Health benefits of biofortification

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

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Overview

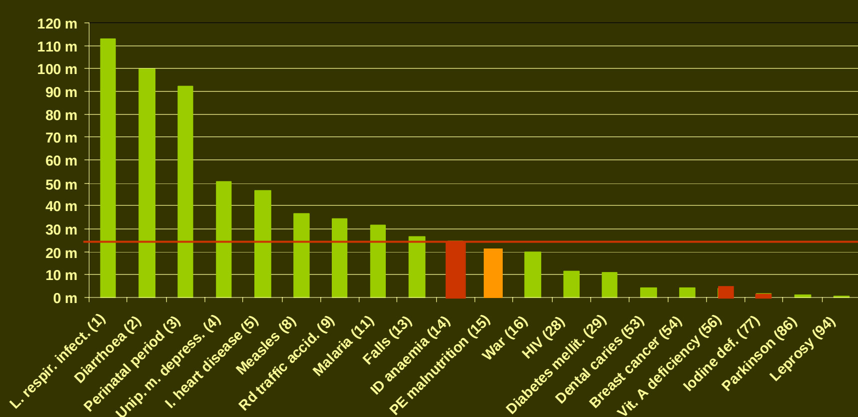
- Micronutrient malnutrition – the problem
- Conventional approaches and solutions
- Biofortification, a new approach
- Quantifying the problem with DALYs
- The impact: food intake & prevalence rates
- The cost-effectiveness: Dollars & DALYs
- CBA: biofortification as an investment
- Conclusion and outlook

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

Micronutrient malnutrition

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

Conventional approaches

- Pharmaceutical supplementation
- 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?

DALYs

- 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"

DALYs

- 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 <u>D</u>isability-<u>A</u>djusted <u>L</u>ife <u>Y</u>ears

DALYs

Formally these DALYs lost are calculated thus:

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

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

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For iron deficiency the diseases *i* are:

- impaired physical activity
- impaired mental development
- stunting
- maternal mortality (incl. stillbirths and child deaths)

DALYs

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... and the target groups *j* are:

- children ≤ 5 years of age
- children aged 6-14 years
- women aged 15+ years
- men aged 15+ years

DALYs

Diseases / functional outcomes	Target groups	DA-weights
Stunting (severe)	children ≤ 5 years	0.001
Impaired mental development (moderate)	children ≤ 5 years	0.006
Impaired mental development (severe)	children ≤ 5 years	0.024
Impaired physical activity (moderate)	children ≤ 5 years	0.011
	children 6-14 years	0.011
	women 15+ years	0.011
	men 15+ years	0.011
Impaired physical activity (severe)	children ≤ 5 years	0.087
	children 6-14 years	0.087
	women 15+ years	0.09
	men 15+ years	0.09

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 & <u>quantities</u>)
  - household composition (adult equivalents)

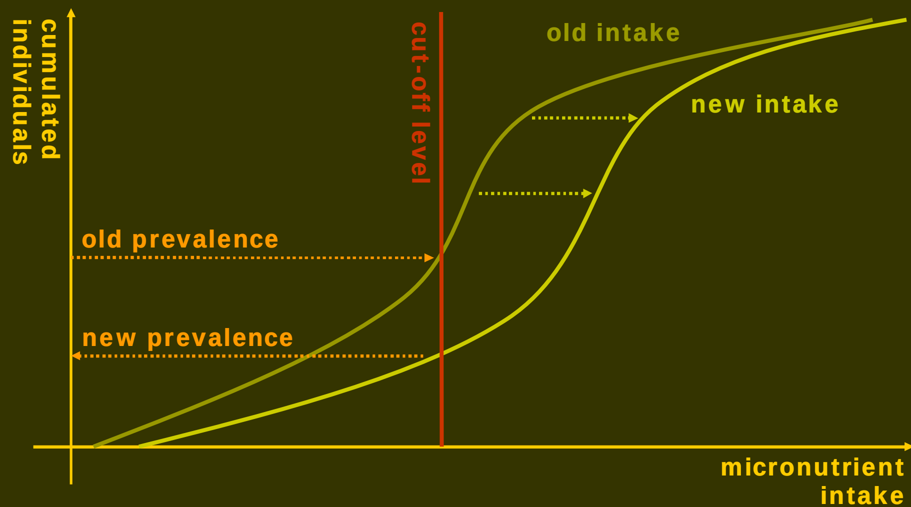
Impact

- 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

Impact



Impact

Target group	Current prevalence rates for moderate IDA	severe IDA
children ≤ 5 years	0.275	0.032
children aged 6-14 years	0.156	0.008
women 15+ years	0.074	0.010
men 15+ years	0.037	0.005

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

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

Impact

	Iron-rich rice		Iron-rich wheat	
	pessimistic	optimistic	pessimistic	optimistic
Increase in iron content	**50%**	**300%**	**5%**	**10%**
Bioavailability	**unchanged**			
Share in production	**42.5%**	**85%**	**47.5%**	**95%**
Full adoption in	**10 yrs**	**7 yrs**	**7 yrs**	**5 yrs**

