Health benefits of biofortification

an economic ex-ante evaluation of iron-rich rice and wheat in India

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Overview

- Micronutrient malnutrition – the problem
- Conventional approaches and solutions
- Biofortification, a new approach
- Quantifying the problem with DALYs
- The impact: food intake & prevalence rates
- The cost-effectiveness: Dollars & DALYs
- CBA: biofortification as an investment
- Conclusion and outlook
Micronutrient malnutrition

Here: case of iron deficiency anaemia (IDA)

Functional outcomes of IDA

- impaired physical activity
- impaired mental development
- stunting
- maternal mortality

- stillbirths
- child deaths due to a lack of breastfeeding and care

DALYs lost due to a variety of diseases and injuries, out of a total of 1,379 m DALYs lost in 1990 (Murray and Lopez 1996).
Conventional approaches

- Pharmaceutical supplementation
  - Targeted prevention of micronut. deficiencies
  - Treatment of severely deficient individuals
  - Medical infrastructure necessary
  - Recurrent costs for supplements
  - Political commitment/monitoring needed
  - Participation/compliance required

- Industrial fortification
  - Potentially easy and cheap prevention
  - Wide potential coverage
  - Central food-processing facilities necessary
  - Suitable food and fortificant required
  - Recurrent costs for addition of fortificant
  - Political commitment/monitoring required
Conventional approaches

- Pharmaceutical supplementation
- Industrial fortification
- Food-based approaches
  - Promotion of home gardens & small livestock
  - Promotion of home-processing techniques
  - Nutrition education & behaviour change
  - Sustainable, empowering, drastic, little studied

A new approach

- Biofortification
  - Wide potential coverage
  - Targeting of remote & rural populations
  - Self-targeting through focus on staples
  - Little continuous commitment & funding needed
  - Continuous benefit stream
  - Subtle, sustainable – and potentially cheap?
How to measure social benefits of plants if they cannot be captured through the price?
How to measure health improvements across different diseases inclusive death?
How to measure improvements below the threshold of head-count approaches?

By defining a common unit for “health”

A disease can be seen as a state in a continuum b/w complete health & death
With these endpoints the relative severity of diseases can be established & normalised
This state can be temporary or permanent
Death is an extreme, permanent state

The norm are healthy lives; losses are measured in Disability-Adjusted Life Years
Formally these DALYs lost are calculated thus:

$$
DALY_{lost} = \sum_j T_j M_j \left( \frac{1-e^{-rL_j}}{r} \right) + \sum_i \sum_j T_j I_i D_j \left( \frac{1-e^{-rd_i}}{r} \right)
$$

where $j$ denotes the target group and $i$ the disease, $T$ is the size of the target group, $M$ the mortality rate, $L$ is remaining life expectancy, $r$ the discount rate, $I$ the incidence rate, $D$ the disability weight, and $d$ the duration of the disease.

→ Biofortification is expected to decrease $M$ and $I$
DALYs

Formally these DALYs lost are calculated thus:

\[
DALY_{lost} = \sum_j T_j M_{ij} \left(1 - e^{-\tau_{ij}}\right) + \sum_i \sum_j T_{ij} D_{ij} \left(1 - e^{-\nu_{ij}}\right)
\]

... and the target groups \( j \) are:
- children \( \leq 5 \) years of age
- children aged 6-14 years
- women aged 15+ years
- men aged 15+ years

### Diseases / functional outcomes

<table>
<thead>
<tr>
<th>Diseases / functional outcomes</th>
<th>Target groups</th>
<th>DA-weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stunting (severe)</td>
<td>children ( \leq 5 ) years</td>
<td>0.001</td>
</tr>
<tr>
<td>Impaired mental development (moderate)</td>
<td>children ( \leq 5 ) years</td>
<td>0.006</td>
</tr>
<tr>
<td>Impaired mental development (severe)</td>
<td>children ( \leq 5 ) years</td>
<td>0.024</td>
</tr>
<tr>
<td>Impaired physical activity (moderate)</td>
<td>children ( \leq 5 ) years</td>
<td>0.011</td>
</tr>
<tr>
<td></td>
<td>children 6-14 years</td>
<td>0.011</td>
</tr>
<tr>
<td></td>
<td>women 15+ years</td>
<td>0.011</td>
</tr>
<tr>
<td></td>
<td>men 15+ years</td>
<td>0.011</td>
</tr>
<tr>
<td>Impaired physical activity (severe)</td>
<td>children ( \leq 5 ) years</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td>children 6-14 years</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td>women 15+ years</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>men 15+ years</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Based on the GBD and own extrapolations
Impact

