Cost-effectiveness of biofortification

Alexander J. Stein

13 December 2007

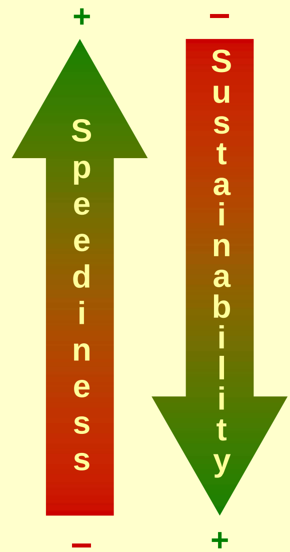
FAO Regional Office
for the Near East, Cairo

Structure of presentation

- Biofortification in the context of other interventions
- Why economic assessment of interventions?
- Measuring costs & benefits = measuring health
- Linking health, nutrition & biofortification
- Assumptions about the success of biofortification
- Projected impact of biofortification (case: India)
- Cost & cost-effectiveness of biofortification
- Comparison of interventions and studies
- Conclusions

Choosing interventions

- Supplementation
- Industrial fortification
- Biofortification
- Dietary diversification
- Nutrition education
- Behaviour change
- Poverty reduction



Cost-effectiveness of interventions

- Clinicians/nutritionists: interest in whether or how an intervention is effective
- Policy makers/budget planners: interest in whether costs can be accommodated within limited budget
- Need to assess interventions also economically, i.e. need to compare costs and benefits/effects
- Need to standardise and measure the health effect of an intervention

Quantification of poor health

- Common *ad hoc* measures for malnutrition:
  - prevalence rates (how many suffer?)
  - mortality rates (how many died?)
  - adequacy of intakes (how many are at risk?)
- Incomplete: how many suffer – but how much?
  - VA def.: night-blindness vs. permanent blindness
- Difficult to compare across deficiencies, e.g.:
  - iron def.: relatively low mortality but high prevalence
- Some measures from health economics may be inequitable (cost of illness, willingness-to-pay)

Quantification of poor health

- A more comprehensive measure that is also used by the World Bank or the WHO are "disability-adjusted life years" or DALYs
- Slightly different methodologies, but DALYs are
  - quantified based on the severity of a health outcome
  - expressed in common units of "lost health" (DALYs)
  - can be summed up across different health outcomes (e.g. measles, corneal scars, blindness, mortality)

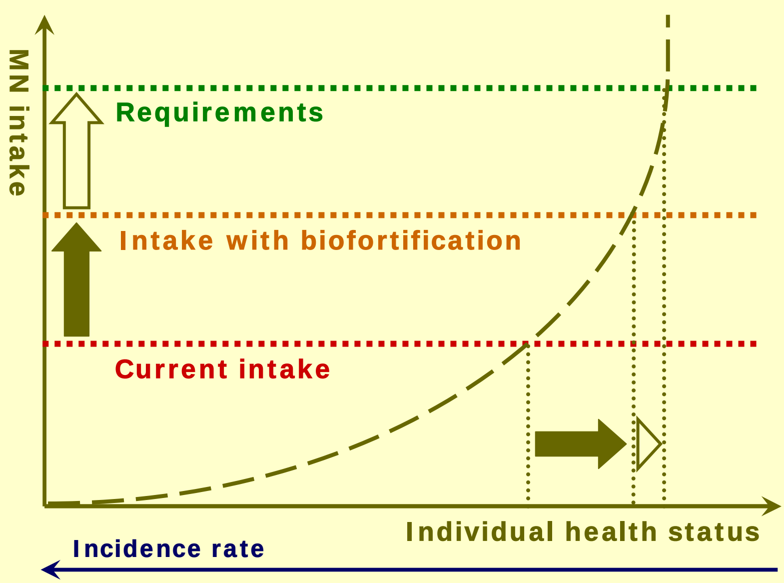
Disability-adjusted life years

- The burden of a disease is the sum of years of life lost (YLL) due to mortality and the years lived with disability (YLD)

