The potential of biofortification of rice, beans, cassava and maize throughout Latin America

International Food Policy Research Institute, Washington, DC

Contract No. 2010X012STE

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Summary

AgroSalud is a research project coordinated by the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia, that aims to increase food and nutrition security in Latin America through biofortification – i.e. through plant breeding with the objective of increasing the nutrient content in staple crops. Thus AgroSalud should help prevent the negative economic and health consequences of malnutrition, in particular of iron, zinc, vitamin A and protein deficiency. The objective of the present study was to evaluate the cost-effectiveness of current AgroSalud crops to inform funding priorities for micronutrient biofortification in the region.

For this ex ante evaluation a commonly used methodological framework based on "disability-adjusted life years" (DALYs) was used. The data for the analysis was mostly taken from current and previous analyses done by AgroSalud and from personal interviews and communications with the experts involved in the project. For nine country-crop combinations enough data could be compiled to carry out an assessment of the biofortified crops in the form of case studies.

The analysis not only determined the burden of micronutrient deficiencies in various countries in the region, it also showed that in case of successful biofortification efforts and if a high degree of consumption of the crops can be achieved, biofortification can eliminate wide-spread mineral deficiencies and considerably reduce the burden of vitamin A deficiency in the target countries. Furthermore the analysis has shown that on average also in Latin America biofortification promises to be a cost-effective micronutrient intervention.

The analysis has also shown that biofortification is more cost-effective if it is done at the international level, covering several countries and thus realising economies of scale. Of the individual crops evaluated in this report, those targeting iron deficiency are the most cost-effective ones. The crops targeting vitamin A deficiency also have some potential, however, uncertainties about their acceptance and some of the data do not allow an unequivocal statement. Finally, the crops aimed at controlling zinc deficiency are at best as cost-effective as industrial zinc fortification is projected to be. Hence, a more careful and qualitative analysis on a case-by-case basis may be required to decide which of the alternative interventions is preferable – or to determine to what extent they complement each other.

Sensitivity analyses that probed the impact of changes to key parameters showed that the results are very robust; only changes in the coverage rates of the crops have the potential to influence the outcomes considerably. This corresponds to the underlying economic rationale of biofortification, which is the exploitation of economies of scale. Therefore, investing in the dissemi-

nation of the biofortified crops is paramount. In this context a more structural limitation for AgroSalud is the relative smallness of its target countries (apart from Brazil and to some extent Mexico), which also limits a scaling up. This may be addressed though more international coordination of basic biofortification efforts, beyond Latin America. Otherwise the use of potential synergies in the execution of the in-country activities could also help improve the economics of the AgroSalud crops. And in places where biofortification cannot immediately have an impact, because other programmes are already in place to control micronutrient deficiencies, it may be worth considering whether biofortification can help scaling back more costly interventions.

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1 Introduction

Biofortification, in its broadest definition, is the process of adding nutritional value to a crop (Montagnac et al. 2009). In this analysis biofortification refers to micronutrient enrichment of staple crops through plant breeding to address the negative economic and health consequences of vitamin and mineral deficiencies in humans (Nestel et al. 2006). Apart from such "genetic" biofortification also "agronomic" biofortification, i.e. the application of mineral fertilisers to increase the mineral content in crops, is an approach that is currently being investigated (e.g. White & Broadley 2009, Cakmak 2008). This latter approach will not be considered further in the present study, in particular because its potential impact and cost-effectiveness are still unclear and therefore no comparisons are possible. Hence, in the present document, "biofortification" refers to the plant breeding approach only.

There is general agreement that dietary diversification would be the ideal remedy to address micronutrient malnutrition, but it is also understood that it is often difficult to achieve in resource-poor areas of the world, at least in the short to medium term (e.g. Bouis 2002). Therefore, in the past, pharmaceutical supplementation and industrial fortification were favoured as interventions to control vitamin and mineral deficiencies. In this context biofortification has to be seen as a new, food-based intervention that relies on agriculture to increase the nutritional quality of crops. As such, biofortification has the potential to complement the existing micronutrient interventions, in particular by targeting the rural poor who eat large quantities of staple crops and often have little access to commercially processed food – i.e. among whom the impact of industrial fortification is limited (e.g. Tanumihardjo et al. 2008). Moreover, if the coverage of the public health system in rural areas is patchy, also the impact of pharmaceutical supplementation in these areas is limited. Apart from this advantage of extending the reach of micronutrient strategies, biofortification also promises to be more cost-effective than current micronutrient interventions – which themselves are already considered to be cost-effective public health interventions (e.g. Meenakshi et al. 2009, Qaim et al. 2007). This economic advantage is due to economies of scale that can be realised in the development of biofortified crops: unlike industrial fortification and pharmaceutical supplementation that incur variable costs for each micronutrient dose delivered, the cost for the development of biofortified germplasm represents a fixed cost and therefore unit costs fall for each additional micronutrient dose delivered through a biofortified crop (even if there are also variable costs that need to be incurred for the dissemination of biofortified crops).