- How to determine the expected decrease in mortality rates $M$ and incident rates $I$?

- The specified diseases are functional outcomes of iron deficiency

- Iron deficiency is a form of malnutrition, i.e. a consequence of insufficient iron intake

- The iron intake for each target group can be ascertained

Impact

- We calculated iron intakes based on data from national, representative surveys for
  - food expenditure (prices & quantities)
  - household composition (adult equivalents)
Impact

- We calculated iron intakes based on data from national, representative surveys
- Disaggregated information takes account of differing food consumption patterns
- We used India-specific food composition tables (Gopalan et al. 1989)
- We obtained figures for iron intake at the individual level

Impact

- Based on individualised data for iron intake and given information on prevalence rates
- We derived outcome-specific cut-off levels for iron intake below which an individual is assumed to suffer from the outcome
- With a higher intake more individuals cross the cut-off level & prevalence rates decline
Current prevalence rates for moderate IDA severe IDA

<table>
<thead>
<tr>
<th>Target group</th>
<th>Current prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>children ≤ 5 years</td>
<td>0.275</td>
</tr>
<tr>
<td>children aged 6-14 years</td>
<td>0.156</td>
</tr>
<tr>
<td>women 15+ years</td>
<td>0.074</td>
</tr>
<tr>
<td>men 15+ years</td>
<td>0.037</td>
</tr>
</tbody>
</table>

Based on NFHS-2 and NIN data

- Maternal mortality is 540 deaths per 100,000 live births
- 5% of this figure is assumed to be due to severe IDA
- 30% of maternal deaths result in stillbirths
- 13% of surviving & otherwise breastfed infants die later
Impact

- We used the new prevalence rates to calculate the DALYs lost with biofortification.
- For the improved iron intake we had to make assumptions about the success:
  - of biofortifying the crops and
  - of disseminating the crops.

- Our assumptions are partly based on estimations of third parties (breeders) and partly on our own assessment.
- We used a pessimistic & optimistic scenario.
### Impact

<table>
<thead>
<tr>
<th></th>
<th>Iron-rich rice</th>
<th></th>
<th>Iron-rich wheat</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pessimistic</td>
<td>optimistic</td>
<td>pessimistic</td>
<td>optimistic</td>
</tr>
<tr>
<td>Increase in iron content</td>
<td>50%</td>
<td>300%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Bioavailability</td>
<td></td>
<td>unchanged</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share in production</td>
<td>42.5%</td>
<td>85%</td>
<td>47.5%</td>
<td>95%</td>
</tr>
<tr>
<td>Full adoption in</td>
<td>10 yrs</td>
<td>7 yrs</td>
<td>7 yrs</td>
<td>5 yrs</td>
</tr>
</tbody>
</table>

*Based on information from breeders and own assumptions*

- With these assumptions we could establish new prevalence rates and calculate the number of DALYs lost for each scenario and for each crop.
- The sum of the individual impacts of rice & wheat is bigger than the combined impact.
- Here we will focus on the results for biofortification of both rice and wheat.
Impact

<table>
<thead>
<tr>
<th>Status quo</th>
<th>DALYs lost due to iron deficiency</th>
<th>DALYs gained through biofortification</th>
<th>Reduction of the burden of iron deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status quo</td>
<td>4.0 m</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Pessimistic scenario</td>
<td>1.8 m</td>
<td>2.2 m</td>
<td>-54 %</td>
</tr>
<tr>
<td>Optimistic scenario</td>
<td>0.4 m</td>
<td>3.5 m</td>
<td>-89 %</td>
</tr>
</tbody>
</table>