Based on information from breeders and own assumptions

Impact

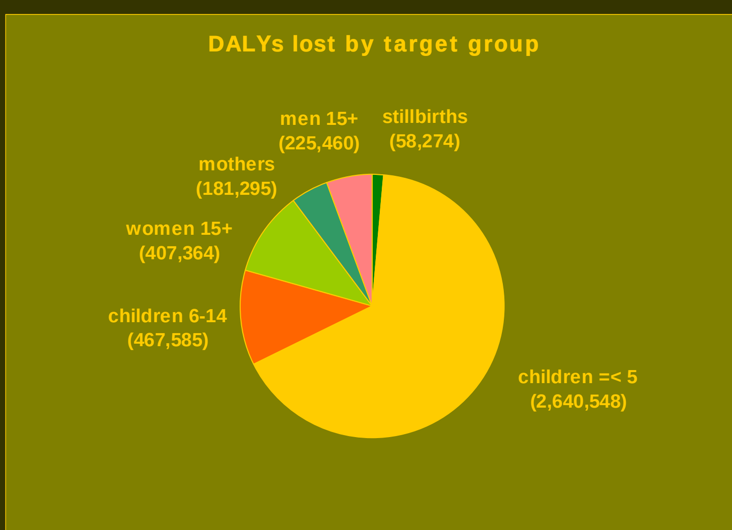
- With these assumptions we could establish new prevalence rates and calculate the number of DALYs lost for each scenario and for each crop
- The sum of the individual impacts of rice & wheat is bigger than the combined impact
- Here we will focus on the results for biofortification of both rice and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

Impact

	DALYs lost due to iron deficiency	DALYs gained through biofortification	Reduction of the burden of iron deficiency
Status quo	*4.0 m*	*none*	*none*
Pessimistic scenario	1.8 m	2.2 m	-54 %
Optimistic scenario	0.4 m	3.5 m	-89 %

Own calculations

Impact



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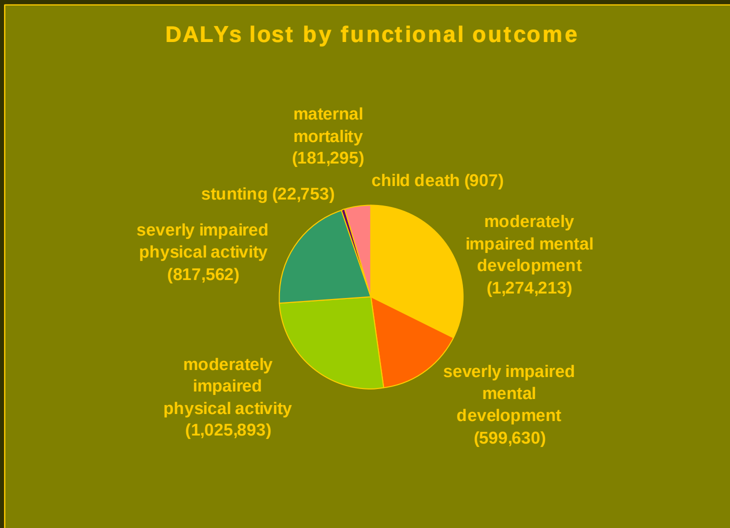

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Own calculations

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

Cost-effectiveness

	Rice		Wheat	
	pessimistic	optimistic	pessimistic	optimistic
Annual basic R&D costs	0.6 m US$	0.35 m US$	0.55 m US$	0.3 m US$
Duration of basic R&D	10 years	9 years	11 years	10 years
Annual country-specific costs	0.5 m US$	0.2 m US$	0.5 m US$	0.2 m US$
Duration of country-specific activities	5 years	3 years	5 years	3 years
Annual maintenance costs	0.2 m US$	0.1 m US$	0.2 m US$	0.1 m US$
Duration of maintenance	15 years	17 years	15 years	17 years

Based on the budget of the Challenge proposal, information from breeders and own assumptions

Cost-effectiveness

	Present costs	Present value of DALYs saved	Cost per DALY saved	Average annual cost per inhabitant
Pessimistic scenario	17.2 m US$	18.4 m DALYs	93 Cents	1/8 Cent
Optimistic scenario	7.8 m US$	33.3 m DALYs	23 Cents	1/20 Cent

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)*

Cost-effectiveness

	Present costs	Present value of DALYs saved	Cost per DALY saved	Average annual cost per inhabitant
Pessimistic scenario	17.2 m US$	18.4 m DALYs	93 Cents	1/8 Cent
Optimistic scenario	7.8 m US$	33.3 m DALYs	23 Cents	1/20 Cent

Based on own calculations

- 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

Cost-benefit analysis

- 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

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

Cost-benefit analysis

	Present costs	Present benefits	Benefit-cost ratio	Internal rate of return
Pessimistic scenario	17.2 m US$	8,818 m US$	513	68 %
Optimistic scenario	7.8 m US$	33,342 m US$	4293	120 %

Based on own 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%)

Cost-benefit analysis

	Present costs	Present benefits	Benefit-cost ratio	Internal rate of return
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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 **bio**fortification could carry forward the benefits agricultural research already brought to the Indian society with the Green Revolution,
- and bio**fortification** 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

DALY framework for iron deficiency

- 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

DALY framework for iron deficiency

Diseases / functional outcomes	Target groups	DA-weights
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Impaired physical activity (severe)	children ≤ 5 years	0.087
	children 6-14 years	0.087
	women 15+ years	0.09
	men 15+ years	0.09

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.

