed to be 10 days. When complications set in, the duration is assumed to be 20 days.

[14] http://www.census.gov/ipc/www/idbnew.html
[15] The prevalence of a disease is the proportion of a population that is number of cases at a point in time. Therefore, the prevalence rate is the number of current cases per population at risk.
[16] The incidence of a disease is the rate at which new cases occur in a population during a specified period of time. Therefore, the incidence rate is the number of new disease cases per population at risk.
[17] The duration depends on different functional outcomes related to VAD.

- To carry out a cost-benefit analysis, we need to give a monetary value to a DALY. Different approaches can be used: (i) A country per capita income (c.f. Zimmermann and Qaim, 2004; Zimmermann et al. 2004; Tolley et al., 1994); (ii) a standardized value of US$1,000 (c.f. World Bank, 1994; Collier and Hoeffler, 2004) or US$500 (c.f. Rijsberman, 2004); (iii) an approach based on value of life estimates (c.f. Mills and Shillcutt, 2004). However, given a DALY a value that is comparable across countries seems to be an appropriate approach, because the comparison of costs and benefits of interventions between different countries will be more transparent and easy to assess. Looking at the per capita national gross product of developing countries makes value between US$300 and US$1,500 more plausible. Therefore, we suggest using two different values; a standardized of US$1,000, and the Gross National Income (GNI) of the study country. The GNI of Bangladesh for 2003 is US$400 (World Bank, 2004). However, attaching a monetary value to one DALY saved does not mean to value life as such, it is only a convenient device for economic analysis.

- A discount rate of 5 percent per annum has been standard in much health economic and other social policy analyses for many years. Environmentalists and renewable energy analysts have argued in recent decades for lower discount rates for social decisions. The World Bank Disease Control Priorities Study and the Global Burden of Disease project both used a 3 percent discount rate. The US Panel on Cost-Effectiveness in Health and Medicine recently recommended that a 3 percent real discount rate be used in health economic analyses to adjust both costs and health outcomes (Gold et al., 1996), but that the sensitivity of the results to the discount rate should be examined. The World Health Report (WHO, 2002) has also used 3 percent social discount. We suggest doing the same for our study.

Appendix C: Rice Production

Country	Item	Element	Unit*	2002	2003	2004		Bangladesh, India, Philippines			Bangladesh, China, India, & Philippines	
Bangladesh	Rice, Paddy	Production	Mt	37.593.000	39.090.000	37.910.000		37.910.000	**21,5%**		37.910.000	**10,4%**
Bhutan	Rice, Paddy	Production	Mt	38.000	46.000	45.000		**Pessimistic**			**Optimistic**	
Brunei Darussalam	Rice, Paddy	Production	Mt	400	400	400						
Cambodia	Rice, Paddy	Production	Mt	3.822.509	4.300.000	4.710.000						
China	**Rice, Paddy**	**Production**	**Mt**	**176.342.195**	**162.304.280**	**186.730.000**					**186.730.000**	**51,4%**
India	**Rice, Paddy**	**Production**	**Mt**	**108.900.000**	**130.400.000**	**124.400.000**		**124.400.000**	**70,5%**		**124.400.000**	**34,2%**
Indonesia	Rice, Paddy	Production	Mt	51.489.696	52.078.832	53.100.104						
Iran, Islamic Rep of	Rice, Paddy	Production	Mt	2.888.000	3.300.000	3.400.000						
Korea, Dem People's Rep	Rice, Paddy	Production	Mt	2.186.000	2.244.000	2.370.000						
Korea, Republic of	Rice, Paddy	Production	Mt	6.687.225	6.015.000	6.351.000						
Laos	Rice, Paddy	Production	Mt	2.416.500	2.646.000	2.700.000						
Malaysia	Rice, Paddy	Production	Mt	2.197.350	2.258.650	2.183.660						
Myanmar	Rice, Paddy	Production	Mt	22.780.000	24.640.000	23.000.000						
Nepal	Rice, Paddy	Production	Mt	4.132.600	4.455.722	4.300.000						
Pakistan	Rice, Paddy	Production	Mt	6.717.750	7.272.000	7.570.000						
Philippines	**Rice, Paddy**	**Production**	**Mt**	**13.270.653**	**14.031.000**	**14.200.000**		**14.200.000**	**8,0%**		**14.200.000**	**3,9%**
Saudi Arabia	Rice, Paddy	Production	Mt	0	0	0						
Sri Lanka	Rice, Paddy	Production	Mt	2.859.480	3.071.200	2.509.800						
Syrian Arab Republic	Rice, Paddy	Production	Mt	0	0	0						
Thailand	Rice, Paddy	Production	Mt	26.057.000	27.241.000	25.200.000						
Timor-Leste	Rice, Paddy	Production	Mt	53.656	65.433	65.433						
Turkey	Rice, Paddy	Production	Mt	360.000	372.000	400.000						
Viet Nam	Rice, Paddy	Production	Mt	34.447.200	34.518.600	35.500.000						
Total Developing Asia				505.239.214	520.350.117	536.645.397		176.510.000	100%		363.240.000	100%

*Million of tones

Appendix D: Cost Effectiveness of VA Supplementation in Bangladesh

We have conducted a cost effectiveness analysis of VA supplementation in Bangladesh to be compared with the GR intervention in the country. The data are from UNICEF-Bangladesh (Torlesse, 2005).