AgroSalud, a biofortification research project funded by the Canadian International Development Agency (CIDA) and coordinated by the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia, aims to increase food and nutrition security among vulnerable populations living in Latin America and the Caribbean through biofortified crops.[1] In the context of a review of AgroSalud by HarvestPlus,[2] the objective of the present study is to evaluate the cost-effectiveness of biofortification of rice, beans, cassava and maize in Latin America to inform funding priorities for biofortification in the region (see Table 1 for the crop-nutrient combinations of interest to HarvestPlus and the corresponding target countries of AgroSalud).

Table 1: Crop-nutrient combinations and potential target countries considered in this study

	Iron-rich rice	Zinc-rich rice	Iron-rich beans	Zinc-rich beans	Zinc-rich maize	bC-rich maize	bC-rich cassava	Total
Bolivia	X							1
NE-Brazil	X		X					2
El Salvador		X		X	X			3
Guatemala				X	X			2
Haiti	X	X	X	X	X	X	X	7
Honduras		X		X	X			3
Mexico						X		1
Nicaragua		X		X	X			3
Total	3	4	2	5	5	2	1	22

Note: bC = beta-carotene. Source: Pachón (2010).

The aim of these biofortification efforts is to help address iron deficiency (FeD), zinc deficiency (ZnD) and vitamin A deficiency (VAD) in the region. In as far as data availability permits, the evaluation includes (1) an ex ante impact assessment of the number of DALYs that can be saved through biofortification of these four crops in Latin America and (2) a ranking of the crop-nutrient combinations and countries. On the latter further recommendations are based regarding the modification of current AgroSalud priorities. As far as possible, the study also considers the cost-effectiveness of alternative interventions and comments on other impact assessment work that has been conducted by AgroSalud. While so far already various impact assessments or economic evaluations of biofortified crops have been carried out in case studies of individual

[1] For more details about the project and the organisations involved see http://www.AgroSalud.org/, http://www.acdi-CIDA.gc.ca/home and http://www.CIAT.cgiar.org/, respectively.

[2] For more details about HarvestPlus see http://www.HarvestPlus.org/.

crops or countries (Meenakshi et al. 2009, Stein et al. 2008a/b, 2007, 2006, Ma et al. 2007, Javelosa 2006, Zimmermann & Ahmed 2006, Sandler 2005, Zimmermann & Qaim 2004, Dawe et al. 2002), this study represents a comprehensive evaluation of a complete set of biofortified crops in an entire world region.

2 Methods

For the ex ante evaluation of biofortified crops a common methodological framework has crystallised (Meenakshi et al. 2009, Stein et al. 2008a/b, 2007, 2006, Ma et al. 2007, Javelosa 2006, Zimmermann & Ahmed 2006, Sandler 2005, Zimmermann & Qaim 2004). This framework builds on "disability-adjusted life years" (DALYs), which are frequently used to measure the burden of disease in developing countries.[3] Specifically for the use in impact assessment and cost-effectiveness studies of biofortification, the DALYs method has been developed further (Stein et al. 2005). Within this framework, the number of DALYs that can be saved through the consumption of biofortified crops are estimated to measure the potential health impact of these crops. In a subsequent step this health benefit is then used for cost-effectiveness analyses (CEAs) of the biofortification efforts. Given the widespread use of DALYs, also in CEAs, this framework is also used in the present study. Thus the results are comparable not only across the results of previous work on biofortified crops, they can also be used to compare the cost-effectiveness of biofortification versus other micronutrient interventions or public health interventions. Such comparisons are useful for decision makers and donors alike to ensure that scarce resources are spent on the most efficient and promising projects, thereby maximising the impact on public health.

While some previous studies of biofortified crops have used detailed household data to simulate the impact of the consumption of biofortified crops at the level of the individual (Stein et al. 2008a/b, 2007, 2006), the other studies used average consumption data to derive the impact of biofortification on the burden of micronutrient deficiencies in the respective region. As Meenakshi et al. (2009) have used the same data to calculate the impact of iron-rich and zinc-rich rice and wheat in India as have Stein et al. (2008a, 2007) – but using average consumption figures to be consistent with the other case-studies in that paper – the results of these two studies can be compared. Table 2 shows that both methods can indeed yield similar results (for iron-rich wheat and zinc-rich rice), but that this need not be the case (for iron-rich rice and zinc-rich wheat).

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[3] For instance DALYs are used by the World Health Organization (WHO), see http://www.WHO.int/topics/Global_Burden_of_Disease/.

However, even in the cases where there is a bigger difference in the results when using the two methods, the orders of magnitude of the results are still comparable – in a note to their analysis, Meenakshi et al. (2009) write that the figures are "somewhat different". Also, across all case studies the average results are similar. Hence, while using average data my not yield the precise results that can be obtained from individual data, the results may nevertheless be used to gauge the overall impact and cost-effectiveness of a programme, in particular as doing the analyses with individual data is much more resource intensive (both in terms of time and data needed). Given these practical considerations, in the following only average consumption data are used.