DALY framework for zinc deficiency

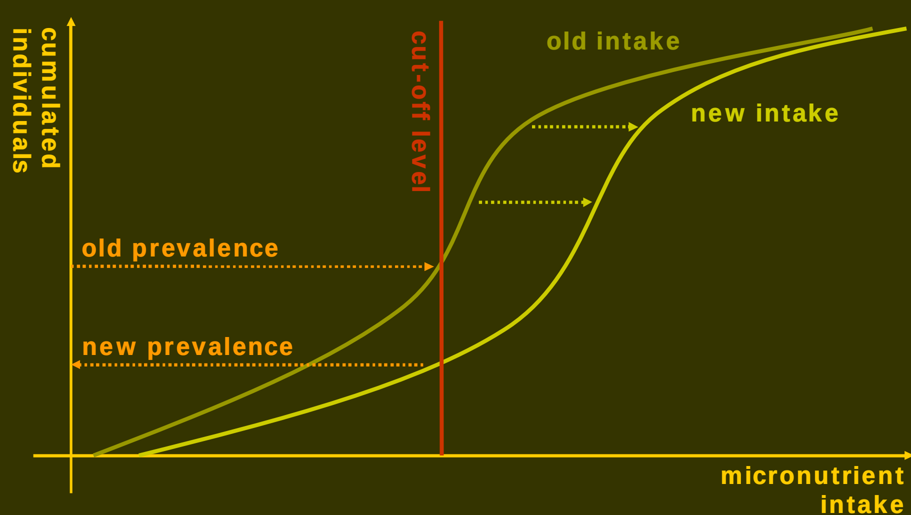
- Disability weights for functional outcomes
  - diarrhoea = 0.2 and 0.15 (infants and children)
  - pneumonia = 0.3 and 0.2 (infants and children)
  - stunting = 0.0001 per centimetre
- Duration of diseases
  - diarrhoea = 3 and 4 days (infants and children)
  - pneumonia = 4 days (infants & children)
  - stunting = permanent (onset in infancy)

DALY framework – standard life table

Sex	Life expectancy	Age	Life expectancy	Sex
males	59.8	<1	62.7	females
males	62.8	1-4	65.9	females
males	60.6	5-9	64.5	females
males	56.1	10-14	60.2	females
males	51.5	15-19	55.6	females
males	46.8	20-24	51.2	females
males	42.3	25-29	46.9	females
males	38.0	30-34	42.5	females
males	33.8	35-39	38.1	females
males	29.5	40-44	33.7	females
males	25.4	45-49	29.4	females
males	21.4	50-54	25.3	females
males	17.8	55-59	21.4	females
males	14.6	60-64	17.7	females
males	11.8	65-69	14.4	females
males	9.3	70-74	11.5	females
males	7.2	75-79	9.0	females
males	5.5	80-84	6.9	females
males	4.2	85-89	5.2	females
males	3.1	90-94	3.9	females
males	2.4	95-99	2.9	females
males	1.9	100+	2.1	females

WHO life table for India (mortality in 2000)

Assessing the impact of biofortification



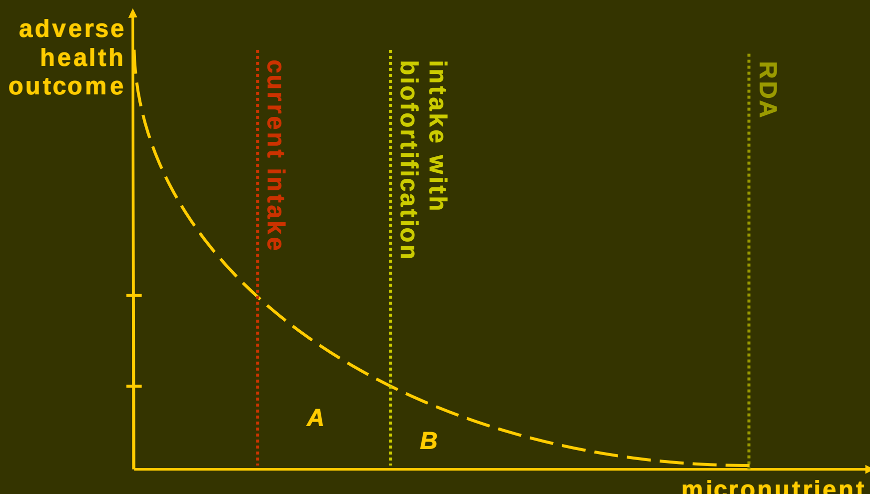
Assessing the impact of biofortification

- 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

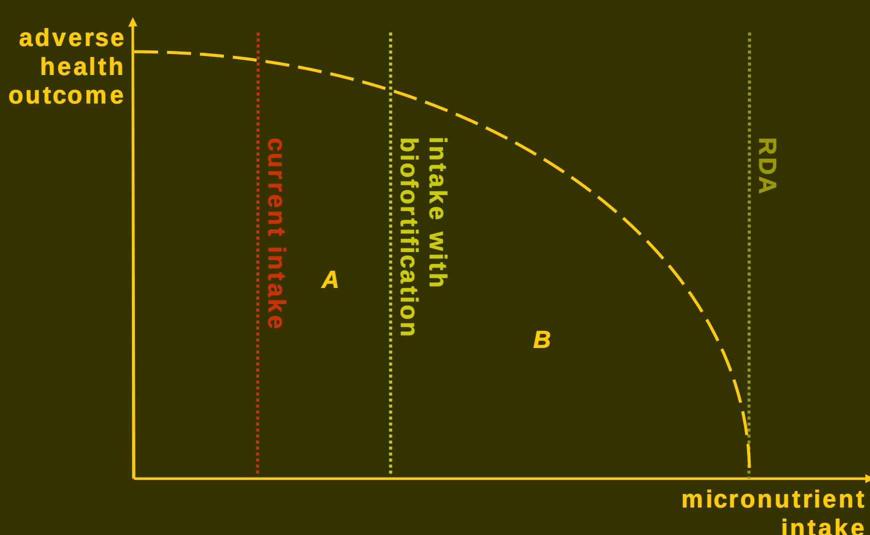
- Our assumption is that, eventually, all HYVs will contain the iron-rich trait, i.e. HYV area = biofortified area
- Furthermore we assume that HYVs yield twice as much as traditional varieties
- From these assumptions we can calculate the production share of biofortified crops