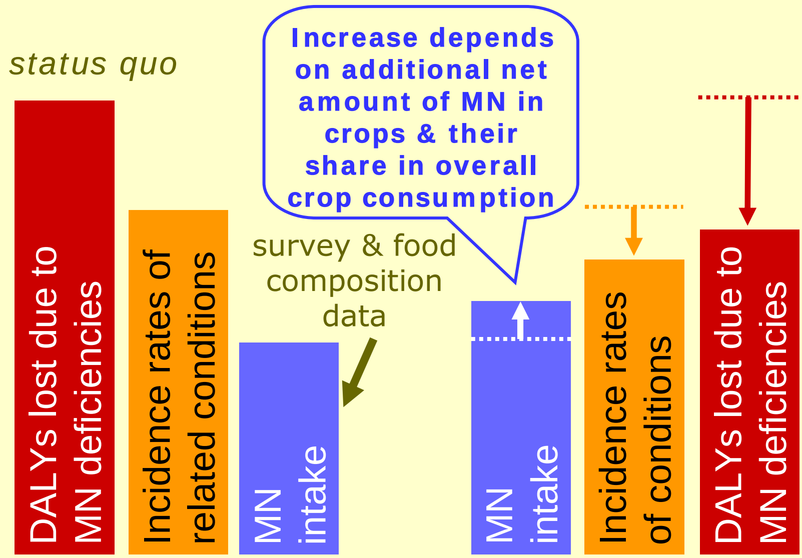
  Burden of disease = $DALYs_{lost} = YLL + YLD_{weighted}$

  - YLD are made comparable to YLL by weighting each disease according to the degree of disability it causes
  - The corresponding "disability weights" range from 0 (perfect health) to 1 (death)
  - Other elements (for each disease): size of target group, mortality rate, incidence rate, duration
  - Data from health statistics or expert consensus

Linking poor health & malnutrition



Impact of biofortification



Inter-disciplinary input: health, nutrition, agriculture, economics

Assumptions used for India

	Fe-rich rice	Fe-rich wheat	Zn-rich rice	Zn-rich wheat	Golden Rice
Baseline MN content	3 ppm	38 ppm	13 ppm	31 ppm	0 µg/g
Increase % (pess./opti.)	100 / 167	20 / 60	54 / 169	20 / 120	∞
New content (pess./opti.)	6 / 8	46 / 61	20 / 35	37 / 68	14 / 31
Coverage % (pess./opti.)	20 / 50	30 / 50	20 / 50	30 / 50	10-20 / 50-100
Post-harvest loss %	Conventional breeding → no change expected				80 / 35
Bioavailabil. (βC:VA)					6:1 / 3:1

Expected impact on IDA in India

Only single-nutrient considered		DALYs saved (per year)	Reduction of burden
Status quo for Fe deficiency		***4.0 million DALYs lost***	
Fe rice & wheat	optim.	2.3 m	-58%
	pessim.	0.8 m	-19%
Fe rice	optim.	1.5 m	-38%
	pessim.	0.5 m	-12%
Fe wheat	optim.	1.0 m	-26%
	pessim.	0.3 m	-7%

Expected impact on ZnD in India

Only single-nutrient considered		DALYs saved (per year)	Reduction of burden
Status quo for Zn deficiency		***2.8 million DALYs lost***	
Zn rice & wheat	optim.	1.4 m	-51%
	pessim.	0.56 m	-20%
Zn rice	optim.	1.2 m	-41%
	pessim.	0.5 m	-18%
Zn wheat	optim.	0.33 m	-12%
	pessim.	60,000	-2%

Expected impact on VAD in India

Only single-nutrient considered		DALYs saved (per year)	Reduction of burden
Status quo for VA deficiency		***2.3 million DALYs lost***	
Golden Rice	optim.	1.4 m	-59%
	pessim.	0.2 m	-9%

- Currently 71,600 children die each year due to VAD
- With Golden Rice 5,500-39,700 lives (pess./opti.) could potentially be saved

Costs attributed to India (Fe & Zn)

