Iron-Biofortification ex-ante Cost- Effectiveness

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Cost-benefit and Cost-effectiveness

- **Cost-benefit (CB):** Often used to calculate and compare benefits and costs of a project, decision, government policy, or intervention. CB has two purposes: to determine if the intervention is a sound investment, and to provide a basis for comparing interventions. CB involves comparing the total expected present cost of each intervention against the total expected present benefits to see whether the benefits outweigh the costs and by how much.
  - Costs as well as benefits have to be expressed in monetary values.

- **Cost-effectiveness (CE):** Compares the relative costs and outcomes (benefits) of two or more interventions. The intervention that achieves a certain (non-monetary) outcome at the least cost is usually preferred.
  - In public health, Disability Adjusted Life Years (DALYs) is often used to measure the outcomes of interventions in terms of the disease burden of a particular condition (i.e. micronutrient deficiencies), expressed as the number of years lost due to ill-health, disability, or early death.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Units used for calculation</th>
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</thead>
</table>
| **CBA** Cost Benefit Analysis assesses the profitability of investments over time by analysing discounted cash flows. | Project costs: in monetary value  
Project outcome: in monetary value |
| **CEA** Cost Effectiveness Analysis compares different intervention strategies based on relative costs and outcomes, without quantifying the benefits. | Project costs: in monetary value  
Project outcome: in natural units |

The easy way to remember the difference is a benefit is a desired financial reward while effectiveness is the potential success of the program.

Biofortification

• The process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding, or modern biotechnology / (WHO)

• The process of increasing the density of vitamins and minerals in a crop, through plant breeding or agronomic practices, so that when consumed regularly will generate measurable improvement in vitamin and mineral nutritional status (Provit. A, carotenoids, zinc, iron). Focus on major staples consumed by poor farming HHs in LMICs. Public good / (HarvestPlus).
### Evidence of success: RCTs & Delivery

**Farming households reached (‘000)**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Country</th>
<th>Nutrient</th>
<th>End of 2013</th>
<th>End of 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beans</strong></td>
<td>Rwanda</td>
<td>Iron</td>
<td>714</td>
<td>1,190</td>
</tr>
<tr>
<td></td>
<td>DR Congo</td>
<td></td>
<td>301</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Uganda</td>
<td></td>
<td>72</td>
<td>486</td>
</tr>
<tr>
<td><strong>Pearl Millet</strong></td>
<td>India</td>
<td>Iron</td>
<td>70</td>
<td>1,700</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>1,157</td>
<td>3,876</td>
</tr>
</tbody>
</table>

**High iron beans:** Murray-Kolb, et al. (2017), Haas JD, et al. (2016) Wenger MJ, et al. (2019); Pompano L et al. (under review)

**High iron pearl millet:** Finkelstein et al. (2015), Scott SP, et al. (2018); Kodkani B et al (2013); Cercamondi C et al (2013)

**Iron enhanced rice:** Haas JD, et al. (2005); Beard J et al. (2007)

**Meta-analyses & Reviews:**
Evolution of Biofortification ex-ante Impact Simulation Models

Components of study categories

A. Population-based data: 24HR or Household Consumption and Expenditure Survey (HCES)

B. Food Composition Tables

C. Agricultural Sector/Biofortified Crop Production Considerations: Adoption Rate, Number of Farmers, Total Land Planted, % Planted in Biofortified Crops, Yield, Output Levels, Post-Harvest Losses, Disposition

D. Baseline Nutrient Intake Adequacy: Usual Intake is Adequate Intake: ≥ EAR Inadequate Intake: < EAR

E. Market Structure: Where biofortified crop is sold, Who purchases it

F. Consumption: Biofortified crop consumers, Amount consumed, Nutrient degradation, Bioavailability, Addit'l nutrient intake

G. Endline Nutrient Intake Adequacy: Usual Intake is Adequate: ≥ EAR Inadequate: < EAR (Biofortified crop consumed, Amount consumed, Nutrient degradation)


Cost per DALY saved?