Assessing the impact of biofortification



Zimmermann and Qaim (2004)

Assessing the impact of biofortification



Assessing the impact of biofortification

Specification of curve by Zimmermann and Qaim (2004)

$$H(x) = {}^{1}/_{x} - {}^{1}/_{RDA}$$

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***

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

where ***CI*** is current intake and
BI is intake with biofortification

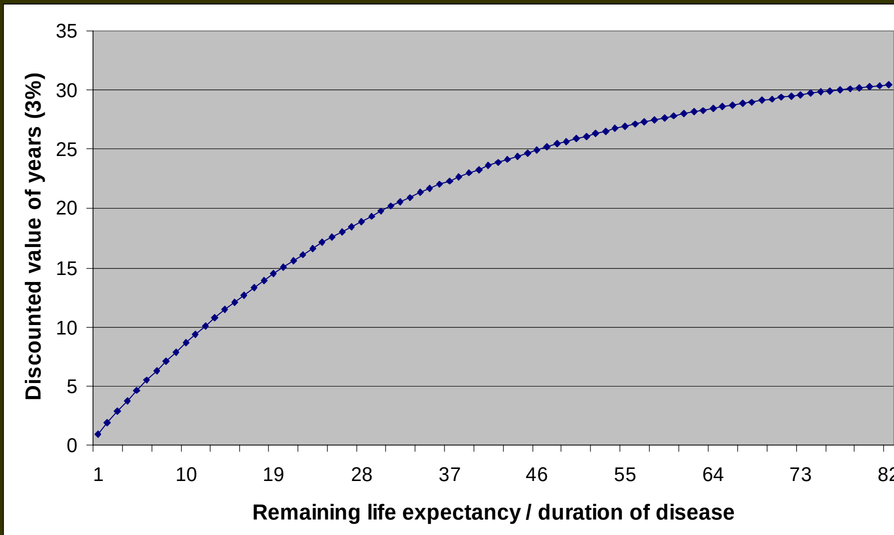
Costs and benefits of DALYs saved

- 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



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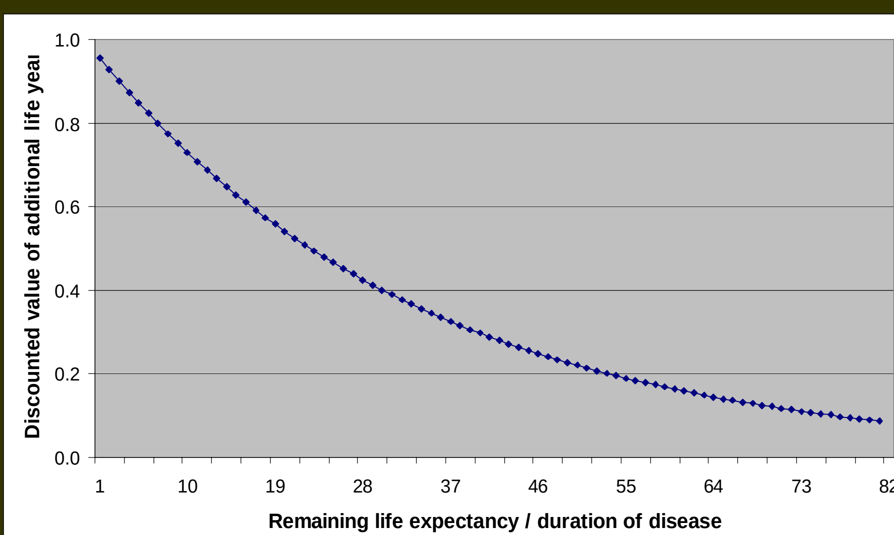


Costs and benefits of DALYs saved

Results for biofortification of rice and wheat for different discount rates

Discounting	Scenario	Loss of DALYs in *status quo*	Loss with biofortific.	DALYs gained	Burden of ID	Cost per DALY	IRR	BCR	Net present value
0 percent	pessim.	7.3 m	3.3 m	4.0 m	- 54%	36 Cents	77%	1318	$ 31 billion
	optimist.		0.8 m	6.5 m	- 89%	9 Cents	134%	10791	$ 114 billion
3 percent	pessim.	4.0 m	1.8 m	2.2 m	- 54%	93 Cents	68%	513	$ 9 billion
	optimist.		0.4 m	3.5 m	- 89%	23 Cents	120%	4293	$ 33 billion
5 percent	pessim.	3.0 m	1.4 m	1.7 m	- 55%	155 Cents	64%	309	$ 4 billion
	optimist.		0.3 m	2.7 m	- 89%	38 Cents	114%	2627	$ 17 billion
10 percent	pessim.	2.0 m	0.9 m	1.1 m	- 55%	433 Cents	58%	111	$ 1 billion
	optimist.		0.2 m	1.8 m	- 89%	102 Cents	105%	983	$ 4 billion