When calculating the efficacy of the biofortified crops in decreasing the adverse health outcomes of the respective micronutrient deficiency (see "dose-response" in Stein et al. (2005) and Meenakshi et al. (2009)), recommended dietary allowances (RDAs) rather than estimated average requirements (EARs) were used as threshold for sufficiency. RDAs were primarily used to obtain a set of results based on a consistent methodology across the various studies mentioned above; otherwise there are conceptual considerations that support the use of EARs as threshold in the assessment of group intakes (Stein 2006, Stein et al. 2008a, Pachón 2010). As EARs are lower than RDAs, it would be easier for the biofortified crops to close the intake gap and achieve sufficiency, i.e. by using RDAs the impact of the biofortified crops is underestimated.

Table 2: Results for biofortification in India with intake data at different levels of aggregation

	Reduction of burden (percent)		**Cost per DALY saved (USD)**	
	Individual data	**Average data**	**Individual data**	**Average data**
Iron-rich rice	12-38	5-15	0.3-4	3-17
Iron-rich wheat	7-26	7-39	0.6-9	1-10
Zinc-rich rice	18-41	20-56	0.4-4	1-6
Zinc-rich wheat	2-12	9-48	2-40	1-11
Average	10-29	10-39	1-14	2-11

Source: The results derived from average consumption data are taken from Meenakshi et al. (2009), the results derived from individual consumption data are taken from Stein et al. (2008a) for iron and from Stein et al. (2007) for zinc.

3 Data

The data used for the analysis is taken from current and previous analyses done by AgroSalud using CIAT's MAIN model (García Castro et al. 2008, Jacobsen 2008, Meenakshi et al. 2009, Pérez Suárez 2010, CIAT 2010). For nine country-crop combinations there is enough data to carry out sound ex ante impact assessments of the biofortified crops through individual country studies (Table 3). This data – mainly population, health and consumption data – has been checked for consistency and where necessary its validity has been confirmed by competent AgroSalud experts; for NE-Brazil and Mexico some additional or updated health data has also been added (DHS 1997, WHO 2009). Moreover, in the subsequent calculations the data has been complemented by integrating the estimated costs of the budget for the second phase of AgroSalud (Pachón 2010), by updating information on the likely biofortification successes and by additional cost information that was obtained from the respective AgroSalud experts (see in the following). Nevertheless, the cost estimates for the eventual distribution and marketing of the biofortified crops are only provisional and quite possibly they represent underestimations; overall the details of the eventual dissemination of the crops are not very clear yet.

Table 3: Data availability for ex ante country studies on the potential impact of target crops

	Iron-rich rice	Zinc-rich rice	Iron-rich beans	Zinc-rich beans	Zinc-rich maize	bC-rich maize	bC-rich cassava
Bolivia	n/a						
NE-Brazil	**OK**		**OK**				
El Salvador		n/a		n/a	n/a		
Guatemala				n/a	n/a		
Haiti	n/a	n/a	n/a	n/a	n/a	n/a	**n/a ***
Honduras		**OK**		**OK**	**OK**		
Mexico						**OK**	
Nicaragua		**OK**		**OK**	**OK**		

Note: NE-Brazil = Northeast Brazil; OK = data available to carry out an analysis; n/a = not enough data available for an analysis; * = provisional assumptions used.

To be able to include an assessment of the potential impact of beta-carotene-rich cassava, the data that was necessary to carry out an analysis of the impact of this crop in Haiti was derived from a number of assumptions and extrapolations from data from other countries (in consultation with Helena Pachón of AgroSalud and in addition to available health data and nutrition data (UNICEF 2010, WHO 2009, FAO 2009, Dessalines 2008). In the following, summaries of the personal communications by these latter experts are given crop-wise and subsequently the main assumptions are provided in an overview (Table 5 further below).

3.1 Rice

Personal communication by Jaime Borrero (CIAT, March 2010): The baseline content of Fe and Zn in rice in Latin America is 2-3 ppm and 17-18 ppm, respectively. With biofortification possible targets are 6 ppm for Fe and 22 ppm for Zn (and in pessimistic scenarios 4 ppm and 20 ppm, respectively). No post-harvest losses are expected to occur, neither is it expected that the bioavailability of the minerals changes. Currently, in 2010, the target levels are being achieved, i.e. by 2015 the mineral-rich rice can be available in agronomically interesting lines and distribution can start in 2020 (or in an optimistic scenario already directly in 2015). The share of biofortified rice in overall rice production that can be achieved realistically is 80 percent (with 70 percent representing a more pessimistic scenario). Target countries for biofortified rice are the Dominican Republic, Colombia, Brazil, Bolivia, Nicaragua, Cuba and Panama. (While in most of these countries the distribution systems are regular to good, it can be expected that it will take somewhat longer in Nicaragua.) Costs that arise in addition to the AgroSalud budget in each target country are the costs for 3-4 professionals that multiply the seeds over 2-3 years.