Overview of outcomes (2015-2018)

On average Iron Beans have an increased yield of about 20%

- HIB accounted for 20% of total bean production in 2018
- An additional $78 per hectare is earned from production of Climbing Iron Beans
- An additional $57 per hectare is earned from production of Bush Iron Beans
- The total additional revenue from production of Iron Beans through 2018 was about $20 million
- The total reduced burden of iron deficiency through 2018 was estimated at an additional savings of $4.9 million
- (Total estimated investment up to 2018: $11 million)

*Nationally representative*
Methods

1. Calculate the number of households growing
   - Derive statistics from the Rwanda 2015 HIB survey for:
     - Continuation percentage
     - Diffusion percentage
     - New growers as a percentage of delivery
   - Utilize M&E delivery data as data inputs for years 2016-2018

2. Calculate average HIB and non-HIB bean yields through 2018

3. Calculate average HIB and non-HIB area per household growing; estimate total HIB and non-HIB production

4. Calculate the unit additional $ value of HIB production and the cumulative added value of HIB production since 2010

5. Use the HIB percentage of total bean supply to calculate the reduction in iron deficiency disease burden (DALYs)
Using the DALY to calculate disease burden

• To calculate the reduction in iron deficiency disease burden, we utilized the Disability-Adjusted Life Year (DALY)

• Simply put, a DALY is a year of life equivalent
  – Some diseases lead to death, but others do not necessarily (e.g. blindness, decreased physical activity, cognitive impairment, etc.)
  – Calculating only deaths then, can result in an underestimate of the negative effect of micronutrient deficiency
  – When we calculate a DALY we sum up total time lost to death (mortality) and/or non-fatal disease (morbidity) and report it in 1-year equivalents

• We use health statistics to identify disease outcomes related to a MN deficiency and the proportion of incidence associated with the deficiency; we use this to quantify DALYs in the status quo, i.e. with no biofortification

• We then calculate how much biofortification lowers disease incidence rates and then we recalculate total DALYs; the difference is the number of DALYs saved
Using DALYs to calculate disease burden: Rwanda

<table>
<thead>
<tr>
<th>Functional outcomes (cause)</th>
<th>Target group</th>
<th>Target group size</th>
<th>Mortality / Incidence</th>
<th>Prevalence rate</th>
<th>Disability weight</th>
<th>Duration / rest Life</th>
<th>Discount rate</th>
<th>DALYs lost</th>
<th>YLD</th>
<th>YLL</th>
<th>Deaths</th>
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</thead>
<tbody>
<tr>
<td>Impaired physical activity (moderate IDA)</td>
<td>children 6-59 mo</td>
<td>2,050,171</td>
<td>0.016</td>
<td>0.07</td>
<td>0.011</td>
<td>4.5</td>
<td>0.03</td>
<td>1,527</td>
<td>1,527</td>
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<tr>
<td>Impaired physical activity (moderate IDA)</td>
<td>children 5-14</td>
<td>3,315,367</td>
<td>0.016</td>
<td>0.13</td>
<td>0.090</td>
<td>9.0</td>
<td>0.03</td>
<td>4,649</td>
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<tr>
<td>Impaired physical activity (moderate IDA)</td>
<td>women 15+</td>
<td>3,833,123</td>
<td>0.00025</td>
<td>0.00</td>
<td>0.087</td>
<td>4.5</td>
<td>0.03</td>
<td>1,527</td>
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<tr>
<td>Impaired physical activity (moderate IDA)</td>
<td>men 15+</td>
<td>3,671,461</td>
<td>0.00015</td>
<td>0.00</td>
<td>0.087</td>
<td>4.5</td>
<td>0.03</td>
<td>1,527</td>
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<td>0.00</td>
<td>0.087</td>
<td>4.5</td>
<td>0.03</td>
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<td>0.03</td>
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<tr>
<td>Impaired physical activity (severe IDA)</td>
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<td>3,833,123</td>
<td>0.00002</td>
<td>0.00</td>
<td>0.090</td>
<td>59.1</td>
<td>0.03</td>
<td>162</td>
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</tr>
<tr>
<td>Impaired physical activity (severe IDA)</td>
<td>men 15+</td>
<td>3,671,461</td>
<td>0.00001</td>
<td>0.00</td>
<td>0.090</td>
<td>50.2</td>
<td>0.03</td>
<td>84</td>
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<td></td>
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<tr>
<td>Impaired mental development (moderate IDA)</td>
<td>children 28-59 mo</td>
<td>1,262,868</td>
<td>0.016</td>
<td>0.00</td>
<td>0.00002</td>
<td>0.00</td>
<td>60.0</td>
<td>0.03</td>
<td>7,823</td>
<td>7,823</td>
<td>316</td>
</tr>
<tr>
<td>Impaired mental development (severe IDA)</td>
<td>children 28-59 mo</td>
<td>1,262,868</td>
<td>0.001</td>
<td>0.00</td>
<td>0.00002</td>
<td>0.00</td>
<td>60.0</td>
<td>0.03</td>
<td>486</td>
<td>486</td>
<td></td>
</tr>
<tr>
<td>Maternal mortality (severe IDA)</td>
<td>live births</td>
<td>13,041,386</td>
<td>0.000024</td>
<td>0.00</td>
<td>0.00024</td>
<td>0.00</td>
<td>60.0</td>
<td>0.03</td>
<td>7,823</td>
<td>7,823</td>
<td>316</td>
</tr>
<tr>
<td>Stillbirths (maternal mortality)</td>
<td>maternal deaths</td>
<td>316</td>
<td>0.3</td>
<td>0.6</td>
<td>60.0</td>
<td>0.03</td>
<td>2,636</td>
<td>2,636</td>
<td>95</td>
<td></td>
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</tr>
<tr>
<td>Child death (maternal mortality)</td>
<td>maternal deaths</td>
<td>316</td>
<td>0.007</td>
<td>0.652</td>
<td>0.03</td>
<td>65</td>
<td>65</td>
<td>2.3</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