Results for biofortification of rice and wheat for different discount rates

Discounting	Scenario	Loss of DALYs in *status quo*	Loss with biofortific.	DALYs gained	Burden of ID	Cost per DALY	IRR	BCR	Net present value
health 0% dollars 3%	pessim.	7.3 m	3.3 m	4.0 m	- 54%	26 Cents	77%	937	$ 16 billion
	optimist.		0.8 m	6.5 m	- 89%	7 Cents	134%	7863	$ 61 billion
health 0% dollars 5%	pessim.	7.3 m	3.3 m	4.0 m	- 54%	22 Cents	77%	739	$ 11 billion
	optimist.		0.8 m	6.5 m	- 89%	6 Cents	134%	6311	$ 41 billion
health 3% dollars 10%	pessim.	4.0 m	1.8 m	2.2 m	- 54%	53 Cents	68%	222	$ 2 billion
	optimist.		0.4 m	3.5 m	- 89%	14 Cents	120%	1972	$ 9 billion
3 percent	pessim.	4.0 m	1.8 m	2.2 m	- 54%	93 Cents	68%	513	$ 9 billion
	optimist.		0.4 m	3.5 m	- 89%	23 Cents	120%	4293	$ 33 billion

Costs and benefits of DALYs saved

Results of the CBA with different DALY-values

Iron biofortification of rice and wheat		annual per capita GNI (US$ 480)	1 DALY = US$ 500	1 DALY = US$ 1,000
Internal rate of return	pessimistic	68 %	68%	79%
	optimistic	104%	105%	120%
Benefit-cost ratio	pessimistic	513	535	1070
	optimistic	2062	2147	4293
Net present benefit (US$)	pessimistic	8.8 billion	9.2 billion	18.4 billion
	optimistic	16.0 billion	16.7 billion	33.3 billion

Own calculations.

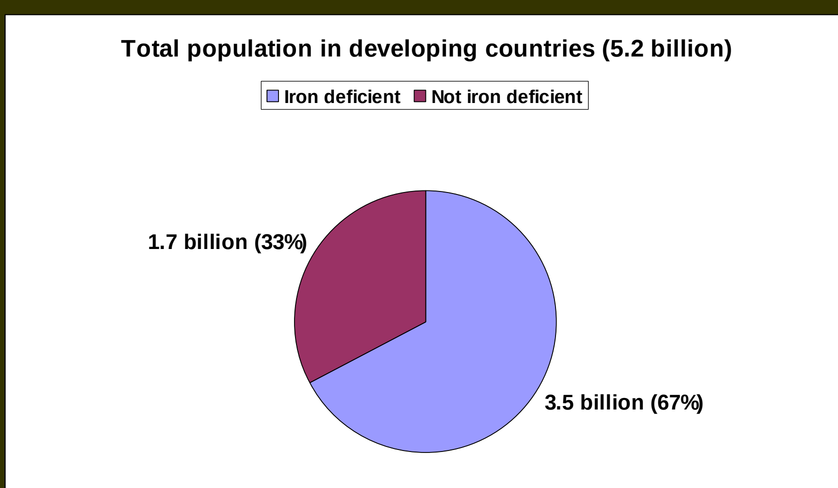
Costs for supplementation

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

Target group	Size of group	Target coverage	Dose	Cost / 100 tablets	Total costs (46 Rs. / US$)
Pregnant women w/o severe IDA	27.4 million	50%	100 big tablets/case	5.45 Rs.	US$ 1.6 million
Pregnant women with severe IDA	0.57 million	50%	200 big tablets/case	5.45 Rs.	US$ 0.07 million
Children aged 1-5 (incl.)	127.6 million	50%	100 small tablets/year	2.5 Rs.	US$ 3.5 million
				Total annual costs for iron and folic acid tablets	**US$ 5.2 million**

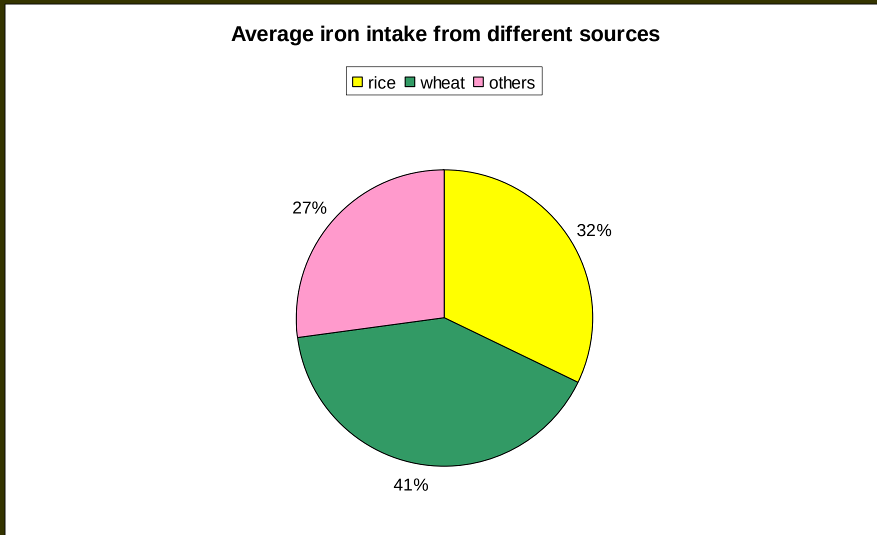
Own calculations based on Census data, NIN anaemia figures and communication of Dr. Kapil

