RETURNS TO GOLDEN RICE RESEARCH IN BANGLADESH: AN EX-ANTE ANALYSIS

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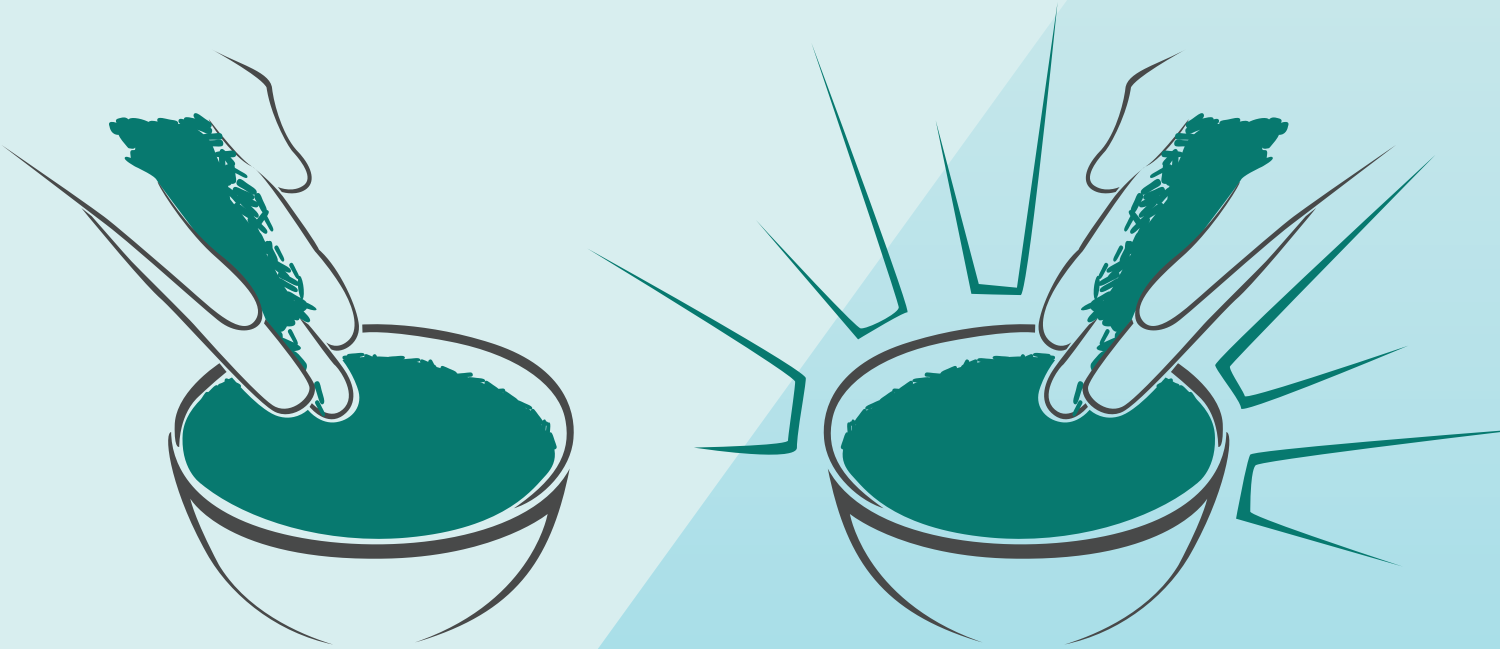

Benefits and Costs of Adopting the Golden Rice in Bangladesh

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Returns to Golden Rice Research in Bangladesh: An Ex-ante Analysis

Bangladesh Priorities

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INTRODUCTION

Vitamin A deficiency is a serious problem in Bangladesh. Deficiency in Vitamin A severely affects small children and pregnant women. One in every five children aged 6 months to 5 years is estimated to be Vitamin A-deficient. Among pregnant women, 23.7% in Bangladesh are affected by vitamin A deficiency (WHO, 2015). Each day about 88 children become blind in Bangladesh due to vitamin A deficiency. Vitamin A is associated with night blindness in about 2 percent of children aged 1-6 years old (Banglapedia, 2016). Rice is the staple food in Bangladesh and accounts for 70 percent of the daily calorie intake. Rice does not contain any beta carotene. Dependence on rice as the predominant food source, therefore, leads to Vitamin A deficiency. Scientists have successfully developed a new rice variety known as Golden Rice (GR-2 E BRRI dhan29) with beta carotene which will be released for cultivation in the Boro season after necessary field testing. The human body converts the beta carotene in Golden Rice to vitamin A as it is needed.

Proven approaches to prevent vitamin A deficiency include: promotion of optimal breastfeeding practices; promotion of proper complementary feeding practices; nutrition education and consumption of a diversified diet that includes nutrient-rich fruits and vegetables and foods from animal sources; vitamin A capsule supplementation; food fortification; and other public health measures, including control of infectious diseases. These approaches to vitamin A deficiency have had real success. However, vitamin A deficiency remains a public health problem in Bangladesh. Target populations are sometimes missed with these interventions, especially in hard to reach areas. Therefore, it is hoped that cultivation and consumption of Golden Rice will complement the existing programs and efforts to address Vitamin A deficiency.

Rice is the major crop grown in Bangladesh which occupies about three-fourths of the total crop area in the country. During the last four decades, total rice production has increased by 3.1 times (from 10.85 million metric tons in the early seventies to 34.71 million metric tons in 2014/15). Traditionally, Aman rice was the major source of rice in Bangladesh but the share of Boro rice to total rice production has superseded that of Aman rice since 1998/99. Thus, Bangladesh has experienced a structural shift in its rice production from a largely weather influenced crop to an irrigated crop, which is much more sensitive to the quality of public policy and governance than the vagaries of nature (Deb, 2002). Now, Boro rice contributes about 54 percent to the total foodgrain production, as opposed to only 18 percent in the early seventies. Despite inter-year fluctuations, rice production had a sustained growth both in the long-term and in recent years. The long-term (FY1969/70 to FY2007/08) annual compound rate of growth in total rice production was 2.67 percent against 0.83 percent in recent years (FY2010/11 to FY2014/15). Bangladesh imported 1490 thousand metric tons of rice in FY2014/15. Due to a rise in population and income, demand for rice is going to increase in the future.

Primary focus of rice research in the past focused on enhancing yield and reduction in per unit cost of production through the incorporation of resistance against biotic (pests and diseases) and abiotic (flood, salinity tolerance) stresses and desired agronomic traits in the improved rice varieties. One important thrust area for rice research in the recent years is the enhancement of grain quality through bio-fortification. During the last three years, Bangladesh has already released three zinc-rich rice varieties (BRRI dhan 62, BRRI dhan 64 and BRRI dhan72). Zinc, iron and vitamin-A are the three most vital micronutrients, deficiency of which hampers children's natural growth and decreases their disease prevention capacity. In Bangladesh, over 40 percent of children under five are stunted while an estimated 44 percent children of the same age group are at risk of zinc deficiency. The Bangladesh Rice Research Institute (BRRI) has also successfully completed a trial of Golden Rice in its transgenic screen house. Golden Rice is rich in pro-vitamin A which has been possible through the incorporation of a corn gene responsible for producing beta carotene through genetic engineering[1]. Upon approval of the National Technical Committee on Crop Biotechnology in its meeting on 20 September 2015, BRRI scientists started confined field trials of Golden Rice (GR-2 E BRRI dhan29) from this Boro season (started in November 2015). This will be followed by open-field and multi-location trials before release of the Golden Rice variety to the farmers for cultivation.

Golden Rice has the potential to reach many people, including those who do not have reliable access to or cannot afford other sources of vitamin A. Golden Rice is intended to be used in combination with existing approaches to overcome vitamin A deficiency, including eating foods that are naturally high in vitamin A or beta carotene, eating foods fortified with vitamin A, taking vitamin A supplements, and optimal breastfeeding practices. The body converts beta carotene in Golden Rice to vitamin A as it is needed. According to research published in the American Journal of Clinical Nutrition in 2009, daily consumption of a very modest amount of Golden Rice – about a cup (or around 150 g uncooked weight) – could supply 50% of the Recommended Daily Allowance of vitamin A for an adult.

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[1] Beta carotene has been incorporated in three improved rice varieties. These are: (i) BRRI Dhan-29, the most popular and productive rice variety of Bangladesh; (ii) IR-64, a popular variety developed by the International Rice Research Institute (IRRI) and cultivated in many countries of the world, and (iii) RC-28, a Filipino variety.

There is both high hopes among many and skepticism among some influential groups in Bangladesh about the potential impacts of Golden Rice. However, no empirical study is available to inform those interested in the likely impacts and pay-off from investment in Golden Rice. The present study has quantified ex-ante returns to investment in golden rice research and dissemination activities in Bangladesh. It has made an attempt to answer the following questions: How Golden Rice will contribute to Bangladesh? What are the investments required for R&D in Golden Rice? What are the potential benefits from Golden Rice? What will be the return to investment in R&D on Golden Rice?

Objectives of the Study

The broad objective of the study is to quantify the return to investment in Golden Rice research and dissemination activities in Bangladesh. Specific objectives of the study are as follows:

- To identify potential areas for cultivation of Golden Rice in Bangladesh
- To estimate costs of and benefits from Golden Rice research and dissemination activities in Bangladesh
- To quantify return to investment in Golden Rice related research and development activities
- To articulate implications of research findings for development strategies in Bangladesh.

After this introduction section, the next section of the paper documents the status of Golden Rice research in Bangladesh. The third section explains the research methodology used in the study. The fourth section discusses the results of the analysis. Summary, conclusions and recommendations are provided in the last section.

Scope and limitations of the study

This study analyzes the return to investment in adaptive research and dissemination of Golden Rice in Bangladesh. In this study, we have considered the investment required for adaptive research on Golden Rice which has already been developed at IRRI. Other related costs are technology exchange to the farmers through the involvement of Rice R&D in Bangladesh and the promotional campaign done through media and the extension system are also taken into account. Benefits from Golden Rice which will be received in Bangladesh through productivity gain and improvement in nutritional status (Vitamin A) are also quantified. An overall assessment of investment in Golden Rice research which started in Germany and Switzerland in the nineties is beyond the scope of the present study.