Own calculations

Impact

DALYs lost by target group

- men 15+ (225,460)
- mothers (181,295)
- women 15+ (407,364)
- children 6-14 (467,585)
- children <= 5 (2,640,548)
- stillbirths (58,274)
Impact

- **DALYs lost by functional outcome**
  - Maternal mortality (181,295)
  - Stunting (22,753)
  - Severely impaired physical activity (817,562)
  - Moderately impaired physical activity (1,025,893)
  - Severely impaired mental development (599,630)
  - Moderately impaired mental development (1,274,213)
  - Child death (907)

Impact

<table>
<thead>
<tr>
<th>Scenario</th>
<th>DALYs lost due to iron deficiency</th>
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</table>

Own calculations
Cost-effectiveness

- Juxtaposing DALYs saved and costs gives the cost-effectiveness of biofortification...
- ... expressed in “Dollars per DALY”, i.e. this gives the “price” of one healthy life year
- But what are these costs of biofortification?
  - basic R&D and testing (issue of attribution)
  - adaptive breeding, dissemination & extension
  - maintenance breeding

### Problem solutions
- biofortification
- DALYs
- impact
- cost-effectiveness
- CBA

### Cost-effectiveness

<table>
<thead>
<tr>
<th></th>
<th>Rice pessimistic</th>
<th>Rice optimistic</th>
<th>Wheat pessimistic</th>
<th>Wheat optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual basic R&amp;D costs</td>
<td>0.6 m US$</td>
<td>0.35 m US$</td>
<td>0.55 m US$</td>
<td>0.3 m US$</td>
</tr>
<tr>
<td>Duration of basic R&amp;D</td>
<td>10 years</td>
<td>9 years</td>
<td>11 years</td>
<td>10 years</td>
</tr>
<tr>
<td>Annual country-specific costs</td>
<td>0.5 m US$</td>
<td>0.2 m US$</td>
<td>0.5 m US$</td>
<td>0.2 m US$</td>
</tr>
<tr>
<td>Duration of country-specific activities</td>
<td>5 years</td>
<td>3 years</td>
<td>5 years</td>
<td>3 years</td>
</tr>
<tr>
<td>Annual maintenance costs</td>
<td>0.2 m US$</td>
<td>0.1 m US$</td>
<td>0.2 m US$</td>
<td>0.1 m US$</td>
</tr>
<tr>
<td>Duration of maintenance</td>
<td>15 years</td>
<td>17 years</td>
<td>15 years</td>
<td>17 years</td>
</tr>
</tbody>
</table>

Based on the budget of the Challenge proposal, information from breeders and own assumptions.
Problem  solutions  biofortification  DALYs  impact  cost-effectiveness  CBA

Cost-effectiveness

<table>
<thead>
<tr>
<th></th>
<th>Present costs</th>
<th>Present value of DALYs saved</th>
<th>Cost per DALY saved</th>
<th>Average annual cost per inhabitant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pessimistic scenario</td>
<td>17.2 m US$</td>
<td>18.4 m DALYs</td>
<td>93 Cents</td>
<td>1/8 Cent</td>
</tr>
<tr>
<td>Optimistic scenario</td>
<td>7.8 m US$</td>
<td>33.3 m DALYs</td>
<td>23 Cents</td>
<td>1/20 Cent</td>
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Based on own calculations

➔ the World Bank rates health interventions as “highly cost-effective” that cost between US$ 50 and **US$ 150 per DALY saved** *(World Development Report 1993)*

Average annual cost per capita is only between 1/8 and 1/20 Cent, i.e.