Iron deficiency in the world

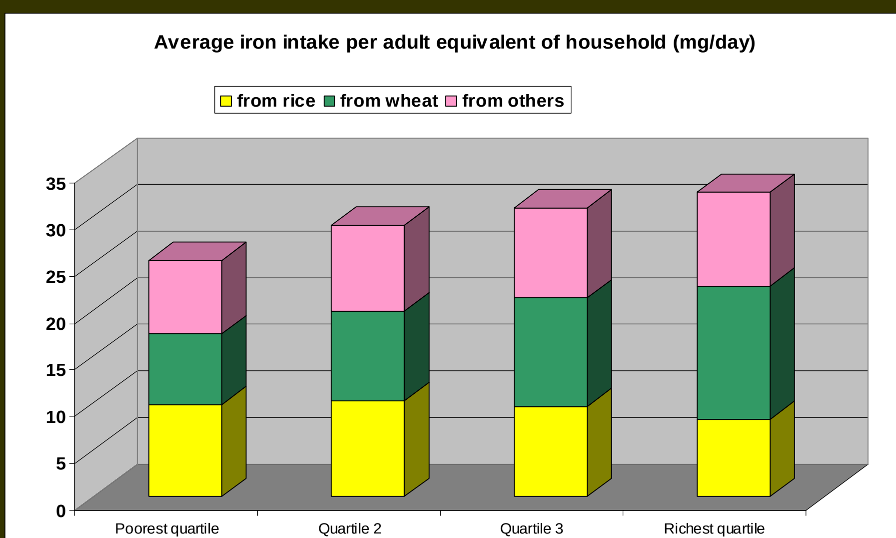


Source: ACC/SCN 2000 and World Development Indicator Database

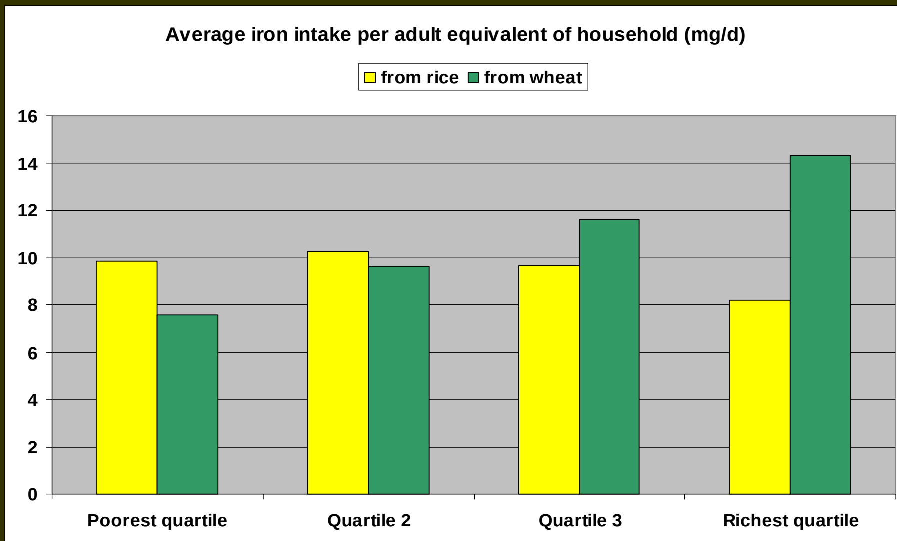
Iron sources for adult equivalents



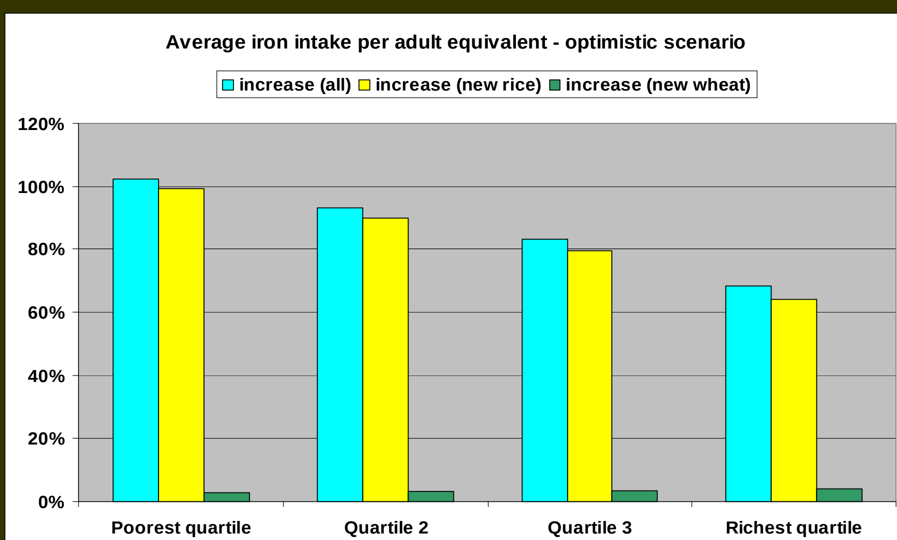
Iron sources in India by quartile