	Rice (Fe & Zn)		Wheat (Fe & Zn)	
	opti.	pess.	opti.	pess.
Average annual costs (US$)				
Share of internat. R&D	0.2 m	1.1 m	0.3 m	1.1 m
In-country activities	0.5 m	0.8 m	0.5 m	0.8 m
Maintenance breeding	0.1 m	0.2 m	0.1 m	0.2 m
Discounted (3%)	*national annual average US$ 80,000-180,000*			
Anaemia programme	*only tablets for 50% of target pop. = US$ 5.2 m*			
Duration of activity				
International R&D	6 years	8 years	7 years	9 years
In-country activities	3 years	5 years	5 years	7 years

Costs attributed to India (GR)

- (Share of internat. R&D: US$ 3.3-7.5 million)
- R&D within India: US$ 0.8-1.2 million
- Regulatory process: US$ 2.2-2.5 million
- Duration until release: 10-12 years
- Social marketing: US$ **30.7-15.6** million
- Maintenance breeding: US$ 1.9-2.1 million
- Average annual cost at national level (3%): US$ 0.8-0.5 million

Cost-effectiveness of interventions

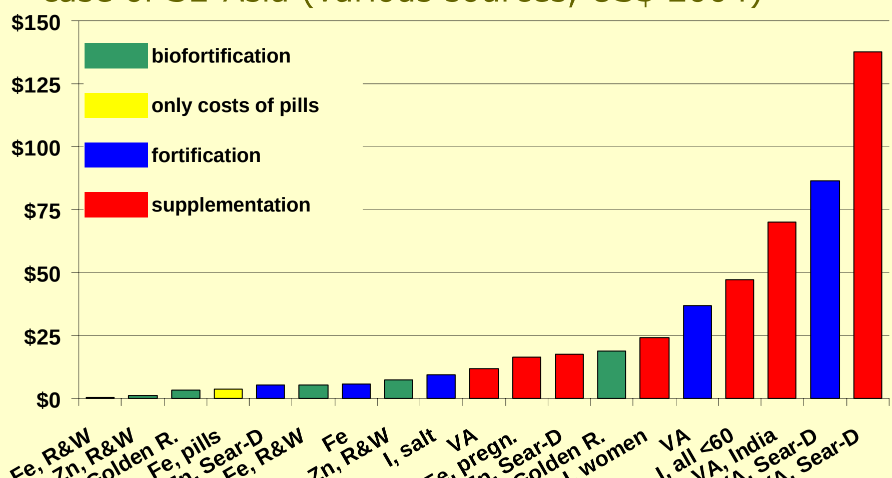
(Incl. internat. R&D costs)	US$/DALY saved		US$/life saved	
	opti.	pess.	opti.	pess.
Fe (rice & wheat)	0.5	5.4		
Other Fe interventions	5-15			
Zn (rice & wheat)	0.7	7.3	12	115
Zn fortification	~15			
Golden Rice (*US$ 0.0007-0.0009 p.c./y*)	3.1	19	54	358
Other VA interventions	85-600			
World Bank benchmark	60-200			
WHO benchmark (GDP/p.c.)	620-1860			

Cost-eff. of dietary diversification

- Cost and cost-effectiveness figures for dietary diversification are less readily available
  - Ruel (2001) does not review cost-effectiveness of food-based interventions because "such studies are noticeably absent from the literature"
  - World Bank (1994): to educate consumers about VA and stimulate production of VA-rich foods costs 8 US$/person/year (incl. extra cost of VA-rich foods)
  - e.g. Tan-Torres et al. (2005): nutrition counselling against undernutrition costs 8,000-42,000 $/DALY
  - But dietary diversification & nutrition education are more holistic and improve nutrition more generally

Cost-effectiveness overview

- Cost-effectiveness of MN interventions in general or case of SE-Asia (various sources, US$ 2004)



The return on biofortification

- Communication with policy makers: simple figures in financial terms matter!
- In India 0.8% to 2.5% of GDP are lost due to MN deficiencies → high economic gains if deficiencies can be controlled (cost-) effectively
- With a monetary value of 1,000 US$/DALY, for India the internal rate of return is:
  - 61% to 168% for iron biofortification
  - 56% to 150% for zinc biofortification
  - 35% to 77% for Golden Rice