- 8 or 20 people **together** only need to pay **1 Cent** per year
Cost-benefit analysis

- Biofortification is very cost-effective and costs of saving one DALY are extremely low.
- But “DALYs” are a unit that needs to be explained;
- many decision makers are used to other, financial indicators
- For advocacy purposes a CBA might be more appropriate

To carry out a CBA, the benefits need to be expressed in monetary terms,
- i.e. a Dollar-value needs to be attached to one healthy life year saved
- Other studies use annual per capita income
- or standard values of US$ 1,000 (or 500)
- The Indian per capita GNI is US$ 480
Cost-benefit analysis

- This is only a pragmatic step and not meant to determine the intrinsic value of life...
- With our two-scenario approach we used the lower value for the pessimistic scenario and the higher value of US$ 1,000 per DALY saved for the optimistic scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Present costs</th>
<th>Present benefits</th>
<th>Benefit-cost ratio</th>
<th>Internal rate of return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pessimistic scenario</td>
<td>17.2 m US$</td>
<td>8,818 m US$</td>
<td>513</td>
<td>68 %</td>
</tr>
<tr>
<td>Optimistic scenario</td>
<td>7.8 m US$</td>
<td>33,342 m US$</td>
<td>4293</td>
<td>120 %</td>
</tr>
</tbody>
</table>

Based on our calculations

- Studies on industrial fortification found benefit-cost ratios of 200, 79, 36 or less.
- Bouis (2002) found a ratio of 19-85 for iron biofortification (or an IRR of 29-45%).
Problem → solutions → biofortification → DALYs → impact → cost-effectiveness → CBA

Cost-benefit analysis

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Based on own calculations

- Bouis (2002) found a ratio of 19-85 for iron biofortification (or an IRR of 29-45%)
- Zimmermann & Qaim (2004) found an IRR of 66-133% for β-carotene biofortification

Conclusion

- Biofortification has the potential to substantially reduce the burden of IDA
- This can be done at very low costs...
- ... and with very high returns...
- ... even and especially when compared to alternative interventions
- Biofortification should become a standard intervention in the “tool-box” of health policy
Conclusion

- To fully unfold their cost-effectiveness and their potential, iron-rich rice & wheat need to be adopted on as big a scale as possible
- This would allow focusing the other interventions on the severest cases
- For iron-rich cereals no change in colour, taste, cooking-qualities, etc. is expected; consumer acceptance is less an issue

Conclusion

- The “high-iron trait” is expected to be compatible with high yields
- To be successful it is “only” necessary to incorporate this trait into the most popular HYVs, i.e. in their successor varieties, ...
- ... and to facilitate their dissemination (extension, pricing, subsidised seeds)
Conclusion

- Then biofortification could carry forward the benefits agricultural research already brought to the Indian society with the Green Revolution,
- and biofortification could carry forward the benefits nutrition interventions already achieved through the iodisation of salt

Thank you for your attention!
Back-up

DALY framework for iron deficiency

- Functional outcomes of IDA
  - impaired physical activity (moderate & severe)
  - imp. mental development (moderate & severe)
  - stunting (severe)
  - increased maternal mortality
    - stillbirths
    - child deaths due to lack of breastfeeding and care
DALY framework for iron deficiency

- Assumptions to derive prevalence rates
  - half of all anaemia is due to ID, for infants and small children it is 60%
  - moderate and severe IDA always cause the related functional outcomes
  - 50% of the prevalence rate for women can be used as proxy for men
  - 5% of maternal mortality is due to ID
    - 30% of maternal deaths lead to stillbirths
    - 13% of children ≤ 5 years who are not breastfed die

- Assumptions to derive incidence rates
  - incidence rate = prevalence rate / duration
    - if duration of a disease is 0.5 years, then prevalence * 2 = incidence
    - if duration of a disease is 2 years, then prevalence / 2 = incidence
  - incidence rate of permanent diseases = prevalence in first age cohort / population size
    - if 30% of population has disease (= prevalence), 30% of “newcomers” must get it (= incidence)
DALY framework for iron deficiency

- Target groups for IDA
  - children ≤ 5 years of age
  - children aged 6-14 years
  - women aged 15+ years
  - men aged 15+ years
  - pregnant women

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<td>0.09</td>
</tr>
</tbody>
</table>

*Based on the GBD and own extrapolations*
DALY framework for zinc deficiency

- Functional outcomes of zinc deficiency
  - diarrhoea
  - pneumonia
  - stunting
  - increased mortality

DALY framework for zinc deficiency

- Assumptions to derive incidence rates
  - 18% of diarrhoea is due to zinc deficiency
  - 41% of pneumonia is due to zinc deficiency
  - 1 cm of all stunting is due to zinc deficiency
  - 4% of under-five mortality is due to zinc def.
DALY framework for zinc deficiency

- **Target groups for zinc deficiency**
  - infants <1 year
  - children aged 1-5 years incl.