3.2 Beans

Personal communication by Stephen Beebe (CIAT, March 2010): The baseline content of Fe and Zn in beans is 55 ppm and 28 ppm, respectively. The target for biofortification is to reach 110 ppm for Fe and 50 ppm for Zn (or in a pessimistic scenario 95 ppm and 48 ppm, respectively). Under normal handling conditions that prevail in Latin America no post-harvest losses are expected (or in a pessimistic scenario they would not exceed 10 percent). The bioavailability of the additional Fe and Zn is expected to remain unchanged. The maximal share of biofortified beans in overall bean cultivation could reach 50 percent. It could take another 5 years to reach the optimistic levels of mineral content; after that it can take 10 years to reach the maximal coverage (or in a pessimistic scenario 20 years). To improve the adoption, new innovative options are needed (e.g. the generation of demand for biofortified beans through NGOs). Target countries within Latin America for the beans are Nicaragua, Honduras, Haiti, El Salvador, Guatemala, and Northeast Brazil (NE-Brazil); the Andean countries are less of a target as consumption there is lower. In addition to the AgroSalud budget, there is approx. one breeder per country who will (have to) dedicate about 33 percent of their time for 5-6 years for the necessary in-country work.

3.3 Cassava

Personal communication by Hernán Ceballos (CIAT, March 2010): The breeding target for beta-carotene in cassava is 15 µg per gram of fresh root (which corresponds approx. to 45 µg beta-carotene per gram of dry root). In 2010 this target has been achieved. Now the beta-carotene-trait will be combined with agronomic traits to ensure adoption by farmers and by 2015 the corresponding genotype should be available; then multiplication and promotion activities should last until 2020, when the biofortified cassava finally will be distributed to farmers. (However, already now cassava with 10 µg beta-carotene is being distributed!) The main agronomic trait that is being targeted is increasing the time to post-harvest physiological deterioration (PPD, which currently occurs already 24-48 hours after harvest). This reduces farmers' risk of losing their harvest (either before they can process it for own consumption or e.g. on the way to the market). It seems as if the antioxidative properties of beta-carotene actually help in reducing PPD. The breeding target of 15 µg was set in the belief that the conversion rate of the beta-carotene into retinol would be 12:1. However, feeding trials have shown that the conversion rate is around 4:1. The target region for biofortified cassava is (primarily) Africa. However, in Latin America also Haiti and NE-Brazil could be potential targets and to a lesser extent Paraguay, Colombia or the Dominican Republic (where the benefits could perhaps materialise rather in the poultry industry where beta-carotene-rich feed could eliminate the need to add beta-carotene as colouring for the egg yolk). In both former countries reaching a coverage of 25 percent is reasonable (in a pessimistic scenario 15 percent should still be reached). At least in Africa the colour change of the biofortified cassava should not pose a problem as people actually like colour, therefore sometimes e.g. palm oil is added to gari (cassava flour). Costs for the R&D have to be obtained from HarvestPlus. HarvestPlus will also have to support basic activities like bioavailability and effectiveness studies or the establishment of foundation planting material. However, there will be little need for dissemination activities, as plenty organisations (like HKI or World Vision) will take on this task (once effectiveness has been demonstrated).

Personal communication by Luis Becerra (CIAT, March 2010): In four years the beta-carotene content in cassava can be increased from the current 15 micrograms to 30 micrograms.

3.4 Maize

Personal communication by Gary Atlin (CIMMYT, March 2010): There is relatively little food use of yellow maize in tropical Latin America; high consumption rates of yellow maize are restricted to Panama and Haiti – which have maize consumption rates that are low for the region (20-25 kg per capita per year), although these rates are no doubt higher among the poor. The prospects for widespread adoption of yellow maize for food use in high maize consumption countries may be quite limited. To convert CIMMYT's best yellow quality-protein maize (QPM) open pollinated varieties (OPVs) to high pro-vitamin A and produce adequate foundation seed will take about three years, require the full-time attention of 1 technician and 2 assistants, as well as a total of 0.5 person years of a scientist; total cost would be approximately $200,000 per year.

For zinc potential impact is greater: There are already fairly high zinc levels in CIMMYT's elite white QPM germplasm and the demand for white maize for food in the region is much greater than for yellow maize. Generating and validating white maize hybrids and OPVs with levels around 40 ppm could be done within three years; to have large quantities of foundation seed ready for commercial seed production would take an additional year. Raising levels above 40 ppm would require a long-term breeding investment, but significant progress could be made in six years (although this would require a about $200,000 investment per year).

Personal communication by Kevin Pixley (CIMMYT, March 2010): For zinc the baseline content in maize is approximately 22 ug/g; 40 ug/g are the target level, with 31 ug/g representing an intermediate level for the breeding efforts. The target level could be reached by 2013-18 and the seeds could then be distributed to farmers by 2015-20. Post-harvest losses are not known, but could be negligible when the whole grain is consumed. Similarly, the bioavailability of the zinc in the maize is not known. 4-10 years after it has been released to farmers the zinc-rich maize could reach overall cultivation shares of 2-20 percent. Additional costs could arise for marketing.