HarvestPlus biofortification CEAs

- Beta-carotene cassava: **8**-125 up to 120-**1000** US$/DALY (Congo & Nigeria, Northeast Brazil)
- Beta-carot. maize: 11-18 up to 110-290 US$/DALY
- Beta-carotene sweetpotato: 9-30 US$/DALY
- Iron beans: 20-65 up to 135-440 US$/DALY
- Iron rice: 5-55 up to 17-235 US$/DALY
- Zinc beans: **150**-575 up to 1500-**6000** US$/DALY (Northeast Brazil, Honduras & Nicaragua)
- Zinc wheat: 2.50-18 US$/DALY (Pakistan)

Factors that affect results

- Effectiveness:
  - Success of breeding to increase MN content?
  - Seed replacement/adoption of crops?
  - Export/import of (biofortified) crops?
  - Importance of target crops in daily diets?
  - Bioavailability/net uptake of MN by individuals?
  - Prevalence/severity of the deficiency?
- Costs & cost-effectiveness:
  - Free suitable germplasm available?
  - Number of crop varieties to be biofortified?
  - Absolute size of target group?

Conclusions

- Biofortification *can* be a very cost-effective intervention that may help considerably in controlling MN deficiencies
- The actual impact and cost-effectiveness depends, however, on various factors (previous slide)
- Given economies of scale (i.e. the possibility to divide its fixed costs), biofortification could be considered on a bigger, cross-country scale
- An ex-ante assessment is needed before starting biofortification efforts (crop? MN?) or before considering alternative/complementary measures

Thank you very much for your attention!

Alexander J. Stein ▪ http://www.AJStein.de

Acknowledgements: Matin Qaim (Univ. of Goettingen), J.V. Meenakshi (HarvestPlus), H.P.S. Sachdev (Sitaram Bhartia Institute), Penelope Nestel (Univ. of Southampton), Zulfiqar Bhutta (Aga Khan University), HarvestPlus/IFPRI, Golden Rice Humanitarian Board, German Research Foundation (DFG)

Back-up

Scope of MN deficiencies in India

- Estimated prevalence of IDA in India:
  - 30% of children under 5 years
  - 15% of children 6-14 years
  - 8.5% of women and 4% of men
- 26% of population at risk of inadequate Zn intake
- >35 m children under 5 suffer from VAD (~20%)

MN interventions in India

Coverage of MN interventions in India (MI 2005)

- VA capsules: 34% of pre-school children 2 doses (other MI publications: 24% receive 1 dose)
- Iron tablets:
  - 30% of pregnant women consuming tablets
  - 10% of adolescent girls receiving it (compliance?!)
- Iron-fortified and VA-fortified foods: <1% each
- Iodised salt: 37% of households (50% in 1995!)
- Zinc: no significant intervention
- Dietary diversification: no bigger programme

Fiedler & Sanghvi (2007): Costs of micronutrient interventions?

- The most cost-effective public health interventions
- but enormous variation in estimated costs depending on programme, intervention, delivery system, country, etc. → not useful generalising
- cost per life saved for VA supplementation is US$ 711 (US$ 90-3383) → US$ 54-358 Golden R.
- 65% of cost in VA supplementation is personnel, 90% of cost in fortification are the fortificants
- more needs to be learned about
  (i) government regulatory and enforcement costs,
  (ii) public education costs

Horton (2006): Economics of fortification

- Fortification is a high-priority investment
- the long-run aim is to diversify people's diets to meet their needs; fortification cannot solve all problems
- fortification works well if there are widespread deficiencies and/or if the cost of the fortificant is not too high
- fortification requires a suitable food vehicle: e.g. those living in remote geographic areas and not utilising purchased foods are hard to reach
- it is harder to reach the poorest who are the most price sensitive and who buy lower grade items that are less likely to be fortified
- biofortification is promising; for rice it is of particular interest because it is more difficult and costly to fortify rice otherwise; preliminary work suggests it could be very cost effective