STATUS OF GOLDEN RICE RESEARCH I BANGLADESH

What is Golden Rice?

The term Golden Rice refers to a genetically engineered, yellow-orange rice grain that contains beta-carotene (IRRI, 2005). The transgenic technology in rice was first applied by Professor Ingo Potrykus, then at the Institute for Plant Sciences of the Swiss Federal Institute of Technology, and Professor Peter Beyer of the University of Freiburg, Germany. The human body converts beta-carotene into vitamin A. The Golden Rice varieties, reported in 2004 and 2005, contain a gene from either maize or daffodil plants and a gene from a common soil bacterium (Erwinia). The enzyme products of these genes lead to the formation of lycopene in the grain — a process completely absent from the polished rice grain — and this lycopene is then converted into beta-carotene and other pro-vitamin A carotenoids (the building blocks of vitamin A) by other enzymes found in the grain. The polished grains from the latest Golden Rice varieties produce up to 36 micrograms per gram of beta-carotene and other pro-vitamin A carotenoids (Paine et al., 2005) more than a 20-fold increase from the original Golden Rice reported 5 years ago (Ye et al., 2000).

Golden Rice: Research Achievements and Challenges

Golden Rice is an outstanding achievement for humanity. However, there are some influential groups against Golden Rice who believe that Golden Rice, being a GMO would harm consumers and the environment. These opponents assert that the spread of Golden Rice must be stopped at any cost, and have even vandalized experimental plots of Golden Rice in the Philippines.

To overcome such misdirected challenges, the global scientific community has come out in support of Golden Rice. Eleven globally renowned scientists co-authored an editorial focusing on Golden Rice in September 20, 2013 edition of Science magazine. The editorial entitled 'Standing Up for GMOs' expressed outrage at the destruction of the trial Golden Rice field in the Philippines by vandals. It has summarized the extensive health consequences of vitamin A deficiency and the contribution that Golden Rice could make in addressing this problem the moment the biotech crop becomes available to the farmers and consumers. Scientists who wrote the article include Bruce Alberts, President Emeritus of the U.S. National Academy of Sciences; Roger Beachy, Wolf Prize laureate and President Emeritus of the Donald Danforth Plant Science Center in Montana, USA; Swapan Datta, Deputy Director General for Crop Science of the Indian Council of Agricultural Research in New Delhi, India; and Gurdev S. Khush, World Food Prize laureate, Japan Prize laureate, and former scientist at the International Rice Research Institute in Los Baños, Philippines.

The Golden Rice Project has won the Patents for Humanity Award 2015 from the White House Office of Science and Technology Policy and the United States Patent and Trademark Office (USPTO). The award was given on April 20, 2015 at the White House to recognize the vision of Golden Rice (GR) co-inventors Ingo Potrykus and Peter Beyer, and GR Humanitarian Board Secretary Adrian Dubock, whose patent application of the project enabled small holder farmers to benefit from Golden Rice. The award is given to patent owners working to bring life-saving technologies to the underserved people of the world in the fields of medicine, sanitation, household energy, living standards, and nutrition.

"Royalty-free access to key technologies used in Golden Rice has enabled IRRI and public institutions to continue research and development of Golden Rice on a not-for-profit basis. Through this royalty-free arrangement and by breeding Golden Rice into already popular inbred varieties, resource-poor farmers can afford and reuse the seeds when they become available," according to the IRRI media release.

Research on Golden Rice in Bangladesh

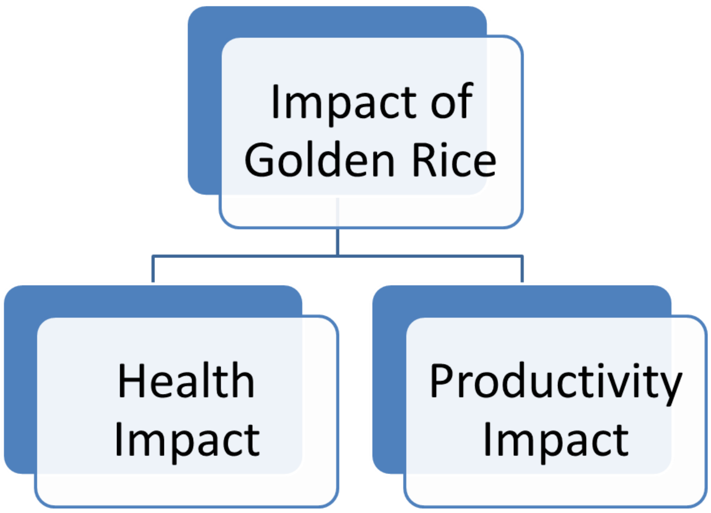
The BRRI is involved in a GE Golden Rice Project funded by the Rockefeller Foundation, Bill & Melinda Gates Foundation (Grand Challenges in Global Health Initiative), USAID, the Philippine Department of Agriculture, HarvestPlus, the European Commission, Swiss Federal Funding, and Syngenta Foundation. The breeding division at IRRI is working with the BRRI to conduct confined field trails for beta-carotene-enriched (Vitamin A, Iron and Zinc contained) BRRI Dhan 29, also called Golden Rice 2 (GR2) Event “R” (GR2-R) (GAIN Report Number: BG5006; Date: 16 Sept 2015).

Research on Golden Rice in Bangladesh has been continuing on genetically improved BRRI Dhan 29 (GR-2 E BRRI Dhan29). Scientists have evaluated the performance of the variety under confined field trial (CFT) conditions in Gazipur during 2013-14 and 2014-15. These trials have revealed that the variety contains the desired agronomic traits available in the BRRI Dhan 29. During 2013-14 Boro season, seven lines were selected from 22 pro-vitamin A enriched BRRI dhan29 Golden Rice (event GR2-R) introgressed lines. The selected lines provided either similar or higher yield than the non-transgenic control, BRRI dhan29. These lines showed up to 12 percent yield advantage over BRRI dhan29. Total carotenoid (TC) levels, analyzed at three months of storage after harvest in brown paper bags, varied from 8.1 to 15.5ug/g in the selected lines. However, original Kaybonnet Golden Rice event GR2-R had average TC value of 13.7ug/g (Biswas and Haque, 2015). In these trials, scientists have also monitored the reactions of Golden Rice (event GR2-R) introgressed lines to different insect pests. The insect pests were monitored on weekly basis and were reported fortnightly. Among the major insects pest, leaf folder and stem borer were appeared below the economic threshold level (ETL) both in vegetative and reproductive stage of the test entries, including BRRI dhan29. However, the leaf folder damage was above 50 percent in the event GR2-R in contrast to BRRI dhan29 at the reproductive stage. In addition to the event GR2-R, four test entries were infested (5-20 percent) by leaf folder while five other test entries gave good performances, having pest (SB & LF) tolerance at field conditions. No unknown pest was recorded during the reporting period (Hossain, Islam and Biswas, 2015). Therefore, the Golden Rice variety is likely to be ready for cultivation in farmers' fields soon.

RESEARCH METHODOLOGY

Golden rice is expected to generate two kinds of benefits: health benefits and an increase in rice productivity (Figure 1). Health benefits are expected to be realized through a reduction in vitamin A deficiency among women and children in Bangladesh. On the other hand, per hectare yield of Golden Rice is expected to be higher than the existing BRRI Dhan 29. Therefore, increase in yield is expected to reduce per ton cost of rice production.

Figure 1: Conceptual Framework to Quantify the impact of Golden Rice Research in Bangladesh



Source: Author's Conceptualization.

3.1 Analytical Procedure for computation of health benefits

Zimmermann and Qaim (2004) have quantified the ex-ante Impact of Golden Rice Research in the Philippines. The study was conducted at an early stage of development of Golden Rice. Therefore, many parameters needed for ex-ante analysis were not known at that time. Naturally, they had to rely on assumptions and scenarios. They have assumed that the Golden Rice will provide health and nutritional benefits through beta-carotene (Vitamin A) without any significant yield advantage. Accordingly, they developed a conceptual frame work for carrying out the empirical research. This study has followed the conceptual framework of Zimmermann and Qaim (2004) for quantifying the health impacts of Golden Rice. The framework is described below.

The primary goal of Golden Rice 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 demand curve. But this presupposes that consumers recognize and appreciate the quality improvement. Awareness of VAD is generally low among the poor. Moreover, due to limited purchasing power, nutritional needs are often not translated into effective market demand. Capturing the benefits of GR in a market model is therefore not appropriate. Instead, the technology's positive health effects have to be identified and measured. As Figure 2 illustrates, the impact will mainly depend on two factors: (i) the technology's efficacy and (ii) its coverage rate. The efficacy of GR is defined as the capacity to improve the health status of a VA-deficient individual. This is influenced inter alia by the beta-carotene content in the grain and its bioconversion to VA in the human body. Coverage, on the other hand, is defined as the fraction of the population actually eating GR. This is a function of technology accessibility and producer and consumer acceptance. To some extent, these factors can still be influenced through adaptive research, but there are also exogenous variables which are harder to control.

Figure 2: Conceptual Framework for Quantifying Health Impact

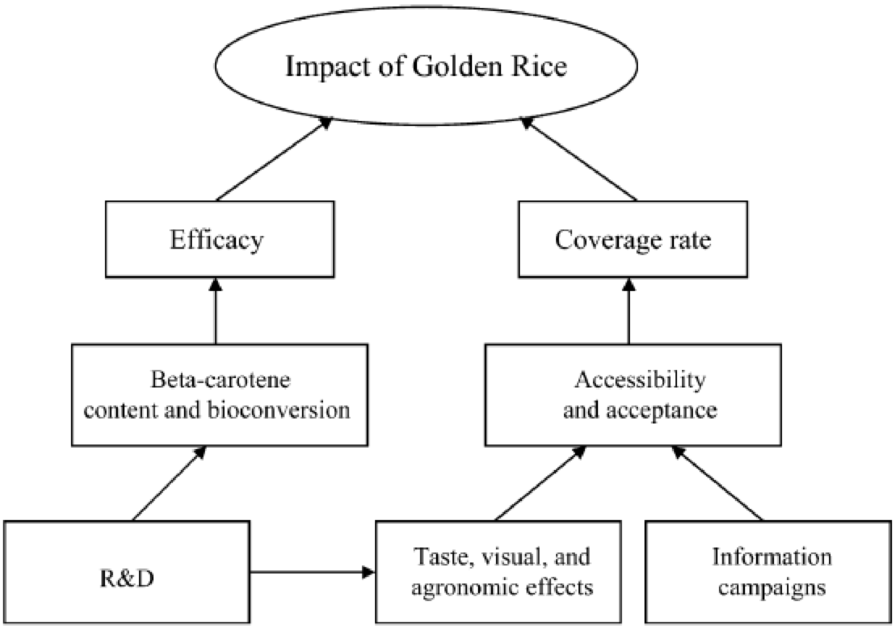


Fig. 1. Factors influencing the impact of Golden Rice.