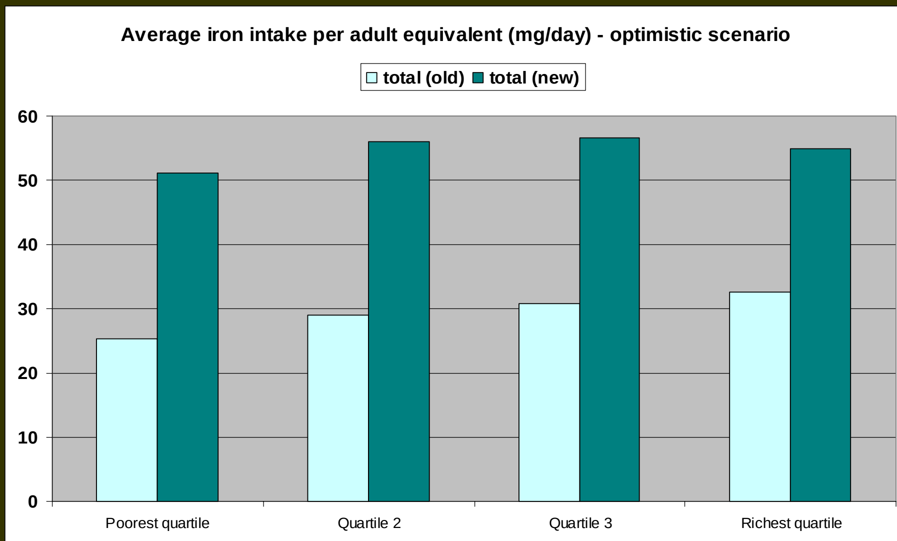
Iron sources in India by quartile



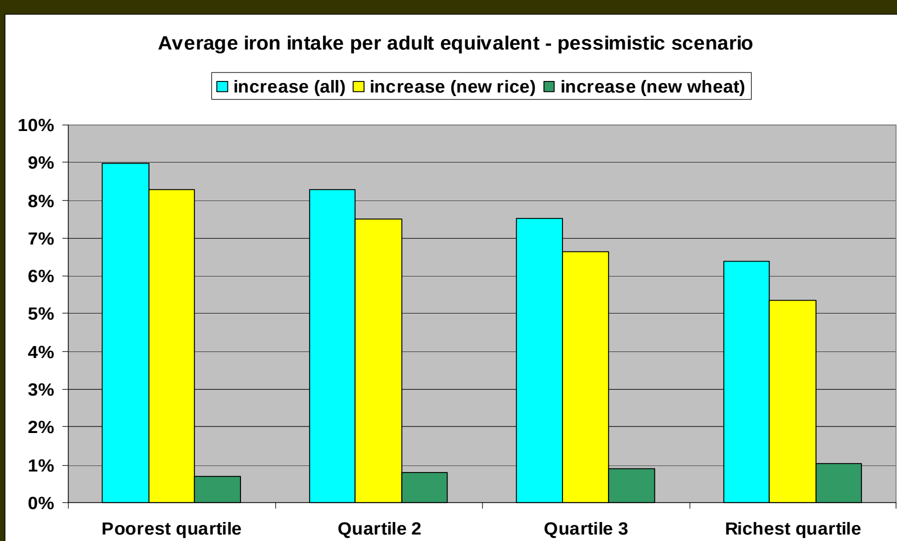
Improved iron intake by quartile



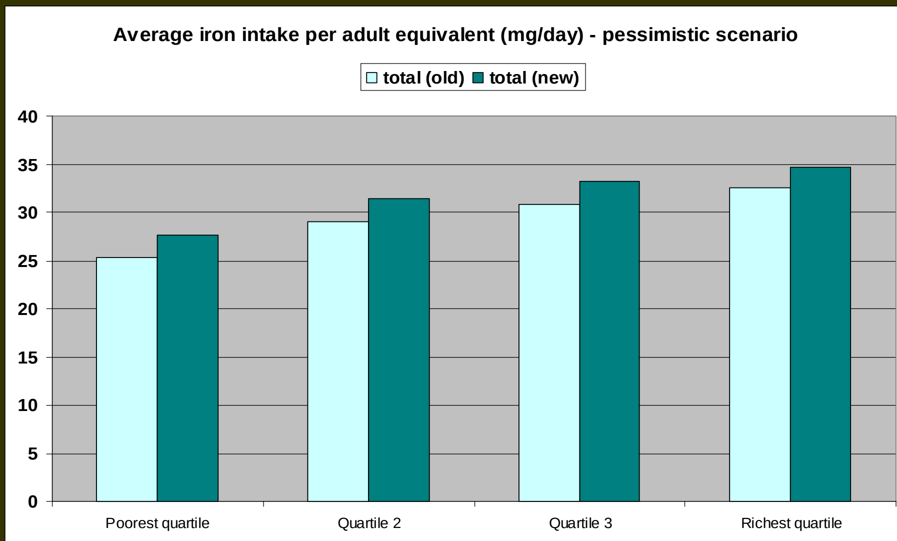
Improved iron intake by quartile



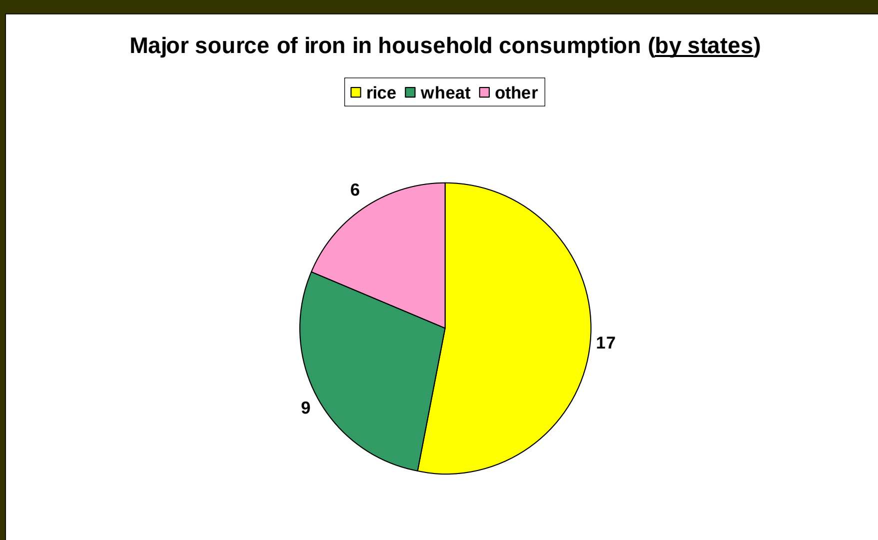
Improved iron intake by quartile