The baseline content of beta-carotene in maize is 0 ug/g for white maize and 1.5 ug/g for yellow maize; the intermediate target in biofortified maize is 8 ug/g, with the final target being 15 ug/g of beta-carotene. CIMMYT may be ready to release cultivars at the intermediate target level within 3-4 years; the complete target will likely take 6-10 years. At about the same time the first seeds can then be distributed to farmers. Beta-carotene maize may be ready for distribution to farmers 1-2 years earlier than zinc maize, i.e. it may be ready by 2014-18 as there are already some pretty good hybrids that have been evaluated in yield trials. Post-harvest losses of beta-carotene are expected to be about 50 percent from harvest to plate and the expected bioavailability of the beta-carotene in the maize could be as high as 3:1 (according to two studies) or as low as 12:1 (with a pessimistic view). But a realistic estimate is rather around 6:1. Beta-carotene maize in Mexico will be accepted first and foremost for use in the chicken feed industry; the area of cultivation may grow within the range suggested for zinc (2-20 percent), but the consumption as human food will likely be slower than the 4-10 years used for zinc; for sure it takes longer than that for most new varieties to become popular and gain market share. Regarding the marketing of beta-carotene maize, a bare-bones approach would involve mostly radio messages, while more aggressive strategies would include television, magazines, free sample distribution, etc. (The difference between success and failure of two equally good varieties is usually marketing.)

3.5 Seeds

Personal communication by Edgar Burbano (CIAT, March 2010): There can be considerable differences regarding the coverage rate of the biofortified seeds if not the whole country is considered but rather the actual target region. For instance, while with 2-3 materials of quality-protein maize (QPM) a coverage of 5 percent over three years and 10 percent over ten years may be achieved in all of Colombia, in the same times the coverage in areas where malnutrition is prevalent may reach 25 percent and 50 percent, respectively. To commercialise newly developed material in Colombia, the material first needs to be increased, then, to be legalised, the official agricultural evaluation trials (Pruebas de Evaluación Agronómicas, PEA) have to be conducted before the material can be registered, and finally the seeds have to be certified. The PEA costs 6,300,000 COP for the trial of 1-9 materials in 1-3 zones. In addition staff costs of 6,000,000 COP have to be considered. The registration of the material itself, with the "Comité Nacional de Cultivares", costs again 1,600,000 COP per material. Finally, the costs for the maintenance of the trait in future seeds is about 10,000,000 COP per year. For logistics and distribution another 50,000 USD could be needed to support local administrations, NGOs or companies. The actual costs for the multiplication of the certified seed will be borne by the seed companies (with which CIMMYT and CIAT seek to collaborate), as they get the biofortified material for free but can hope to sell the seeds easier as they are superior to the normal seeds while the costs for the company are the same. (Currently in Colombia one kilogram of conventional seeds costs around 5,000-6,000 COP, which is also the price for QPM seeds; hybrid seed sells at 15,000 COP and GM seeds sells at 35,000 COP.)

4 Results

For this study, for nine country-crop combinations there was enough data to carry out sound ex ante impact assessments of biofortified crops through individual country studies (Table 3). In addition, to include an assessment of the potential impact of beta-carotene-rich cassava, an analysis was carried out for the impact of this crop in Haiti based largely on a number of assumptions and extrapolations from data from other countries, i.e. these results have to be interpreted cautiously. To give an overview of the burden of the micronutrient deficiencies in the target countries, the absolute and relative numbers of DALYs lost due to the respective deficiency are provided in Table 4. Then the impact and cost-effectiveness results for the individual crop-nutrient combinations in each target country are reported in Table 6 and the results for overall diet-nutrient combinations in each target country are reported in Table 7. For comparison, Table 8 provides an overview of the impact and cost-effectiveness of other micronutrient interventions in Latin America. These latter results were estimated within the CHOICE project of the World Health Organization (WHO 2010), for which a similar methodology is used (see fn 3). Here, as far as possible, the results are reported in the same format to facilitate comparison.

Table 4: Key data for the target countries

		Population (million)	GNI per capita (USD)	DALYs lost ('000)	DALYs lost per 1m capita
NE-Brazil	FeD	48	7,300 *	99	2,067
Honduras	ZnD	7.2	1,740	15	2,029
Nicaragua	ZnD	5.4	1,080	9	1,664
Mexico	VAD	106	9,990	83	784
Haiti	VAD	9.9	n/a	21	2,091
All	all	176	n/a	226	1,284

Source: Own calculations, gross national income (GNI)per capita is for 2008, taken from World Bank (2010).

5 Discussion

5.1 Overall appraisal and sensitivity analyses

The calculations of the burden of iron deficiency in NE-Brazil, of zinc deficiency in Honduras and Nicaragua and of vitamin A deficiency in Mexico and Haiti show – only for these few case studies – the loss of several hundred thousand DALYs each year in absolute terms and an annual loss of far over 1,000 DALYs per 1 million individuals (Table 4).[4] Biofortification of the main staple crops consumed in these countries could more than halve this burden and save tens of thousands of years of healthy lives – at a cost of 10-20 USD/DALY saved (Table 7). As such, on average biofortification in Latin America is more cost-effective than fortification, which itself is projected to cost between 20-200 USD/DALY saved, and which is considered more cost-effective than supplementation (Table 8).[5]

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[4] For comparison, in India FeD, ZnD and VAD cause the loss of 3,943 DALYs, 2,758 DALYs and 2,267 DALYs per 1 million individuals of its population, respectively (own calculations).