DALY formula inputs:
- Total burden: 11,278
- YLD: 11,278
- YLL: 0
- Deaths: 0

Components of a DALY: mortality and morbidity

Adverse outcomes

Incidence rates: biofortification acts to lower these
Observed (2010-2018)
$4.9 \text{ mil}
Value of reduced iron deficiency

Simulated (2010-2025)
Scenario 1: status quo
$16.2 \text{ mil}
Value of reduced iron deficiency

Scenario 2: 40%
$22.3 \text{ mil}
Value of reduced iron deficiency
How do these DALY benefits translate back to disease incidence rates (2010-2025)?

- If the population eats 40% of its beans as iron beans, then the annual burden of iron deficiency in DALYs would be reduced by 30.6%.

- If the population eats 40% of its beans as iron beans, then the incidence of impaired physical activity due to iron-deficiency anemia among children under 5 and women of reproductive age would be reduced by 20% and 16%, respectively.
### Cost-effectiveness of biofortification: “cost per DALY saved”: 30-year horizon

<table>
<thead>
<tr>
<th>Country</th>
<th>Micronutrient</th>
<th>Biofortification Cost per DALY saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRC</td>
<td>Iron</td>
<td>Beans: $4.95* ($18-$98** )</td>
</tr>
<tr>
<td>Rwanda</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*50% coverage average and cost per year at year 30;  **25-50% coverage; averages discounted over 30 yrs.
Conclusions

• Biofortification is highly cost effective (high iron beans).
• It is expected to benefit particularly poor farmers in rural areas. Generally biofortification will have a greater impact on reducing the prevalence of inadequate intakes among children and women in rural areas and the benefits will be directed more toward lower income groups.
• More research is clearly needed to better understand these differences, risks and impacts among these groups (rural, age, gender, etc.).

Thank you for accelerating the eradication of nutritional anemia together!

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Extra slides
Formula for Calculating DALYs

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

where:

- \(T_j\) = total number of people in target group \(j\)
- \(M_j\) = mortality rate associated with the deficiency in target group \(j\)
- \(L_j\) = average remaining life expectancy for target group \(j\)
- \(I_{ij}\) = incidence rate of disease \(i\) in target group \(j\)
- \(D_{ij}\) = disability weight for disease \(i\) in target group \(j\)
- \(d_{ij}\) = duration of disease \(i\) in target group \(j\)
- \(r\) = discount rate for future years

(for permanent diseases \(d_{ij}\) equals the average remaining life expectancy \(L_j\))
Evidence of Success: the Efficacy of Iron Crops


High iron pearl millet: Finkelstein et al. (2015), Scott SP, et al. (2018);

Iron enhanced rice: Haas JD, et al. (2005)

Meta-analyses & Reviews:


Evidence of success: Delivery

4.47M HH reached in Africa and Asia and 33K HH reached in LAC by 2018
Biofortification Has Become a Core Nutrition Strategy

Other strategies for increasing access to critical micronutrients:

- **Biofortification** of staple foods (upfront investment)
- **Fortification** added to foods (sustained investment)
- **Supplementation** Consumed as pills, powders, drops, etc. (sustained investment)

A nourishing, diverse diet is the ideal nutrition strategy as long as people can afford and access the right mix of foods.
Fig. 7. Reduction in the prevalence of inadequate intake with high iron pearl millet, by geographic region, Rajasthan, India 2043.

Source: Fiedler and Lividini (2015)