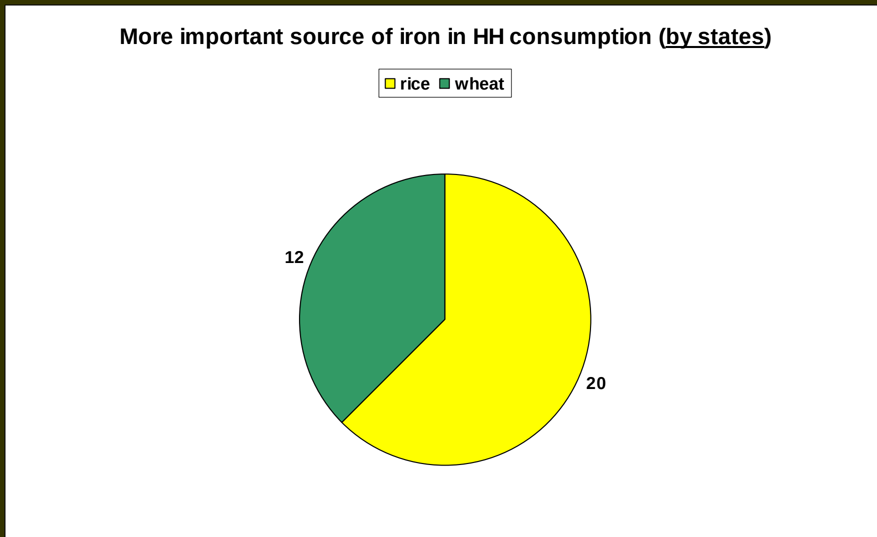
Improved iron intake by quartile



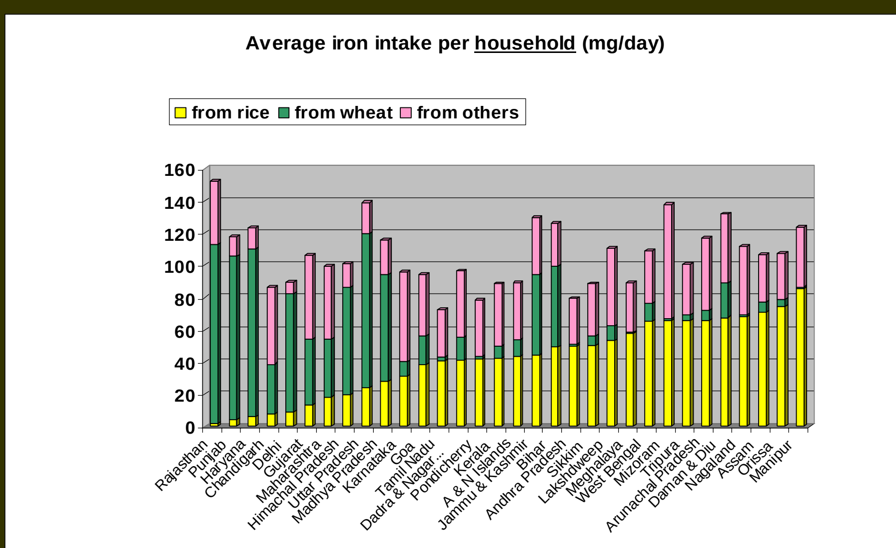
Iron sources by states



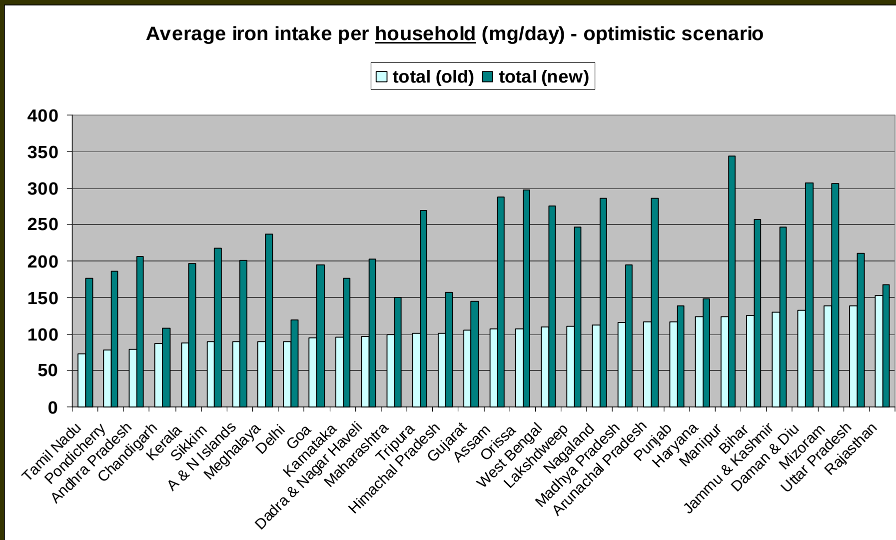
Iron sources by states



Iron sources in India by state



Improved iron intake by state



Improved iron intake by state