[5] While ex-post studies in the region found that supplementation and fortification are effective in controlling micronutrient deficiencies (Mora and Bonilla 2002, Mora et al. 2000), they did not analyse the cost-effectiveness of these programmes. Therefore in this assessment we use the estimations of Baltussen et al. (2004) and WHO (2010), which are reported in Table 8. Most of these values are below the threshold of USD 500-1000 that is commonly used to gauge cost-effectiveness (Stein et al. 2005).

Table 5: Main assumptions used in the analysis of AgroSalud crops

	NE-Brazil		Honduras			Nicaragua			Mexico	Haiti
	Iron-rich rice	Iron-rich beans	Zinc-rich rice	Zinc-rich beans	Zinc-rich maize	Zinc-rich rice	Zinc-rich beans	Zinc-rich maize	bC-rich maize	bC-rich cassava
Total population [m]	48		7			5			106	10
Current intake of crop by children [g/d, different ages]	204	67	131	56	120	131	45	120	27	30
Current intake of micro-nutrient by children [µg/d]	11,524		5,131			4,044			265	91-152
Recommended intake for children [µg/d]	14,000		10,000						500	500
Baseline micronutrient content in crop [µg/g]	2.5	55	17.5	28	22	17.5	28	22	1.5	0.5
Micronutrient content with biofortification [µg/g]	4-6	95-110	20-22	48-50	31-40	20-22	48-50	31-40	8-15	15
Post-harvest loss of micronutrient [%]	0%	0-10%	0%	0-10%	0-10%	0%	0-10%	0-10%	50%	33-67%
Bioavailability / bioconversion	100%	90-100%	100%	100%	100%	100%	100%	100%	17-25%	17-25%
Adoption / consumption share of biofortified crops	75-90%	55-60%	70-80%	50%	2-20%	75-85%	55-60%	7-30%	2-20%	15-25%
Release of seeds to farmers (year)	2016-21	2016	2016-21	2016	2015-20	2016-21	2016	2015-20	2014-18	2015-20
Full coverage reached (year)	2022-30	2025-30	2022-30	2025-30	2018-29	2022-30	2025-30	2018-29	2019-29	2021-29
Phase II annual costs (incl. in-country costs, '000 USD)	290-350	275-330	160-195	155-185	250-300	225-270	220-260	310-370	250-300	100-120
National costs for logistics and distribution ('000 USD)	75-90		50-60							
National annual costs for maintenance ('000 USD)	8.3-10		5.5-6.6							

Table 6: Overview of the impact and cost-effectiveness of selected AgroSalud crops

		High impact scenario				**Low impact scenario**			
		DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**	Cost per capita (cents)	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**	Cost per capita (cents)
NE-Brazil	Fe-rich rice	75	1,567	**2.3**	0.1	39	826	**10**	0.1
	Fe-rich beans	98	2,062	**1.9**	0.1	92	1,931	**3.0**	0.1
Honduras	Zn-rich rice	2.9	409	**35**	0.4	1.5	208	**165**	0.5
	Zn-rich beans	2.5	340	**46**	0.4	2.0	283	**81**	0.4
	Zn-rich maize	2.6	366	**32**	0.4	0.3	35	**853**	0.5
Nicaragua	Zn-rich rice	1.8	337	**73**	0.6	0.9	173	**337**	0.8
	Zn-rich beans	1.3	233	**116**	0.6	1.0	178	**225**	0.7
	Zn-rich maize	2.0	372	**55**	0.6	0.5	85	**604**	0.8
Mexico	bC-rich maize	6.7	64	**18**	0.0	0.2	2	**1,408**	0.1
Haiti *	bC-rich cassava	7.0	714	**9.8**	0.2	1.7	175	**87**	0.2

Note: * The analysis for Haiti was based largely on a number of assumptions and extrapolations from data from other countries, i.e. these results have to be interpreted cautiously.

Table 7: Overview of the combined impact and cost-effectiveness of the AgroSalud crops

		High impact scenario				**Low impact scenario**			
		DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**	Cost per capita (cents)	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**	Cost per capita (cents)
NE-Brazil	Fe-rich rice & beans	99	2,067	**3.7**	0.2	99	2,067	**7.0**	0.2
Honduras	Zn-rich rice, beans & maize	15	2,029	**21**	1.1	15	2,029	**43**	1.3
Nicaragua	Zn-rich rice, beans & maize	9.0	1,664	**44**	1.9	9.0	1,664	**90**	2.3
Mexico	bC-rich maize	6.7	64	**18**	0.0	0.2	2	**1,408**	0.1
Haiti	bC-rich cassava	7.0	714	**9.8**	0.2	1.7	175	**87**	0.2
All	all	136	774	**9.7**	0.2	124	706	**21**	0.2

Table 8: Impact and cost-effectiveness of other micronutrient interventions in Latin America