Source: Zimmermann and Qaim (2004), Figure 1.

For computation of the health benefits in the present study, we have used the formula developed by Murray and Lopez (1996), which was used by Zimmermann and Qaim (2004) to study the Impact of Golden Rice Research in the Philippines.

$$DALYsLost = YLL + YLDtemp + YLDperm \quad \ldots (1)$$

Where DALY is the Disability Adjusted Life Years, YLL is the number of life years lost due to mortality, YLDtemp is the years of life with temporary disability and YLDperm is years of life with permanent disability. In this study, we have concentrated on three target groups—children under five years of age, pregnant women and lactating mothers. Furthermore, different disease levels resulting from Vitamin A deficiency (VAD) were taken into account.

Clinical vitamin A deficiency has long been linked to poor child growth on a cross-sectional basis; often the more severe the eye signs, the more severe the stunting and wasting (Sommer, 1982). Hadi et al. (2000) examined the effect of vitamin A supplementation on height and weight increments among Indonesian preschool children. Data was obtained from a randomized, double-masked, placebo-controlled trial of rural Javanese children aged 6–48 months. Children received 206 000 IU vitamin A (103 000 IU if aged < 12 months) or placebo every 4 months. Results indicated that a high-dose of vitamin A supplementation modestly improved the linear growth of the children by 0.16 cm/4 months. The effect was modified by age, initial vitamin A status, and breast-feeding status. Vitamin A supplementation improved height by 0.10 cm/4 month in children aged < 24 month and by 0.22 cm/4 month in children aged ≥ 24 month. The vitamin A–supplemented children with an initial serum retinol concentration < 0.35 mmol/L gained 0.39 cm/4 month more in height and 152 g/4 month more in weight than did the placebo group. No growth response to vitamin A was found among children with an initial serum retinol concentration ≥ 0.35 mmol/L. In non-breast-fed children, vitamin A supplementation improved height by 0.21 cm/4 month regardless of age. In breast-fed children, vitamin A supplementation improved linear growth by approximately 0.21 cm/4 month among children aged ≥ 24 months, but had no significant effect on the growth of children aged < 24 months.The study concluded that a high-dose of vitamin A supplementation improves the linear growth of children with very low serum retinol and the effect is modified by age and breast-feeding.

Kimani-Murage et al. (2012) examined whether there is an association between vitamin A supplementation and stunting among young children in Kenya. The study used Kenya Demographic and Health Survey 2008-09 data, involving children aged 24- 35 months, a weighted sample of 1029 children. Descriptive and logistic regression analyses were conducted. The study showed that receiving vitamin A supplement was significantly associated with children’s growth. The prevalence of stunting in the study group was 46 percent, underweight 20 percent and wasting 6 percent. The prevalence of ever receiving vitamin A supplement was 78 percent. The study observed that receiving vitamin A supplement was significantly negatively associated with stunting and underweight status, adjusting for other co-risk factors. The odds of stunting were 50 percent higher (p=0.038), while for underweight were 75 percent higher (p=0.013) among children who did not receive Vitamin A supplement compared with those who did.

Sedgh et al. (2000) has shown that dietary Vitamin A intake was associated with reversal of stunting in children in Sudan. They examined the associations between dietary vitamin A intake, non-dietary factors and growth in 8174 Sudanese children ages 6–72 months who were stunted at the start of follow-up. All subjects were weighed and measured at baseline and at 6-months intervals for 18 months of follow-up. Dietary vitamin A intake during the prior 24 hours was assessed using a recall of vitamin A–containing foods at baseline and 6-months intervals. The study found that the carotenoid intake was associated with a greater incidence of reversal of stunting. Children in the highest quintile grew 13 mm more during the study period than children in the lowest quintile in multivariate analyses. The relative risk (RR) of recovery associated with vitamin A intake was greater in infants up to 1 year old than in children ≥3 years of age. The study concluded that diets rich in carotenoids may increase the rate of recovery from stunting in children. Dietary effects on growth might be strongest among very young children and those who have been most malnourished. Age, sex, breast-feeding status, socioeconomic status and severity of baseline stunting also were associated with the reversal of stunting in this population.

Hoddinott et al. (2008) quantified the effect of a nutrition intervention during early childhood on economic productivity in Guatemalan adults. They have analysed economic data from 1424 Guatemalan individuals (aged 25–42 years) between 2002 and 2004.The sample included individuals who had been enrolled in a nutrition intervention as children (aged 0–7 years) during 1969–77. The study showed that participation in the nutrition program from age zero to two years was associated with an increase of US$0.67 in men’s hourly wages, which translated into a 46 percent increase in average wages. No such increase occurred for those who were exposed to the nutrition intervention after age three.

3.2 Analytical Procedure for computation of productivity benefits

Productivity benefits of Golden Rice research in Bangladesh are estimated using ex-ante economic surplus technique. The theoretical model used to quantify productivity benefits can be explained with the help of Figure 3. The original supply curve without technological change is represented by S_0 and the demand curve by D_0. The original price and quantity are P_0 and Q_0. The supply curve shifts to S_1 due to adoption of a new technology, resulting in a new price and quantity of P_1 and Q_1. The change in consumers' surplus from the technological change is represented by the area $P_0EE_1P_1$ and the change in producers' surplus is represented by the area BE_1P_1 - AEP_0. The net benefit to producers is either positive or negative depending on the magnitude of the demand and supply elasticities. The total net economic benefits (CTS) equal the sum of the changes in producers and consumers surplus:

$$CTS = P_0EE_1P_1 + BE_1P_1 - AEP_0$$

$$= P_0EE_1P_1 + ABE_1C - P_0ECP_1$$

$$= ABE_1E$$

To measure the changes in total economic surplus, we have assumed a parallel shift in the supply curve. To estimate the changes in total economic surplus (CTS) and net present value (NPV) we have used the following formula suggested by Norton et al. (1991):

$$CTS_t = KP_0Q_0(1 + 0.5\ K\ e) \qquad \text{.... (2)}$$

$$NPV = (CTS_t - RC_t)/(1 + r)^t \qquad \text{... (3)}$$

Where,

CTS_t = change in economic surplus in time period t,

P_0 = domestic price

Q_0 = initial quantity produced

e = price elasticity of supply

K = per unit cost reduction or yield increase due to research

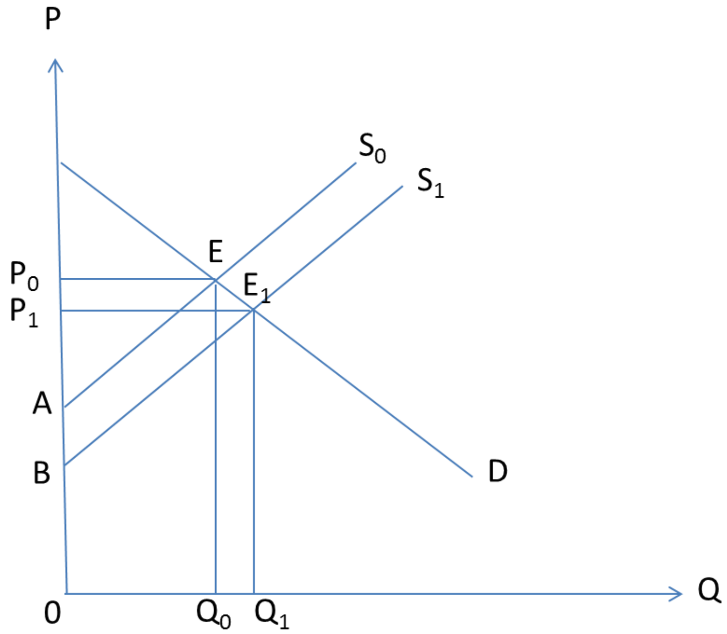
r = discount rate

RC_t = research cost in the period t.

Yearly values of K for different types of rice were determined using the following formula:

Kt = (Projected percentage change in yield) * (Probability of research success in percentage) * (Adoption rate in percentage in year t) * (Percent intensification).

Figure 3: Conceptual Framework to Quantify the Productivity Impact of Golden Rice Research in Bangladesh



Source:

Basic parameters and assumptions used for the calculation of productivity impacts of Golden Rice are summarized in Table 1.

Table 1: Basic Parameters and Assumptions used for Calculation of Productivity Impacts of Golden Rice

Parameter	Value
Yield gain (%)	10
Supply Elasticity	0.60
Demand Elasticity	-0.20
Rice Price (USD/ton)	500
Probability of Success	1.0
Year of Release for Cultivation	2018
Economic Life of Golden Rice after Release	
Optimistic Scenario	15 Years
Conservative Scenario	10 Years

Costs and Benefits

Activities related to Golden Rice research, technology dissemination, awareness building, knowledge dissemination and service delivery (seed and other inputs) are complementary to each other. Costs for all the related activities have been measured for adaptive research for Golden Rice, multiplication of Breeders Seed and Foundation Seed, costs for extension services for technology exchange through thr Department of Agriculture Extension (DAE), ICT enabled extension service and electronic and print media oriented knowledge dissemination and costs of service delivery for seed and other inputs. Resultant benefits will be achieved by producers and consumers of golden rice in Bangladesh.

The total Benefit from Golden Rice research and development was calculated as:

$$B_t = HealthB_t + YieldB_t$$

... (4)

Where, B_t is the total benefit from Golden Rice in year t, $HealthB_t$ is the health benefit from Golden Rice in year t, and $YieldB_t$ is the yield or productivity benefit from Golden Rice in year t.