- **Disability weights for functional outcomes**
  - diarrhoea = 0.2 and 0.15 (infants and children)
  - pneumonia = 0.3 and 0.2 (infants and children)
  - stunting = 0.0001 per centimetre

- **Duration of diseases**
  - diarrhoea = 3 and 4 days (infants and children)
  - pneumonia = 4 days (infants & children)
  - stunting = permanent (onset in infancy)
### DALY framework – standard life table

<table>
<thead>
<tr>
<th>Sex</th>
<th>Life expectancy</th>
<th>Age</th>
<th>Life expectancy</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>males</td>
<td>59.8</td>
<td>&lt;1</td>
<td>62.7</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>62.6</td>
<td>1-4</td>
<td>65.9</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>60.6</td>
<td>5-9</td>
<td>64.5</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>56.1</td>
<td>10-14</td>
<td>60.2</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>51.5</td>
<td>15-19</td>
<td>55.6</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>46.6</td>
<td>20-24</td>
<td>51.2</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>42.3</td>
<td>25-29</td>
<td>46.9</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>38.0</td>
<td>30-34</td>
<td>42.5</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>33.8</td>
<td>35-39</td>
<td>38.1</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>29.5</td>
<td>40-44</td>
<td>33.7</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>25.4</td>
<td>45-49</td>
<td>29.4</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>21.4</td>
<td>50-54</td>
<td>25.3</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>17.8</td>
<td>55-59</td>
<td>21.4</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>14.6</td>
<td>60-64</td>
<td>17.7</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>11.4</td>
<td>65-69</td>
<td>14.4</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>9.3</td>
<td>70-74</td>
<td>11.5</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>7.2</td>
<td>75-79</td>
<td>9.0</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>5.3</td>
<td>80-84</td>
<td>6.9</td>
<td>females</td>
</tr>
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<td>85-89</td>
<td>5.2</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>3.1</td>
<td>90-94</td>
<td>3.9</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>2.4</td>
<td>95-99</td>
<td>2.9</td>
<td>females</td>
</tr>
<tr>
<td>males</td>
<td>1.9</td>
<td>100+</td>
<td>2.1</td>
<td>females</td>
</tr>
</tbody>
</table>

WHo life table for India (mortality in 2000)

### Assessing the impact of biofortification

![Assessing the impact of biofortification](image)

**cumulated individuals**

**old intake**

**new intake**

**old prevalence**

**new prevalence**

**micronutrient intake**
Assessing the impact of biofortification

- Our assumption is that if an iron-rich crop has a production share (coverage rate) of 80%, this will translate into a share of 80% in the consumption of each individual.
- Alternatively it could be assumed that the iron-rich crop is consumed exclusively by 80% of the population.
- International trade in the crop is neglected.

Assessing the impact of biofortification

- Our assumption is that, eventually, all HYVs will contain the iron-rich trait, i.e. HYV area = biofortified area.
- Furthermore we assume that HYVs yield twice as much as traditional varieties.
- From these assumptions we can calculate the production share of biofortified crops.
Assessing the impact of biofortification

Zimmermann and Qaim (2004)

Assessing the impact of biofortification

Zimmermann and Qaim (2004)
Assessing the impact of biofortification


\[ H(x) = \frac{1}{x} - \frac{1}{RDA} \]

where \( H \) is the health outcome and \( x \) the micronutrient intake.