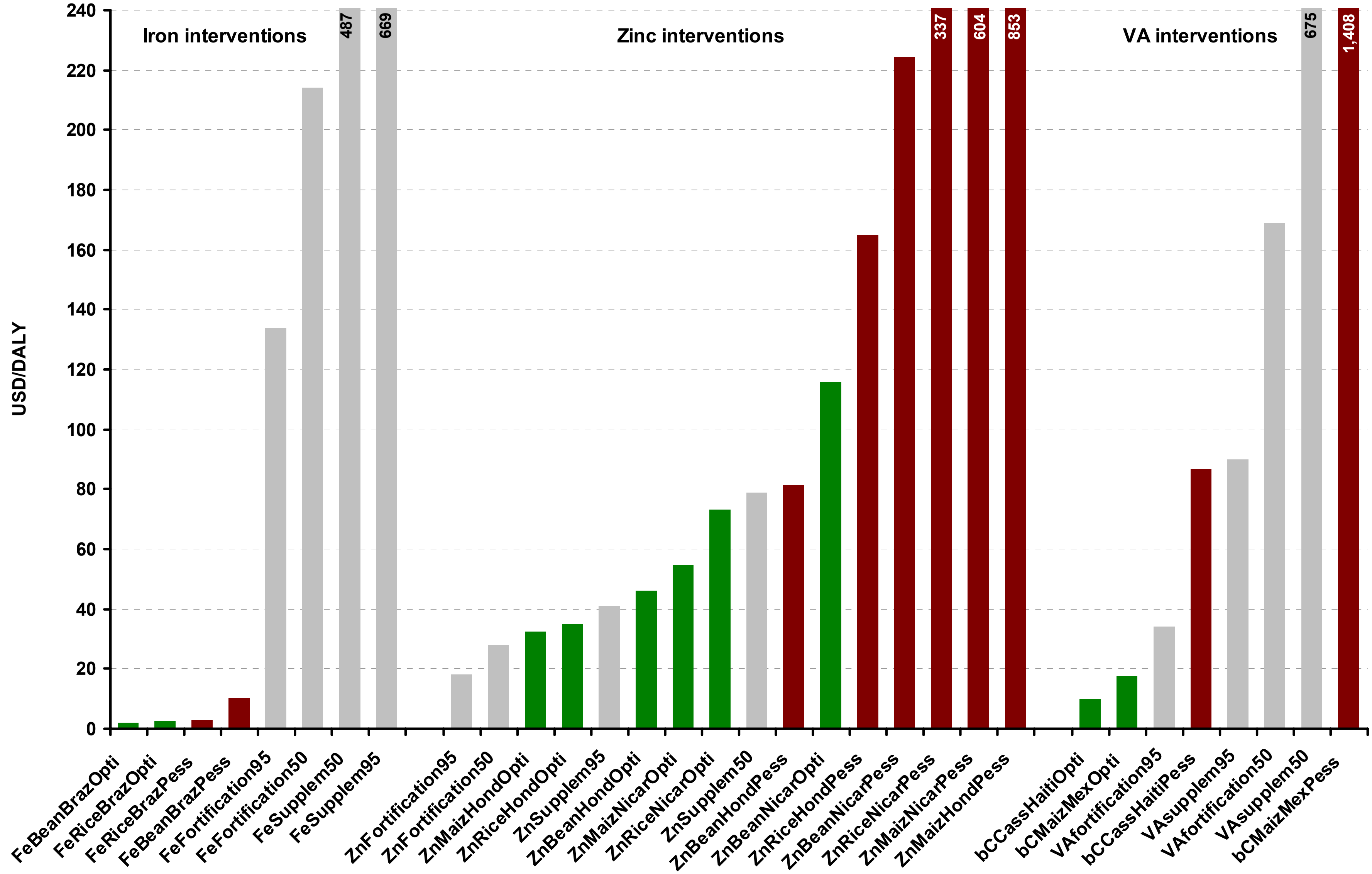
		95% coverage rate				50% coverage rate			
		DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (I$)**	Cost per capita (cents)	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (I$)**	Cost per capita (cents)
AMR B	Fe fortification *	139	n/a	**134**	n/a	73	n/a	**214**	n/a
	Fe supple-mentation *	247	n/a	**(669)**	n/a	130	n/a	**(487)**	n/a
	Zn fortification	n/a	824	**18**	1	n/a	433	**27**	1
	Zn supple-mentation	n/a	1,100	**(70)**	8	n/a	579	**(79)**	5
	Zn fortification & supplementation	n/a	1,056	**(130)**	14	n/a	556	**(135)**	8
	VA fortification	n/a	824	**34**	3	n/a	433	**43**	2
	VA supple-mentation	n/a	1,392	**(287)**	40	n/a	733	**(90)**	7
AMR D	Zn fortification	n/a	1,210	**24**	3	n/a	637	**28**	2
	Zn supple-mentation	n/a	2,524	**(41)**	10	n/a	1,328	**(43)**	6
	Zn fortification & supplementation	n/a	2,089	**(86)**	18	n/a	1,099	**(72)**	8
	VA fortification	n/a	351	**155**	5	n/a	185	**169**	3
	VA supple-mentation	n/a	737	**(675)**	50	n/a	388	**(209)**	8

Notes: Results are reported for the year 2000 and in international dollars (I$); if converted I$ 1 = USD 1, also see http://www.who.int/choice/costs/ppp/en/. Results in brackets indicate that another intervention in the same column for the same micronutrient in the same region is more cost-effective – this is consistently the case for fortification, which thus dominates supplementation.