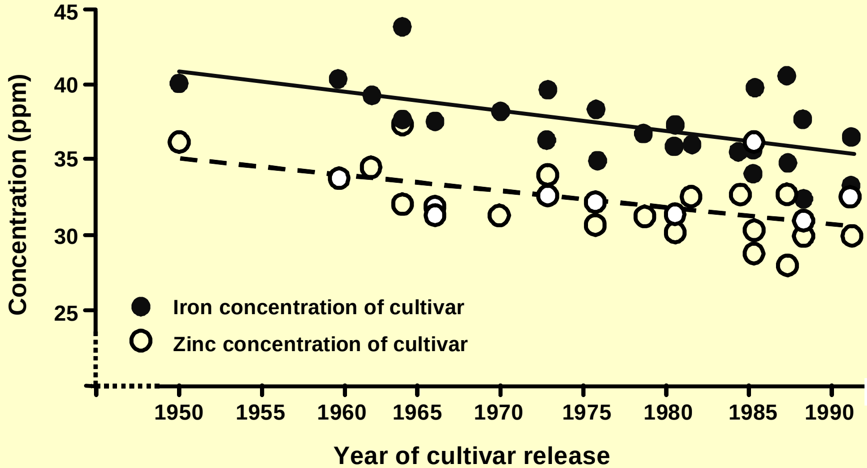
Bioavailability of MNs from biofortified crops

- "The efficacy of consuming high-iron rice was tested during a 9-mo feeding trial with a double-blind dietary intervention [...] The greatest improvements in iron status were seen in those nonanemic women who had the lowest baseline iron status and in those who consumed the most iron from rice. Consumption of biofortified rice, without any other changes in diet, is efficacious in improving iron stores of women with iron-poor diets in the developing world" (Haas et al. 2005)
- "We grew Golden Rice in heavy water and produced intrinsically labeled rice to be fed to subjects. [...] The results from the sample analysis tell us that both acute dose and multiple dose studies showed very effective conversion of β-carotene to retinol. Golden Rice is one of the most bio-available plant foods to provide vitamin A" (Tang et al. 2007)

Feasibility of breeding crops for higher mineral content

- Perspective: ... mineral malnutrition presents a significant global challenge. ... The ultimate solution is dietary diversification, but this is not immediately practical. In the meantime, biofortification of edible crops is advocated through either mineral fertilization and/or plant breeding. ... plant breeding might provide a more sustainable and cost-effective solution in the long run... There is ample natural genetic variation to enable increased mineral concentrations in edible portions of crop plants to be selected and bred for without affecting yield or quality. ... (White and Broadley 2007).

Iron and zinc concentrations in wheat cultivars released by CIMMYT



Source: Monasterio and Graham (2000).

Nutrient balances in a wheat-growing soil of South Australia

Element	Amount removed in grain		Total amount in deficient soil		Equivalent crops	Amount extractable from deficient soil		Equivalent crops
	(milligrams per kilogram)	(grams per hectare)	(milligrams per kilogram)	(grams per hectare)	(number)	(milligrams per kilogram)	(grams per hectare)	(number)
Nitrogen	20,000	30,000	1,200	2×10^6	67	12	20,000	0.67
Phosphorus	2,000	3,000	250	3.8×10^6	1,250	5	75,000	25
Copper	2	3	3	45,000	15,000	0.3	4,500	1,500
Zinc	20	30	5	75,000	2,500	0.3	4,500	150
Manganese	33	50	10	150,000	3,000	1	15,000	300
Molybdenum	0.1	0.15	1	15,000	100,000	0.05	750	5,000

Source: Graham 1978.

Strengths & weaknesses of interv.

- Supplementation
  - potentially very quick & effective
  - recurrent costs – donor/government commitment?
  - resource intensive (e.g. trained staff needed)
  - special distribution – coverage?
  - increasing marginal costs (e.g. for remote areas)
  - targeting possible – compliance?
  - monitoring possible
- Fortification
  - fits into food habits & consumption patterns
  - central processing – monitoring of industry necessary
  - recurrent costs (usually for consumers)
  - targeting – do the poor eat processed food items?
  - compliance? (if commercial and not mandatory)

Strengths & weaknesses of interv.