Internal Rate of Return (IRR) and Benefit-Cost Ratio (BCR) from investment in Golden Rice research, extension and delivery of inputs and other services are calculated using the formula given below. The IRR is calculated as the discount rate at which the NPV is exactly zero.

$$NPV_t = \sum_{k=0}^{n} \frac{B_{t+k} - C_{t+k}}{(1+r)^k}$$

... (5)

$$0 = \sum_{k=0}^{n} \frac{B_{t+k} - C_{t+k}}{(1+IRR)^k}$$

... (6)

Benefit Cost Ratio (BCR) is the ratio of present value of benefits and costs.

$$BCR = (\sum_{k=0}^{n} \frac{B_{t+k}}{(1+r)^k}) / (\sum_{k=0}^{n} \frac{C_{t+k}}{(1+r)^k})$$

... (7)

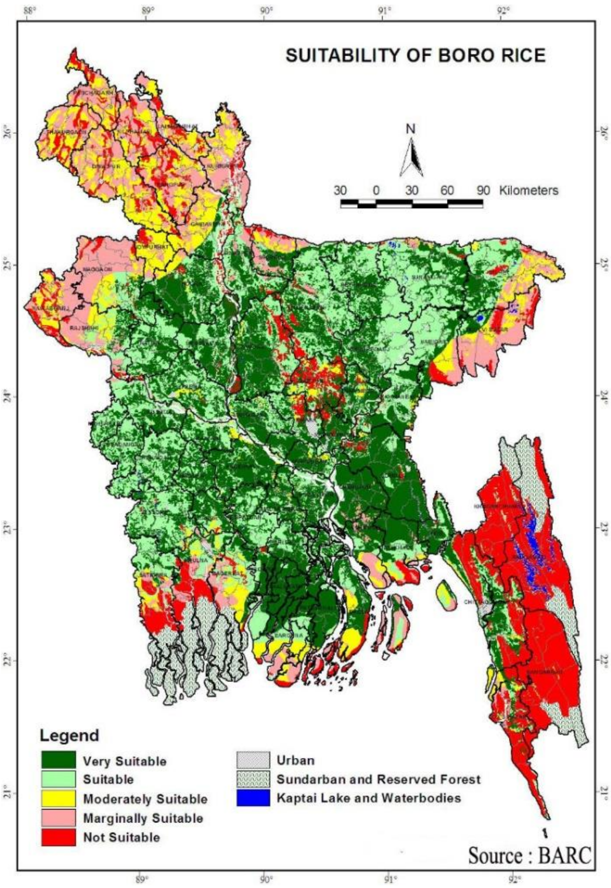
RESULTS AND DISCUSSION

The results of our analysis can be discussed under four major issues: (1) Potential Areas for Cultivation of Golden Rice, (2) Malnutrition in Bangladesh: Trends, Depth and Distribution, (3) Economic Benefits from Golden Rice Cultivation, and (4) Returns to Investment in Golden Rice.

Potential Areas for Cultivation of Golden Rice

Potential areas for Golden Rice cultivation are likely to be the locations where BRRI Dhan 29 has been grown by the farmers. Bangladesh Agricultural Research Council (BARC) has prepared a map identifying locations suitable for Boro rice cultivation in Bangladesh (Figure 4). BRRI Dhan 29 has been popularly grown in Sylhet, Chittagong, Dhaka and Rajshahi division of Bangladesh.

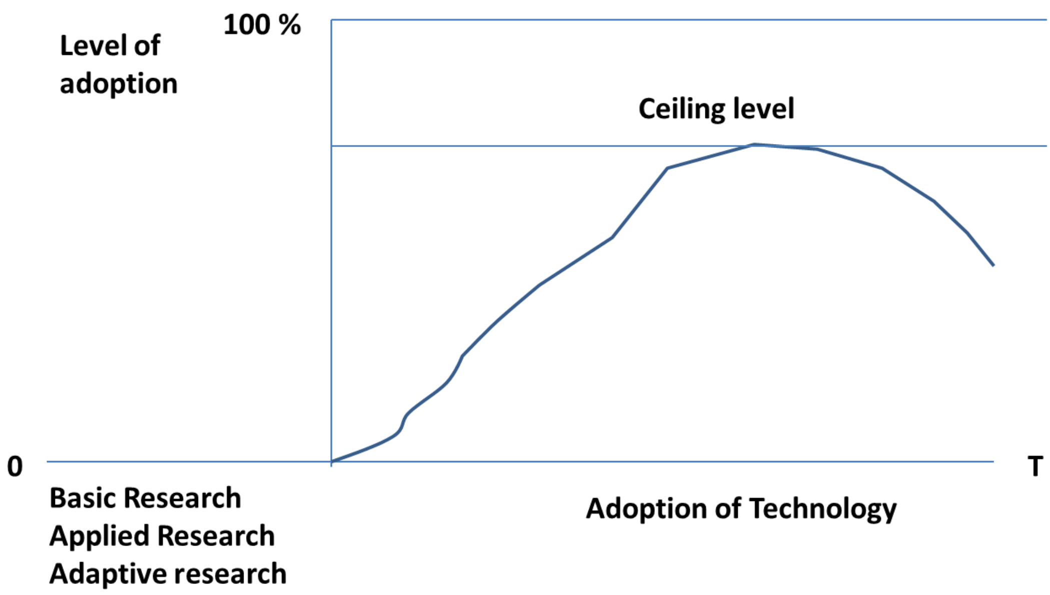
Figure 4: Areas suitable for cultivation of Boro rice in Bangladesh



Source: Bangladesh Agricultural Research Council (BARC)

Improved rice variety development, release and adoption are continued process (Figure 5). Development of the Golden Rice required several years of upstream research at the advanced research institutes in Switzerland and Germany in partnership with IRRI. It was then followed by adaptive research at the Bangladesh Rice Research Institute (BRRI) and then trials in farmers' fields will be conducted in various locations of the country. Then the variety will be released through the Seed Certification Agency in Bangladesh. After the release of the Golden Rice variety for commercial cultivation by the farmers, it is expected that farmers will start growing the variety. In the initial years, adoption will be low due to lack of knowledge and exposure among large sections of potential farmers and limited availability of seed. The adoption will increase and after some years, it will be stabilize and then decline because of availability of new crops/ varieties which will provide higher economic returns.

Figure 5: Research and Development Process of Golden Rice

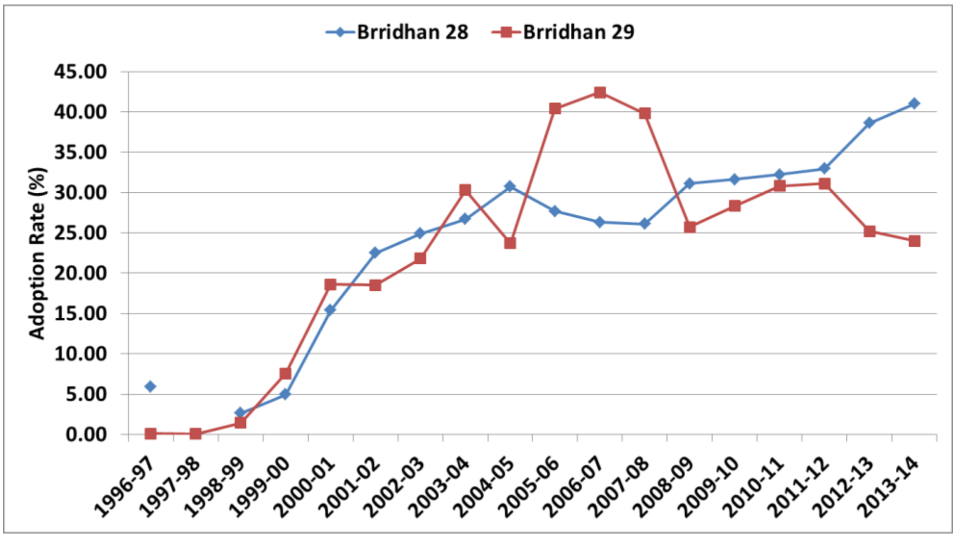


Source:

In this study, it is assumed that the adoption pathway of the Golden Rice will be more or less like the BRRI Dhan 29 (Figure 6). BRRI Dhan 29 was released in 1994. During the first three years (up to 1997/98) adoption rate was very low (less than 0.10 percent) due to lack of knowledge, exposure to the technology and limited availability of seed. In the fourth year (1998/99), adoption rate was 1.4 percent. Adoption picked up in the fifth year (7.5 percent) and adoption level increased exponentially for the next five years and reached to 30.3 percent in the year 2003-04. Then annual increase in the adoption level slowed down. The highest level of adoption (42.2 percent) was in 2006-07. The adoption level then started to decline. In 2013/14, about 20 years after the release of the variety for commercial cultivation, the adoption rate of BRRI Dhan 29 was 24.0 percent of the total Boro rice area in Bangladesh. The Golden Rice has many agronomic characteristics of BRRI Dhan 29 and is likely to provide 10 percent higher yield. Therefore, we can assume that it will have a high adoption rate like

BRRI Dhan 29. Thus, Golden Rice has the potential to reach up to 1.703 million hectares i.e., 40 percent of the Boro rice area in Bangladesh.

Figure 6: Trends in adoption rate of most popular rice varieties: Brri Dhan 28 and BRRI Dhan 29



Source: Bangladesh Rice Research Institute (BRRI)

Under Nutrition in Bangladesh

Under nutrition is prevalent in Bangladesh. About 20 percent of the children under-five years were suffering from Vitamin A deficiency in 2012. On the other hand, 23.7 percent of the pregnant women and lactating mothers suffered from vitamin A deficiency. Vitamin A deficiency can lead to stunted growth, blindness, and increased mortality due to the lack of nutrients in the body. Stunting is high among under-five children. More than 130 thousand (4.13 percent) children have been suffering from stunting. About two percent of under-five children had night blindness while more than 32 thousand children (0.02 percent of children) have been suffering from blindness. Each day about 88 children become blind in Bangladesh due to vitamin A deficiency. Vitamin A associated night blindness in children of 1-6 years of age is about 2 percent (Banglapedia, 2016).