There are two different costs used for the calculation: the direct cost of supplements and the associated costs.

Costs of supplements

Infants 9-11 months receive 100,000 IU capsules (one time only at nine months of age with measles vaccination). 500 capsules cost US$6.82. The coverage rate is 95%, that means in this age group 5% of children are not covered.

Children 12-59 months receive 200,000 IU capsule (twice a year), at a cost of US$9.41 per 500 capsules. The coverage rate is 95%, this in this age group 5% of children are not covered.

Postpartum women receive 200,000 IU capsules (once, within 6 weeks of delivery), at a cost of US$9.41 per 500 capsules. The coverage rate is 70%; that implies 30% of lactating women are not covered.

Pregnant women receive no capsules.

10% of the total numbers of capsules used are for therapeutic use, and 5% are lost due to handling.

Other associated costs

Freight/insurance/handling costs for vitamin A capsule (VAC): approx US$ 200,000 per year supply of VAC.

Programme support costs (human resources, internal transportation, distribution, IEC materials, advocacy, training and orientation) are highly dependent on the distribution mechanisms used. Between 1995 and 2004, VAC distribution was often linked with the polio national immunization days, which minimized these costs. As the polio NIDs have ended, the government introduced the "National Vitamin A Plus Campaign" which is designed to deliver a package of interventions to children 12-59 months, including VAC, deworming treatment, information, education and communication (IEC) messages, birth registration, etc. Because it is a package of interventions, it is impossible to separate out the costs of distributing VAC alone. The programme support costs are in the region of US$ 700,000 to 800,000 per year, excluding cost of human resources. The government contributes an additional US$ 120,000 each year to provide each volunteer with a token honorary for their participation in the Campaign.

These costs may sound quite high, but when expressed as a cost per child reached; it is one of the lowest costs in the world (the high population density of and high coverage of VAC in Bangladesh helps).

Cost calculation

We have first calculated the total cost of VAC requirement for 200,000 IU. That is the number of VAC times the cost of one capsule. The number of capsules is a product of the number of people in the group, the number of doses per year received per person and the coverage rate. The total cost is US$756.033 (c.f. Table D1). We have added the associated cost to it to build a total cost of supplementation for 200,000 IU (Table D-3). We use the same approach to calculate the total cost of VAC requirement for 100,000 IU (c.f. Table D-2). The total cost of VAC is about US$1.886.061 (c.f. Table D-4). This cost is used for our pessimistic scenario.

The coverage rate in each group shows that preschool children and lactating women are not fully covered; pregnant mothers are not covered at all. In our optimistic scenario, we have assumed an unrealistic scenario whereby 100% of people are covered; we have calculated the remaining costs and added them to the cost in the pessimistic scenario. The remaining cost is calculated using the approach above. We have used a new coverage rate, which is the difference between the coverage in the optimistic scenario and the one of the pessimistic scenario. The total cost of VA supplementation in the optimistic scenario is US$2.037.168 (c.f. Table D-4).

We have juxtaposed these costs with the DALYs saved through the supplementation programme, to calculate the cost effectiveness of the supplementation programme. Our results show that one DALY can be saved at a cost of US$171 and US$156 in the pessimistic and optimistic scenarios, respectively.

Table D-1: Estimated Requirements of VAC 200,000 IU

	# person/yr	# doses/yr	Coverage	#VAC	cost of 1 VAC	Total cost	Uncovered	Remaining Cost
Children 12-59 months	16.934.647	2	95%	32.175.830	0,01882	$605.549	846.732	$31.871
Pregnant	3.834.901	1	0%	0		$0	3.834.901	$72.173
Postpartum women	3.721.317	1	70%	2.604.922		$49.025	1.116.395	$21.011
Therapeutic use (10%)				3.478.075		$65.457		$12.505
Handling losses (5%)				1.912.941		$36.002		$6.878
Total				40.171.768		$756.033		$144.438

Table D-2: Estimated Requirements of VAC 100,000 IU

	# person/yr	# doses/yr	Coverage	#VAC	cost of 1 VAC	Total cost	Uncovered	Remaining Cost
Children 9-11 months	4.233.662	1	90%	3.810.296	0,01364	$51.972	423.366	$5.775
Therapeutic use (10%)				381.030		$5.197		$577
Handling losses (5%)				209.566		$2.858		$318
Total				4.400.891		$60.028		$6.670

Table D-3: Other Associated Costs

	Total cost	Remaining Cost
Cost of frieght/insurance/handling of VAC/yr	$200.000	
Programm support costs / yr	$750.000	
Costs of human resources / yr	$120.000	
Total	$1,070,000	

Table D-4: Total Cost of VA Supplementation

Total cost of VA supplementation	Pessimistic scenario	Optimistic scenario
	$1.886.061	**$2.037.168**

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