- Biofortification
  - fits into food habits & consumption patterns
  - mostly only start-up costs (for R&D and distribution) → economies of scale through expansion
  - cost-neutral, distribution via normal food chain
  - self-targeting through focus on staple crops
  - decentralised, on farmers' fields
  - compliance in case of beta-carotene?
  - in some cases recourse to genetic engineering
  - slower process & lower MN levels but less costly & more sustainable

Strengths & weaknesses of interv.

- Dietary diversification
  - empowers consumers
  - provision of multiple micronutrients
  - recurrent costs for new/different food items (also e.g. labour & inputs for home gardens)
  - start-up costs for nutrition education
  - compliance? (behaviour/diet change)
  - scope of programmes limited
  - long-term & costly but sustainable when established
  - less studied than other interventions

Scope and time frame of biofortification

- "We all envision a future when nutrition education and increased incomes of the poor will be combined with greater availability and lower food prices to improve dietary quality. However, this will require the eventual investment of many billions of dollars by small farmers, the business sector, and governments over several decades to increase the production and availability of these nutrient-rich, non-staple foods. In the meantime, specific agricultural strategies can be implemented to improve nutritional status. One of these is 'biofortification' – breeding for micronutrient-dense staple food crops, a strategy of getting plants to fortify themselves" (Bouis 2002).

The rationale for looking at the cost-effectiveness of interventions

- Determining the effectiveness of health interventions is necessary but not sufficient: in a world of scarcity (relative) costs matter
- Because interventions differ in cost-effectiveness, "making allocative decisions badly [...] costs lives. [...] Insisting on value for money is not only fully consistent with compassion for the victims of disease, it is the only way to avert needless suffering" (World Bank 1993).
- The WHO's CHOICE Team (Evans et al. 2005) finds that "making best use of resources is vital in developing countries that are struggling to improve public health with limited funds."

References (I)

Bouis, H.E. (2002). Three criteria for establishing the usefulness of biotechnology for reducing micronutrient malnutrition. *Food and Nutrition Bulletin* **23**: 351-353.

Chadha, M.L. & M.O. Oluoch (2003). Home-based vegetable gardens and other strategies to overcome micronutrient malnutrition in developing countries. *Food, Nutrition and Agriculture* **32**: 17-23; http://www.fao.org/DOCREP/005/y8346m/y8346m00.htm

Evans, D.B., T. Adam, T. Tan-Torres Edejer et al. (2005). Time to reassess strategies for improving health in developing countries. *British Medical Journal* **331**: 1133-1136.

Fiedler, J., M. Saunders & T. Sanghvi (2007). What are the costs of interventions? *Food and Nutrition Bulletin* **28**: S197-S203.

Gillespie, S. (1998). Major issues in the control of iron deficiency. Micronutrient Initiative, Ottawa.

Haas, J.D., J.L. Beard, L.E. Murray-Kolb et al. (2005). Iron-biofortified rice improves iron stores in non-anemic Filipino women. *Journal of Nutrition* **135**: 2823-2830.

Horton, S. (2006). The economics of food fortification. *Journal of Nutrition* **136**: 1068-1071.

Meenakshi, J.V., N. Johnson, V.M. Manyong et al. (2007). How cost-effective is biofortification in combating micronutrient malnutrition? *HarvestPlus Working Paper* **2**, International Food Policy Research Institute, Washington, DC. http://www.harvestplus.org/pubshp.html#wp

MI (2005). Controlling vitamin & mineral deficiencies in India. Micronutrient Initiative, New Delhi; http://www.micronutrient.org/resources/publications/Controlling%20VMD%20India.pdf

Monasterio, I. & R.D. Graham (2000). Breeding for trace minerals in wheat. *Food and Nutrition Bulletin* **21**: 392-396.