Mohsena et al (2015) studied regional variation in maternal and childhood undernutrition in Bangladesh. Sylhet was found to have highest prevalence of undernourished mothers and children. The trends from 1996 to 2007 also established Sylhet as the poorest-performing region overall. The study concluded that Sylhet administrative division needs specially focused attention from policy-makers if the overall performance of the health, nutrition and population sector is to reach the targets set by the country.

Distribution of Vitamin A Capsule: Bangladesh Demographic and Health Surveys (BDHS) regularly collect information about Vitamin A supplementation among children. The BDHS Reports calculate percentage of children age 6-59 months who received a vitamin A capsule in the six months preceding the survey. The most recent BDHS report (BDHS2014) published in 2015 revealed that percentage of children age 6-59 months receiving vitamin A supplementation in the 6 months preceding the survey has reduced from 83.5 percent in 2007 to 59.5 percent in 2011 and then increased to 62.1 percent in 2014 (Table 2). The 2014 BDHS reported that 62 percent of children aged 6-59 months had received vitamin A supplementation in the six months before the survey. It added that the coverage for children age 9-59 months was similar (63 percent). The level of vitamin A supplementation varied across subgroups of children. It was higher among older children and children who live in urban areas. Across divisions, vitamin A supplementation was 65 percent or higher in Chittagong, Khulna, and Rangpur, but lower than 60 percent in Rajshahi and Sylhet (Table 3). The children's likelihood of receiving vitamin A increased with their mother's education and wealth status (NIPORT, Mitra and Associates, and ICF International, 2015).

Table 2: Vitamin A supplementation in Bangladesh, 1999/00 to 2014.

Year	Percentage of children age 6-59 months receiving vitamin-A supplementation in the 6 months preceding the survey	Percentage of children age 9-59 months receiving vitamin-A supplementation in the 6 months preceding the survey
1999-00	NA	80.4
2004	NA	81.8
2007	83.5	88.3
2011	59.5	61.6
2014	62.1	63.2

Source: Appendix B, Summary Indicators, Bangladesh Demographic and Health Survey 2014.

Table 3: Vitamin A supplementation in 2011 and 2014

Division	Received vitamin A capsule, 2014	Received vitamin A capsule, 2011
Barisal	64.1	71.5
Chittagong	65.0	66.3
Dhaka	62.0	49.3
Khulna	64.5	56.4
Rajshahi	56.6	66.1
Rangpur	65.5	56.0
Sylhet	55.5	69.1
BANGLADESH	62.1	59.5

Source: 2014 data were taken from Table 30, Bangladesh Demographic and Health Survey 2014; and 2011 data were taken from Table 11.8, Bangladesh Demographic and Health Survey 2011.

Bangladesh has also invested in delivering Vitamin A to the mothers of new born children. The percentage of women who received a vitamin A dose during the first two months after the birth of their most recent child in 2007 and 2011 is reported in Table 4. Postpartum vitamin A coverage has increased by 7 percentage points between 2007 and 2011 (20 percent in 2007 to 27 percent in 2011). Postpartum Vitamin A coverage has increased more in rural areas (18 percent in 2007 to 26 percent in 2011) than in urban areas (24 percent in 2007 to 30 percent in 2011).

Table 4: Vitamin A supplementation among mothers in 2007 and 2011.

Division	Received vitamin A dose postpartum, 2007	Received vitamin A dose postpartum, 2011
Barisal	23.4	24.7
Chittagong	23.4	26.8
Dhaka	16.5	24.0
Khulna	17.3	26.2
Rajshahi	19.7*	28.6
Rangpur	19.7*	35.9
Sylhet	20.1	25.8
Residence		
Rural	18.2	26.1
Urban	24.2	29.6
BANGLADESH		

Note: * data on Rangpur was reported in Rajshahi. Rangpur Division was created from the Rajshahi Divison.

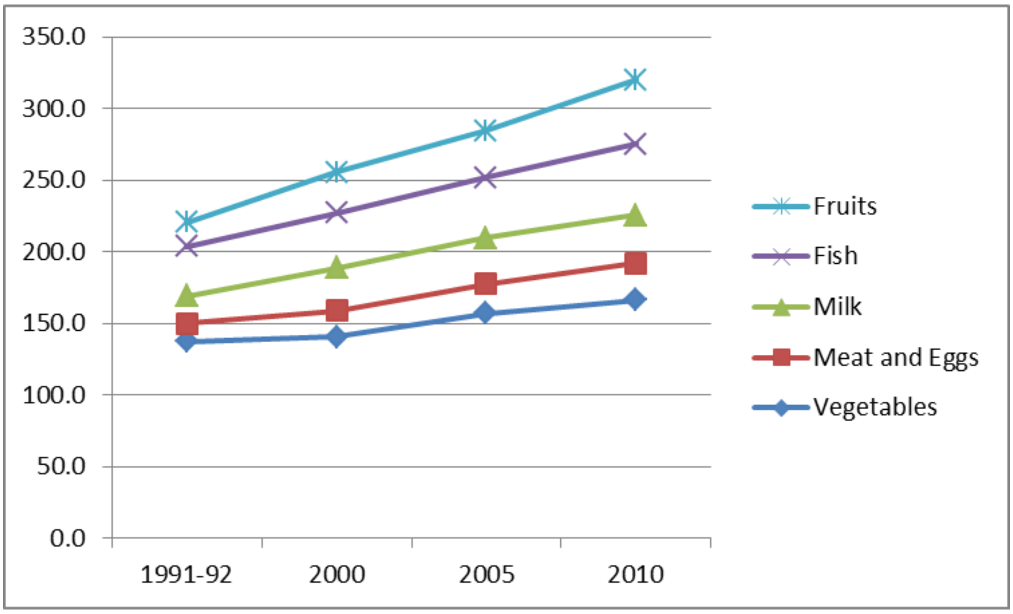
Source: 2011 data were taken from Table 11.12, Bangladesh Demographic and Health Survey 2011; and 2007 data were taken from Table 11.9, Bangladesh Demographic and Health Survey 2007.

Overall, 27 percent of women age 15-49 with a child born in the past five years received a postpartum vitamin A dose in 2011. This proportion varied by urban-rural residence, division, educational attainment, and household wealth. There was no discernible pattern with respect to the age of the women. Women in urban areas (30 percent) are more likely to receive vitamin A supplements than those in rural areas (26 percent). The percentage of women who received a postpartum vitamin A dose was highest in Rangpur (36 percent) and lowest in Dhaka (24 percent). Postpartum vitamin A supplementation increases steadily with women's educational level, ranging from 18 percent of women with no education to 41 percent of women who have completed secondary or higher education. Vitamin A supplementation was also associated with household wealth, increasing from 19 percent among mothers in the lowest wealth quintile to 35 percent among mothers in the highest quintile (NIPORT, Mitra and Associates, and ICF International, 2013).

The above findings indicate that there are substantial ongoing efforts to address the Vitamin A deficiency and significant progress has been made over time. In spite of the remarkable progress, a large number of Vitamin A deficient children and mothers could not be reached. For longer term sustainable solutions to vitamin A deficiency, the availability and affordability of vitamin A rich foods needs to be improved through food-based approaches such as homestead gardening and food fortification (BBS/UNICEF 2007, p.4). It seems Golden Rice (bio fortified with Vitamin A) fits well to this strategy. Hopefully, it will help to reach the unreached.

Consumption of Nutritional Food: There is substantial increase in consumption of nutritional food over the last two decades. Household Income and Expenditure Surveys (HIES) conducted by the Bangladesh Bureau of Statistics in various years revealed that per capita daily intake of foodgrains has decreased from 509 grams in 1991-92 to 442 grams in 2010. During the same period, per capita daily consumption of vegetables has increased by 19 grams (Figure 7). Meat consumption has doubled (increased from 12.8 grams to 25.8 grams). Milk consumption increased by 75 percent (from 19.1 grams to 33.7 grams). On the other hand, fish consumption has increased by 15 grams (from 34.5 grams to 49.5 grams). In 2010, fruits consumption was about 2.5 times than that of early nineties (increased from 16.9 grams to 44.7 grams). Consumption of edible oils was doubled (increased from 10.1 grams to 20.5 grams). Per capita consumption of poor and well-off increased both in rural and urban areas. Though per capita consumption has increased but there are significant differences in food consumption between the poor and well-off households. According to the Poverty Monitoring Surveys, poor households consumed about 25 percent less food in term of quantity and about 20 percent less in terms of calories, compared to the well-off households at the national level. Hence, economic access to food by all, particularly for the poor people of the country is indeed a major concern. Another pertinent concern is stability in food consumption particularly during rapid increase in price and during the time of natural disaster.

Figure 7: Per capita daily intake (grams) of fruits, vegetables, fish, milk, meat and eggs has increased over the last two decades (1991-2010)

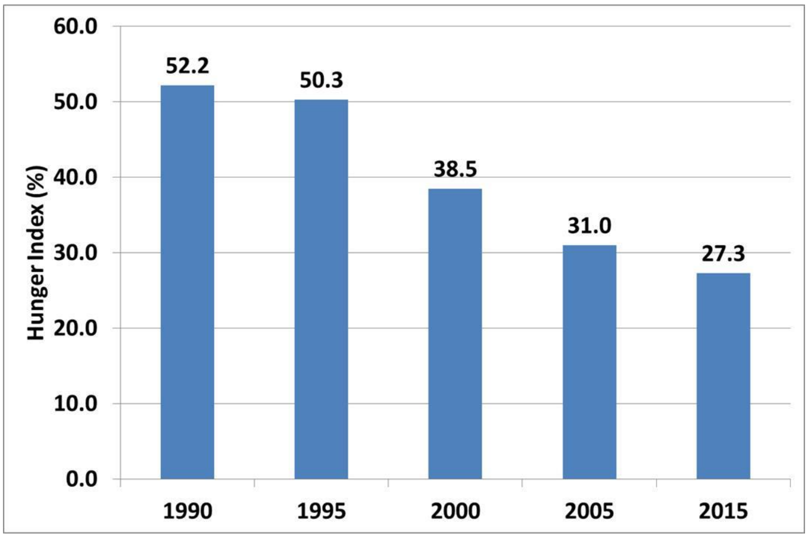


Source: Household Income and Expenditure Surveys (HIES), 1991-92, 2000, 2005 and 2010.