Assessing the impact of biofortification

Calculating the efficacy \((E)\) by means of the ratio of the areas \(A\) and \(A+B\)

\[
E = \frac{\ln\left(\frac{BI}{CI}\right) - \frac{BI - CI}{RDA}}{\ln\left(\frac{RDA}{CI}\right) - \frac{RDA - CI}{RDA}}
\]

where \( CI \) is current intake and \( BI \) is intake with biofortification.
Costs and benefits of DALYs saved

- Rationale for discounting monetary terms
  - to take account of alternative investment possibilities (opportunity costs)
  - to take account of people’s time preference (of consuming now rather than later)

Costs and benefits of DALYs saved

- Rationale for discounting health benefits
  - to take account of people’s time preference
  - to take account of uncertainty
    - investments can become irrelevant before all benefits have materialised because of new interventions
    - limited time frame of the analysis (R&D + 20 years) already takes account of uncertainty?
  - discounting health benefits also implies that *ceteri paribus* the same illness causes a bigger loss today than tomorrow
### Costs and benefits of DALYs saved

#### Results for biofortification of rice and wheat for different discount rates

<table>
<thead>
<tr>
<th>Discounting Scenario</th>
<th>Loss of DALYs in status quo</th>
<th>Loss with biofortific.</th>
<th>DALYs gained</th>
<th>Burden of ID</th>
<th>Cost per DALY</th>
<th>IRR</th>
<th>BCR</th>
<th>Net present value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$ 31 billion</td>
</tr>
<tr>
<td>pessim.</td>
<td>7.3 m</td>
<td>3.3 m</td>
<td>4.0 m</td>
<td>-54%</td>
<td>36 Cents</td>
<td>77%</td>
<td>1318</td>
<td>$ 31 billion</td>
</tr>
<tr>
<td>optimist.</td>
<td></td>
<td>0.8 m</td>
<td>6.5 m</td>
<td>-89%</td>
<td>9 Cents</td>
<td>134%</td>
<td>10791</td>
<td>$ 114 billion</td>
</tr>
<tr>
<td>3 percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$ 33 billion</td>
</tr>
<tr>
<td>pessim.</td>
<td>4.0 m</td>
<td>1.8 m</td>
<td>2.2 m</td>
<td>-54%</td>
<td>93 Cents</td>
<td>66%</td>
<td>513</td>
<td>$ 9 billion</td>
</tr>
<tr>
<td>optimist.</td>
<td></td>
<td>0.4 m</td>
<td>3.5 m</td>
<td>-89%</td>
<td>23 Cents</td>
<td>120%</td>
<td>4293</td>
<td>$ 33 billion</td>
</tr>
<tr>
<td>5 percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$ 4 billion</td>
</tr>
<tr>
<td>pessim.</td>
<td>3.0 m</td>
<td>1.4 m</td>
<td>1.7 m</td>
<td>-55%</td>
<td>155 Cents</td>
<td>64%</td>
<td>309</td>
<td>$ 4 billion</td>
</tr>
<tr>
<td>optimist.</td>
<td></td>
<td>0.3 m</td>
<td>2.7 m</td>
<td>-89%</td>
<td>36 Cents</td>
<td>114%</td>
<td>2627</td>
<td>$ 17 billion</td>
</tr>
<tr>
<td>optimist.</td>
<td></td>
<td>0.9 m</td>
<td>1.1 m</td>
<td>-59%</td>
<td>433 Cents</td>
<td>59%</td>
<td>111</td>
<td>$ 1 billion</td>
</tr>
<tr>
<td>10 percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$ 4 billion</td>
</tr>
<tr>
<td>pessim.</td>
<td>2.0 m</td>
<td>0.2 m</td>
<td>1.8 m</td>
<td>-89%</td>
<td>102 Cents</td>
<td>105%</td>
<td>983</td>
<td>$ 4 billion</td>
</tr>
<tr>
<td>optimist.</td>
<td></td>
<td>0.4 m</td>
<td>3.5 m</td>
<td>-89%</td>
<td>102 Cents</td>
<td>105%</td>
<td>983</td>
<td>$ 4 billion</td>
</tr>
</tbody>
</table>