Qaim M., **A.J. Stein** & J.V. Meenakshi (2006). Economics of biofortification. Plenary paper, 26th Conference of the International Association of Agricultural Economists, August 12-18, Broadbeach. http://agecon.lib.umn.edu/cgi-bin/detailview.pl?paperid=22998

References (II)

Ruel, M.T. (2001). Can food-based strategies help reduce vitamin A and iron deficiencies? International Food Policy Research Institute, Washington, DC. http://www.ifpri.org/pubs/fpreview/fpreview05.pdf

SCN (2004). Fifth Report on the World Nutrition Situation. UN System, Standing Committee on Nutrition, Geneva. http://www.unsystem.org/scn/Publications/html/RWNS.html

Stein A.J., J.V. Meenakshi, M. Qaim et al. (2005). Analyzing the health benefits of biofortified staple crops by means of the Disability-Adjusted Life Years approach. *HarvestPlus Technical Monograph* **4**, International Food Policy Research Institute, Washington, DC. http://www.harvestplus.org/pubshp.html#tech

Stein A.J., M. Qaim, J.V. Meenakshi et al. (2006). Potential impacts of iron biofortification in India. *Research in Development Economics and Policy* **4**, University of Hohenheim, Stuttgart. http://www.uni-hohenheim.de/i490a/dps/dps_06.html

Stein A.J. (2006). *Micronutrient malnutrition and the impact of modern plant breeding on public health in India: how cost-effective is biofortification?* Cuvillier Verlag, Göttingen. http://deposit.d-nb.de/cgi-bin/dokserv?idn=980792789

Stein A.J., H.P.S. Sachdev & M. Qaim (2006). Potential impact and cost-effectiveness of Golden Rice. *Nature Biotechnology* **24**: 1200-1201. http://dx.doi.org/10.1038/nbt1006-1200b

Stein A.J., P. Nestel, J.V. Meenakshi et al. (2007). Plant breeding to control zinc deficiency in India: how cost-effective is biofortification? *Public Health Nutrition* **10**: 492-501. http://dx.doi.org/10.1017/S1368980007223857

Stein A.J. & M. Qaim (2007). The human and economic cost of hidden hunger. *Food and Nutrition Bulletin* **28**: 125-134.

Stein A.J., H.P.S. Sachdev & M. Qaim (2007). What we know and don't know about Golden Rice. *Nature Biotechnology* **25**: 624. http://dx.doi.org/10.1038/nbt0607-624a

References (III)

Stein A.J., H.P.S. Sachdev & M. Qaim (2008). Genetic engineering for the poor: Golden Rice and public health in India. *World Development* **36**: in press. http://dx.doi.org/10.1016/j.worlddev.2007.02.013

Talukder, A. L. Kiess, N. Huq, et al. (2000). Increasing the production and consumption of vitamin A-rich fruits and vegetables. *Food and Nutrition Bulletin* **21**: 165-172. http://www.unu.edu/unupress/food/fnb21-2.pdf

Tan-Torres Edejer, T., M. Aikins, R. Black et al. (2005). Cost effectiveness analysis of strategies for child health in developing countries. *British Medical Journal* **331**: e1177.

Tang, G., J. Qin, M.A. Grusak & R.M. Russell (2007). Quantitative determinations of vitamin A value of Golden Rice given as single or multiple meals. Poster presented at the Micronutrient Forum, Istanbul, 16-18 April 2007; http://www.ars.usda.gov/research/publications/Publications.htm?seq_no_115=210533

World Bank (1993). World Development Report 1993. World Bank, Washington, DC.

World Bank (1994). Enriching lives: overcoming vitamin and mineral malnutrition in developing countries. World Bank, Washington, DC. http://www.worldbank.org/html/extdr/hnp/nutrition/enrich.htm

White, P.J. & M.R. Broadley (2007). Biofortifying crops with essential mineral elements. *TRENDS in Plant Science* **10**: 586-593. http://dx.doi.org/10.1016/j.tplants.2005.10.001

WHO (2001). Macroeconomics and health: investing in health for economic development. World Health Organization, Geneva. http://whqlibdoc.who.int/publications/2001/924154550X.pdf

Zimmermann, R. & M. Qaim (2004). Potential health benefits of Golden Rice: a Philippine case study. *Food Policy* **29**: 147 168.