Bangladesh has been able to significantly reduce the hunger and malnutrition situation in the country over the last two decades. The Global Hunger Index (GHI) is a comprehensive measure to track hunger globally and by country and region (IFPRI, 2015). International Food Policy Research Institute (IFPRI) calculates the GHI each year. ***Hunger*** is usually understood to refer to the distress associated with lack of food. The Food and Agriculture Organization of the United Nations (FAO) defines food deprivation, or undernourishment, as the consumption of fewer than about 1,800 kilocalories a day—the minimum that most people require to live a healthy and productive life. In the IFPRI GHI Report, ***"hunger"*** refers to the index based on the four component indicators. Taken together, the component indicators (undernourishment, child stunting, child wasting, and child mortality) reflect deficiencies in calories as well as in micronutrients. Thus, the GHI reflects both aspects of hunger (food deprivation and malnutrition). ***Malnutrition*** refers more broadly to both under-nutrition (problems of deficiencies) and over-nutrition (problems of unbalanced diets, which include consuming too many calories in relation to energy requirements, with or without low intake of micronutrient-rich foods).The GHI ranks countries on a 100-point scale. Zero is the best score (no hunger), and 100 is the worst, although neither of these extremes is reached in practice.

Hunger index in Bangladesh has consistently declined from 52.2 in 1990 to 31.0 in 2005 and then to 27.3 in 2015 (Figure 8). During the last 10 years reduction in hunger condition was 3.7 points. It implies that in the early nineties one out of two persons was in the "hunger" category. On the other hand, one out of four persons was in "hunger" category in the 2015. This is a significant achievement. However, we have to do a lot more to eradicate hunger from the country and ensuring nutrition security for all.

Figure 8: Trends in Hunger Index in Bangladesh: 1990-2015

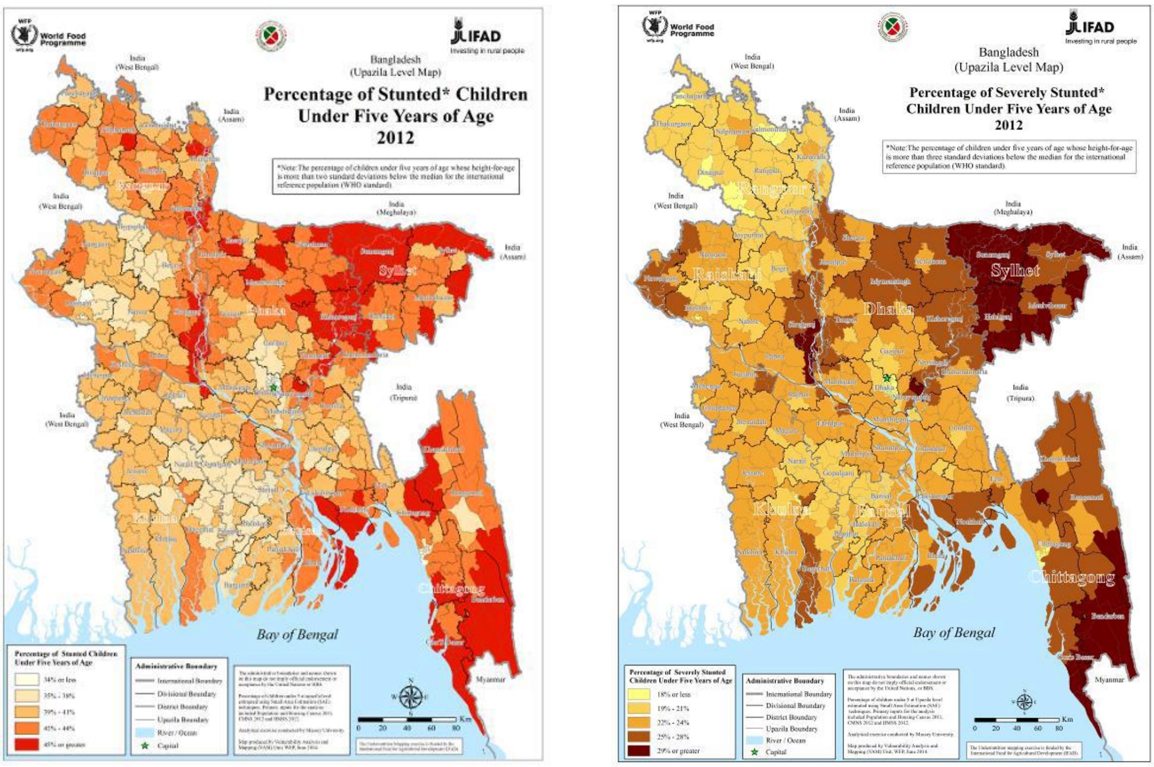


Source: IFPRI Global Hunger Index Report 2015.

There are continuing efforts among the researchers to know the underlying factors which have contributed towards improvement in nutrition situation in Bangladesh. Headey (2013) reported that from 1997 to the 2007 Bangladesh recorded one of the fastest prolonged reductions in child underweight and stunting prevalence in recorded history, 1.1 and 1.3 percentage points per annum respectively. Another study by Heady et al. (2015) has investigated the changes in child growth outcomes using five rounds of DHS surveys from 1997 to 2011. Using regression and decomposition analysis, the study concluded that rapid wealth accumulation and large gains in parental education are the two largest drivers of change, though health, sanitation, and demographic factors have played significant secondary roles.

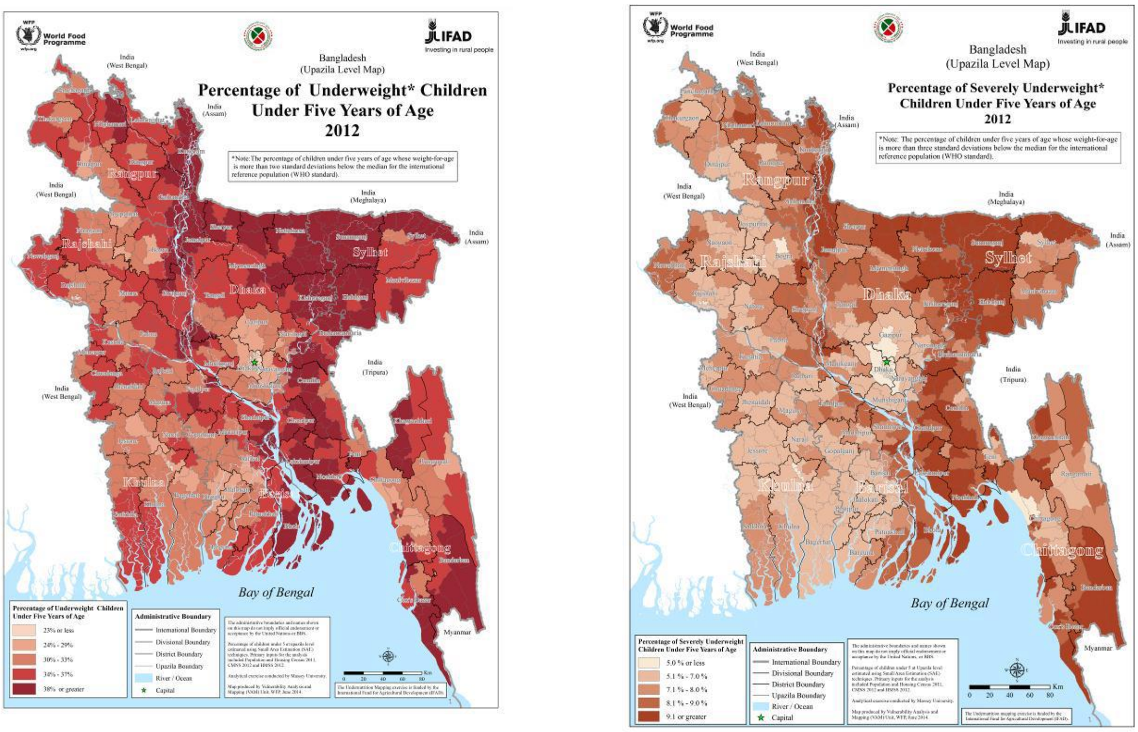
The World Food Program (WFP), Bangladesh Bureau of Statistics (BBS) and International Fund for Agricultural Development (IFAD) have jointly developed the Under Nutrition Maps of Bangladesh 2012. The percentage of stunted and severely stunted children in different sub-districts (Upazilas) of Bangladesh in 2012 is shown in Figure 9. It can be seen from the figure that there is ahigh prevalence of stunting and severe stunting in Sylhet, Dhaka and Rangpur Division. Percentage of underweight and severely underweight children in different sub-districts (Upazilas) of Bangladesh in 2012 is shown in Figure 10. It is observed that it is high in Sylhet, Dhaka and Rangpur Division.