#### Results of the CBA with different DALY-values

<table>
<thead>
<tr>
<th>Iron biofortification of rice and wheat</th>
<th>annual per capita GNI (US$ 480)</th>
<th>1 DALY =</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US$ 500</td>
<td>US$ 1,000</td>
</tr>
<tr>
<td>Internal rate of return</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pessimistic</td>
<td>68%</td>
<td>79%</td>
</tr>
<tr>
<td>optimistic</td>
<td>104%</td>
<td>120%</td>
</tr>
<tr>
<td>Benefit-cost ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pessimistic</td>
<td>513</td>
<td>1070</td>
</tr>
<tr>
<td>optimistic</td>
<td>2062</td>
<td>4293</td>
</tr>
<tr>
<td>Net present benefit (US$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pessimistic</td>
<td>8.8 billion</td>
<td>18.4 billion</td>
</tr>
<tr>
<td>optimistic</td>
<td>16.0 billion</td>
<td>33.3 billion</td>
</tr>
</tbody>
</table>

Own calculations.
Costs for supplementation

**Costs for India’s Nutrition Anaemia Control Programme (tablets only)**

<table>
<thead>
<tr>
<th>Target group</th>
<th>Size of group</th>
<th>Target coverage</th>
<th>Dose</th>
<th>Cost /100 tablets</th>
<th>Total costs (46 Rs./US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pregnant women w/o severe IDA</td>
<td>27.4 million</td>
<td>50%</td>
<td>100 big tablets/case</td>
<td>5.45 Rs.</td>
<td>US$ 1.6 million</td>
</tr>
<tr>
<td>Pregnant women with severe IDA</td>
<td>0.57 million</td>
<td>50%</td>
<td>200 big tablets/case</td>
<td>5.45 Rs.</td>
<td>US$ 0.07 million</td>
</tr>
<tr>
<td>Children aged 1-5 (incl.)</td>
<td>127.6 million</td>
<td>50%</td>
<td>100 small tablets/year</td>
<td>2.5 Rs.</td>
<td>US$ 3.5 million</td>
</tr>
</tbody>
</table>

**Total annual costs for iron and folic acid tablets**: US$ 5.2 million

*Own calculations based on Census data, NIN anaemia figures and communication of Dr. Kapil*

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Iron deficiency in the world

**Total population in developing countries (5.2 billion)**

- Iron deficient: 1.7 billion (33%)
- Not iron deficient: 3.5 billion (67%)

*Source: ACC/SCN 2000 and World Development Indicator Database*
Iron sources for adult equivalents

Average iron intake from different sources

- Rice: 32%
- Wheat: 27%
- Others: 41%

Iron sources in India by quartile

Average iron intake per adult equivalent of household (mg/day)

Poorest quartile

Quartile 2

Quartile 3

Richest quartile

From rice

From wheat

From others
Iron sources in India by quartile

Average iron intake per adult equivalent of household (mg/d)

- from rice
- from wheat

Poorest quartile: 8 mg/d
Quartile 2: 10 mg/d
Quartile 3: 12 mg/d
Richest quartile: 14 mg/d

Improved iron intake by quartile

Average iron intake per adult equivalent - optimistic scenario

- increase (all)
- increase (new rice)
- increase (new wheat)

Poorest quartile: 0% increase
Quartile 2: 20% increase
Quartile 3: 40% increase
Richest quartile: 60% increase
Improved iron intake by quartile

Average iron intake per adult equivalent (mg/day) - optimistic scenario

Poorest quartile | Quartile 2 | Quartile 3 | Richest quartile
---|---|---|---
Total (old) | Total (new)

Improved iron intake by quartile

Average iron intake per adult equivalent - pessimistic scenario

Poorest quartile | Quartile 2 | Quartile 3 | Richest quartile
---|---|---|---
Increase (all) | Increase (new rice) | Increase (new wheat)
Improved iron intake by quartile

Average iron intake per adult equivalent (mg/day) - pessimistic scenario

Iron sources by states

Major source of iron in household consumption (by states)
Iron sources by states

More important source of iron in HH consumption (by states)

- Rice
- Wheat

Average iron intake per household (mg/day)

- From rice
- From wheat
- From others
Improved iron intake by state

Average iron intake per household (mg/day) - optimistic scenario

Average iron intake per household (mg/day) - pessimistic scenario