Figure 9: Percentage of stunted and severely stunted children in Bangladesh, 2012



Source: WFP, BBS and IFAD. Under Nutrition Maps of Bangladesh 2012

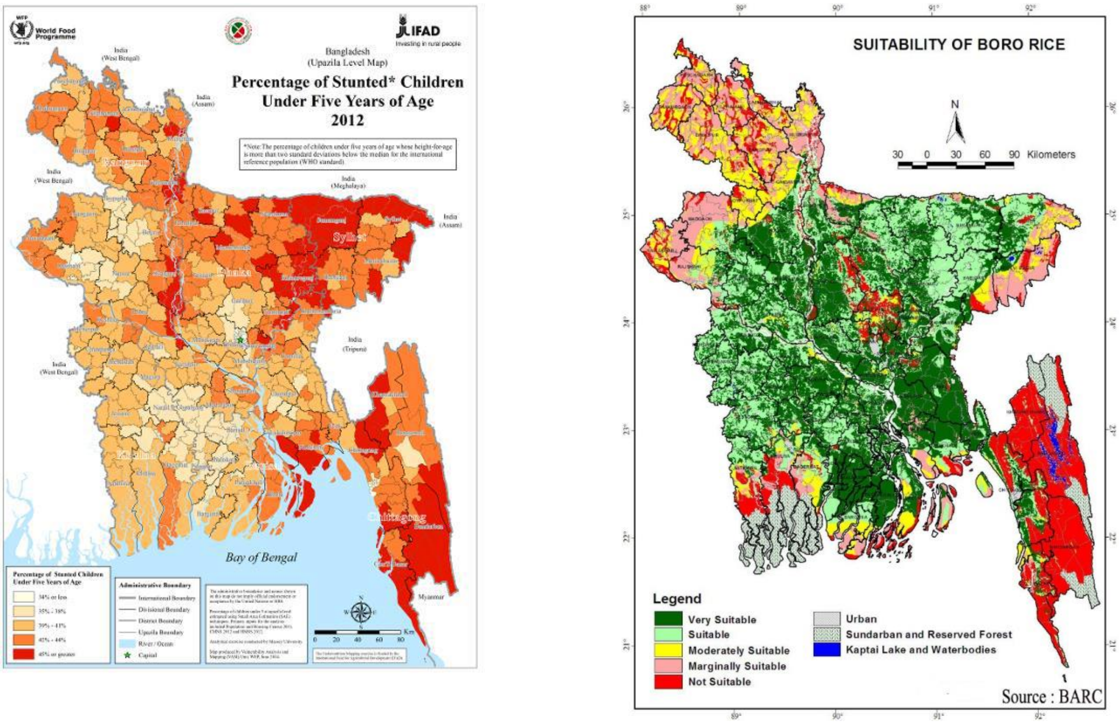
Figure 10: Percentage of underweight and severely underweight children in Bangladesh, 2012



Source: WFP, BBS and IFAD. Under Nutrition Maps of Bangladesh 2012

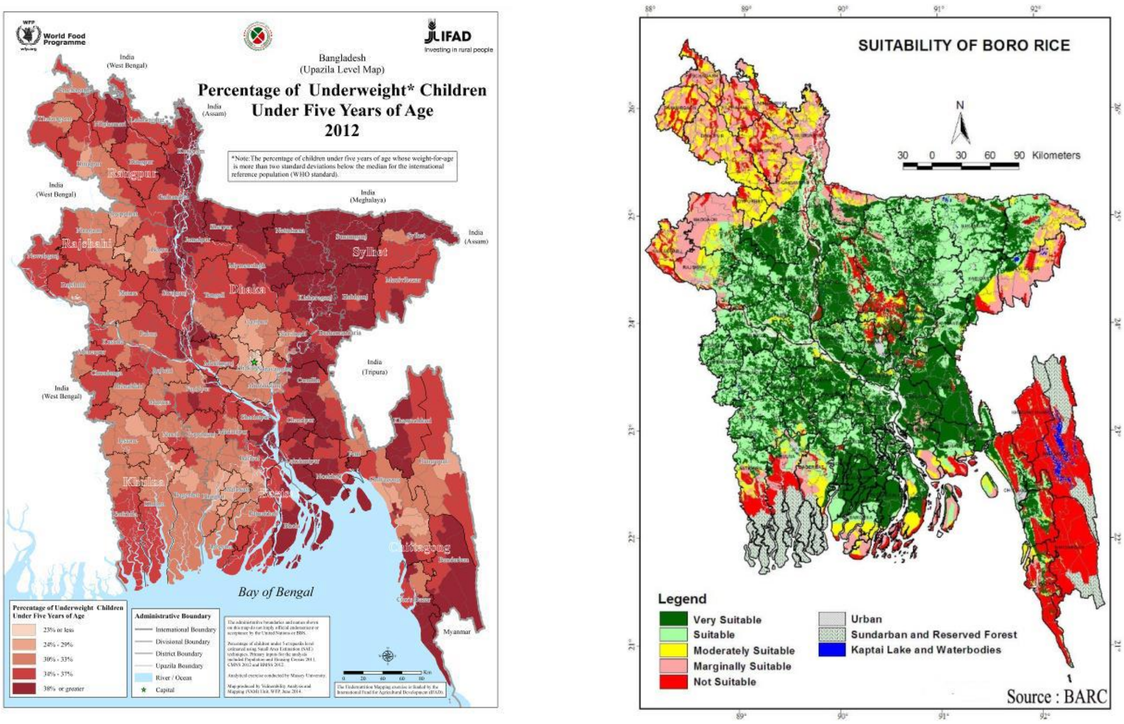
It is expected that the Golden Rice will benefit the VAD population of the country. Farmers and rural households living in the localities where Golden Rice will be produced will naturally consume it. Therefore, a comparison of potential Golden Rice cultivation areas with WFP-BBS-IFAD prepared map on distribution of stunted and underweight children under five years of age in Bangladesh in 2012 is made. We observe high prevalence of stunting and underweight (in other words, vitamin A deficiency) in the potential areas for cultivation of Golden Rice (Figure 11 and 12). Number of children below five years is high in Dhaka division and it has high suitability for cultivation of Golden Rice (Figure 13).

Figure 11: Comparison of Suitable Areas for Boro Rice cultivation and distribution of stunted children under five years of age in Bangladesh, 2012



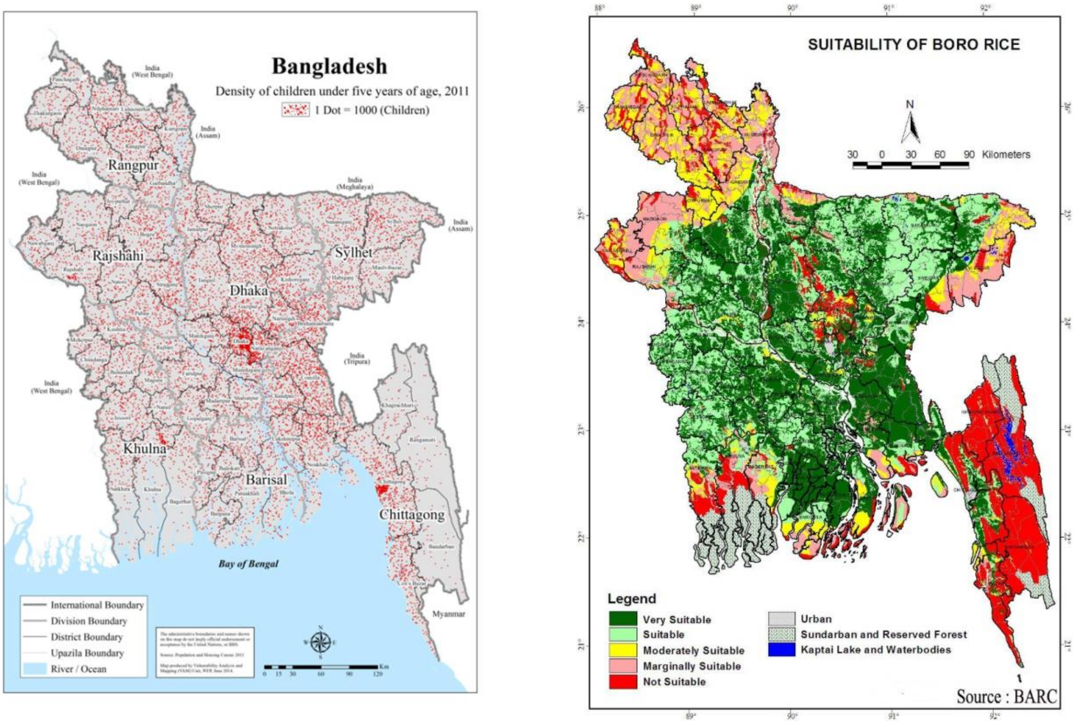
Source: WFP, BBS and IFAD. Under Nutrition Maps of Bangladesh 2012

Figure 12: Comparison of Suitable Areas for Boro Rice cultivation and distribution of underweight children under five years of age in Bangladesh, 2012



Source: WFP, BBS and IFAD. Under Nutrition Maps of Bangladesh 2012

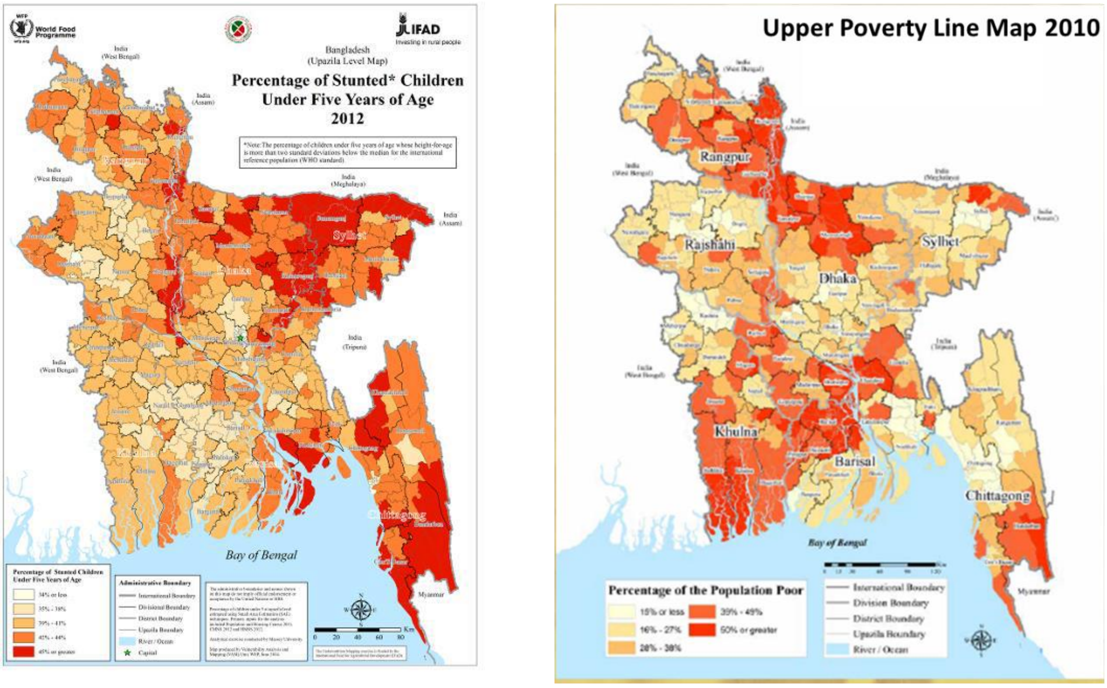
Figure 13: Comparison Suitable Areas for Boro Rice cultivation and distribution of stunted children under five years of age in Bangladesh, 2012



Source: WFP, BBS and IFAD. Under Nutrition Maps of Bangladesh 2012

Critics of Golden Rice argue that people who have a deficiency in Vitamin A can consume food items such as fruits, vegetables and meats which have Vitamin A, rather than having rice burdened to deliver vitamin A. This would be a good solution. Unfortunately, the data suggest that this is not possible for Bangladesh at this point in time. A comparison of distribution of stunted children under-five years of age in 2012 and poverty situation in 2010 has revealed that poverty rates were relatively less in different upazilas of Sylhet and Dhaka Division but prevalence of stunted children was relatively high in these areas (Figure 14). On the other hand, poverty rates were higher in different Upazilas of Khulna Division but prevalence of stunting among children was relatively at a lower rate. This provides us a clear indication that reductions in poverty and hunger alone are not sufficient to solve the problem of undernutrition. We need to take additional measures. As mentioned earlier, areas suitable for Golden Rice in Bangladesh are also the locations which have higher rates of stunting among under-five children. Therefore, Golden Rice is expected to benefit the people who are suffering from Vitamin A deficiency.

Figure 14: Comparison distribution of stunted children under five years of age in 2012 and poor population in 2010



Source: WFP, BBS and IFAD. Under Nutrition Maps of Bangladesh 2012

Economic Benefits from Golden Rice Cultivation

How much will the net return from investment on Golden Rice be? To answer this, annual investment requirement (Total Costs) was calculated. Similarly, potential benefits were calculated on an annual basis. As mentioned earlier, Golden Rice will provide two types of benefits: (i) health benefit and (ii) productivity benefits. Following the procedure mentioned in Section 3, annual benefits were measured for both productivity enhancement and health improvement. These were summed up to get the Total Benefits on an annual basis. Then, the difference between Total Benefits and Total Costs was calculated to derive the Net Benefits from Golden Rice on an annual basis. Estimated value of Costs, Benefits and Net Benefits were discounted using three discount rates (3%, 5% and 10%) to obtain the present value. These calculations were done under two scenarios: Optimistic and Conservative Scenario. Under the Optimistic Scenario, it is assumed that the Golden Rice variety, after its release for cultivation in the farmers' field, will have an economic life for 15 years. On the other hand, Conservative Scenario assumes that the Golden Rice variety will have an economic life of 10 years in the farmers' field after its release.

Health Benefits: The Global Burden of Disease estimates the number of DALYs lost each year in Bangladesh due to Vitamin A deficiency is 25,065 exclusively for children under the age of 5. Given the high calorific intake in Bangladesh from rice, we assume that the presence of Golden Rice in a diet is able to eliminate VAD, the amount of DALYS averted each year depends on the coverage of golden rice. Each 1% increase in coverage reduces annual DALYs by 251. At a value of one GDP per DALY (USD 1285) this implies a value of 0.3m per year for 1% adoption of golden rice. In the optimistic scenario this benefit equals $40m dollars at the 5% level, while the equivalent value for the conservative scenario is $25m.

Stunting Benefits: The literature outlined previously shows a relationship between Vitamin A consumption and stunting prevalence. Using the findings from Kimani-Murage et al. (2012) – namely a 50% increase in the odds ratio of being stunted, having not had Vitamin A, the implied reduction in stunting incidence is 10% in Bangladesh if a diet contains golden rice. To calculate the benefits of stunting we use the approach in Horton and Hoddinott (2015). If a child is not stunted, this leads to a 59.4% increase in wages by the time that person enters the labor force at 18 – and the benefit is the net present value of that stream of increased wages to age 60. We adjust this figure by the labor force participation rate in Bangladesh of 70% (ILO). Each 1% adoption rate of Golden rice leads to about 5400 fewer stunted children in Bangladesh each year, who when older would experience increased wages over their lifetime valued at $3600 at the 5% discount rate. Accordingly, each percentage increase in the adoption rate of golden rice leads to a 19.8m USD benefit from reduced stunting (at the 5% discount rate). In the optimistic scenario this benefit equals $2,223m dollars at the 5% level, while the equivalent value for the conservative scenario is $2,687m dollars.

Productivity Benefits: Annual costs and benefits from Golden Rice research and development in Bangladesh are reported in Table 5. Net Present Value of benefits and returns to Investment are given in Table 6. Present value of benefits from productivity enhancement by 10 percent and subsequent reduction in per unit cost of production under Optimistic Situation was $2,927m dollars (discounted at 3 percent), $2,090m dollars (discounted at 5 percent) and $1,496m dollars (discounted at 10 percent). In the case of Conservative Scenario, it was $1,739m dollars (discounted at 3 percent), $1,290m dollars (discounted at 5 percent) and $630m dollars (discounted at 10 percent).

Table 5: Costs and Benefits from Golden Rice R&D in Bangladesh: 2010-2032

Year	R&D Cost (m USD)	Productivity Benefit (m USD)	Health Benefit (m USD)	Stunting Benefit (m USD) - 5%	Total Benefit ('000 USD)
2010	1.50		-		-
2011	1.50		-		-
2012	1.50		-		-
2013	1.50		-		-
2014	1.50		-		-
2015	1.50		-		-
2016	1.50		-		-
2017	0.50		-		-
2018	0.50	1	0.0	1	3
2019	0.50	1	0.0	1	2
2020	0.50	24	0.5	26	50
2021	0.10	129	2.5	138	270
2022	0.10	322	6.1	342	670
2023	0.10	323	6.1	343	672
2024	0.10	364	6.9	387	758
2025	0.10	483	9.2	513	1,005
2026	0.10	531	10.1	564	1,105
2027	0.10	581	11.0	618	1,210
2028	0.10	576	10.9	612	1,199
2029	0.10	508	9.7	540	1,058
2030	0.10	426	8.1	453	887
2031	0.10	364	6.9	387	758
2032	0.10	316	6.0	336	657

Source: Author's calculation.

Table 6: Net Present Value of Benefits and Returns to Investment on Golden Rice Research and Development in Bangladesh: 2010-2032 (in Million US Dollars)

Indicators	3% Discount	5% Discount	10% Discount	IRR (%)
Optimistic Scenario: 15 Years				70.5
Total R&D Costs	11.6	10.5	8.4	
Health + Stunting Benefit	5767.4	2262.3	276.0	
Productivity Benefit	2927.4	2089.6	937.6	
Total Benefits	8695	4352	1214	
Net Benefit (NPV)	8683.2	4341.5	1205.2	
Benefit Cost Ratio (BCR)	**751**	**416**	**145**	
Conservative Scenario: 10 Years				69.86
Total R&D Costs	11.31	10.28	8.29	
Health + Stunting Benefit	3,426	1,397	186	
Productivity Benefit	$1,739	$1,290	$630	
Total Benefits	5,165	2,687	816	
Net Present Value (NPV)	5,154	2,677	808	
Benefit Cost Ratio (BCR)	**457**	**261**	**98**	

Source: Author's calculation.

Investment: Present value of investment (costs) under Optimistic Situation was 11.58 million dollars (discounted at 3 percent), 10.46 million dollars (discounted at 5 percent) and 8.35 million dollars (discounted at 10 percent) (Table 6). In the case of Conservative Scenario, present value of costs (investment) was 11.31 million dollars (discounted at 3 percent), 10.28 million dollars (discounted at 5 percent) and 8.29 million dollars (discounted at 10 percent).

Returns to Investment in Golden Rice

The internal Rate of Return (IRR) from investment in Golden Rice research is estimated under the Optimistic and Conservative Scenario. Under the Optimistic Scenario, it is assumed that the Golden Rice variety, after its release for cultivation in the farmers' fields, will have an economic life of 15 years. On the other hand, the Conservative Scenario assumes that the Golden Rice variety will have an economic life of 10 years in the farmers' fields after its release. Value of estimated IRR was 70.50 percent for Optimistic Scenario and 69.86 percent under Conservative Scenario (Table 6). In other words, from each 100 dollars invested on Golden Rice R&D will provide an annual return of 70.5 dollars, if the variety is cultivated for 15 years. On the other hand, returns from each 100 dollar invested on Golden Rice R&D will give annual return of 69.86 dollars.

Under the Optimistic Scenario, the Benefit Cost Ratio (BCR) is 751 when the benefits and costs are discounted at 3 percent indicating that each dollar investment on Golden Rice research and development will generate a social return which wills be 751 dollars (Table 6). If we use a higher discount rate, then the BCR naturally reduces. It becomes 416 when benefits and costs are discounted at 5 percent. On the other hand, the value of BCR will be 257 when discount rate is 10 percent. Under Conservative Scenario, estimated BCR at 3 percent discount rate is 446. BCR will be reduced to 257 at 5 percent discount rate and 98 at 10 percent discount rate. Thus, it is clear that each dollar invested on Golden Rice research and development activities will generate at least 98 dollars as social returns for every dollar invested.

CONCLUSION

A systematic review of the trends, distribution and causes of Vitamin A deficiency (VAD) in Bangladesh have confirmed that research on Vitamin A rich 'Golden Rice' will contribute positively towards addressing the VAD problem, particularly for mothers, pregnant women and children. Investment on Golden Rice will provide substantial benefit. Net Present Value (NPV) of benefits, at the 5% discount rate, can reach up to $4,300m million under the Optimistic Scenario and up to $2,687m dollars under the Conservative Scenario. Benefits will be derived through improvement in nutrition situation via reduction in Vitamin A deficiency, and increase in rice productivity and reduction in per unit cost of rice production. The Internal Rate of Return (IRR) will be around 70 percent, indicating that the annual return from investment on Golden Rice research and development activities will be 70 percent. Therefore, activities related to Golden Rice research should be continued and necessary policy support must be rendered by policy makers and other stakeholders. At the same time, BRRI should monitor progress in the cultivation of Golden Rice (GR-2 E BRRI dhan29) and the effects of this genetically engineered product on human health and the environment.

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