AMR D = South American subregion with high rates of adult and child mortality (Bolivia, Ecuador, Guatemala, Haiti, Nicaragua and Peru),

AMR B = South American subregion with low adult and child mortality (rest of Latin America except Cuba, which belongs to AMR A); also see http://www.who.int/choice/demography/american_region/en/. Sources: * Baltussen et al. (2004, for AMR B only), all other results from WHO (2010).

Figure 1: Cost-effectiveness of AgroSalud crops and alternative micronutrient interventions



Notes: Values indicate USD/DALY saved. Green columns represent the cost-effectiveness of biofortified crops in the high impact scenarios, red columns represent the low impact scenarios and light/grey columns represent the cost-effectiveness of alternative micronutrient interventions in Latin America to provide appropriate micro-nutrient-specific benchmarks. Source: Table 6 and Table 8.

However, there are large differences in the cost-effectiveness of the various biofortified crops, which can cost as little as 2 USD/DALY for iron-rich beans in NE-Brazil under more optimistic assumptions or as much as 1,400 USD/DALY for beta-carotene-rich maize in Mexico under pessimistic assumptions (Figure 1). For these differences various reasons may be responsible. These are discussed in the following and where appropriate examined by means of sensitivity analyses.

The consumption of the targeted crops (rice and beans) in NE-Brazil appears to be relatively high. Although these figures were estimated by AgroSalud based on the last World Bank's Living Standards Measurement Study for Brazil, a sensitivity analysis was done to determine the potential impact of lower consumption levels of these crops. The results indicate that also with a lower consumption of the target crops the initial results would hardly change (Table 9).

Table 9: Sensitivity analysis for the crop consumption levels in NE-Brazil

	High impact scenario			**Low impact scenario**		
	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**
Fe-rice	75	1,567	**2.3**	39	826	**10**
Fe-rice (rice consumption -25%)	64	1,335	**2.7**	33	685	**12**
Fe-beans	98	2,062	**1.9**	92	1,931	**3.0**
Fe-beans (bean consumption -25%)	96	2,002	**1.9**	87	1.825	**3.2**

Another factor for the high cost-effectiveness of iron-rich crops in NE-Brazil could be that iron deficiency is a rather important public health problem in NE-Brazil (with over 2,000 DALYs lost per 1 million inhabitants), whereas, e.g., vitamin A deficiency in Mexico is less of a problem (with less than 800 DALYs lost per 1 million inhabitants). In absolute terms the number of DALYs lost in Mexico is nevertheless big compared to other target countries, simply because Mexico is a very populous country (Table 4). This also explains why under optimistic assumptions beta-carotene-rich maize in Mexico can still be very cost-effective. Therefore, the poor cost-effectiveness of the beta-carotene-rich maize in Mexico under pessimistic assumptions – as well as the poor cost-effectiveness of the zinc-rich maize in Honduras and Nicaragua – can rather be explained by the very low adoption rates assumed for a low impact scenario, which result in very low consumption shares of the biofortified maize (Table 5). In the case of Honduras and Nicaragua, another reason is that they are rather small countries where the burden of micronutrient deficiencies in absolute terms is necessarily small, even if the respective micronutrient deficiency affects a rather big proportion of the population (Table 4). Hence, the impact in terms of the number of DALYs that can be saved can only be comparatively modest. Then, if the costs for the development of the biofortified crops are attributed equally on the beneficiary countries, a relatively small benefit in terms of DALYs saved needs to compensate relatively important costs – i.e. cost-effectiveness is low because the economies of scale of biofortification cannot fully unfold.

To determine the potential influence of the attribution of the AgroSalud budget on the individual crop-country combinations, the analysis was re-run with the AgroSalud budget being attributed to each crop-country combination based on the population size of the target country instead of attributing the budget equally across all micronutrient-crop combinations in all target countries, using this as a proxy of the number of potential beneficiaries of the respective biofortified crops (Table 10). As could be expected, the cost-effectiveness of the biofortified crops in the bigger countries (NE-Brazil and Mexico) decreases somewhat, while targeting crops at the smaller countries becomes slightly more efficient (compared to the results of Table 6). However, the only country where the attribution changes the results more noticeably is Mexico – which also was to be expected, as Mexico was attributed a bigger share of the costs although the share of its population suffering from vitamin A deficiency is relatively small (Table 4). This little sensitivity to the attribution of the central AgroSalud budget may be due to the importance of the in-country costs (for adaptive breeding, registration, dissemination, marketing, maintenance, etc.), which means that – where and in as far as possible – also in these fields synergies should be exploited across borders.

Table 10: Results with a population-based attribution of the AgroSalud budget

		High impact scenario Cost per DALY (USD)		**Low impact scenario** Cost per DALY (USD)	
		equal shares	population-based	equal shares	population-based
NE-Brazil	Fe-rich rice	**2.3**	3.1	**10**	14
	Fe-rich beans	**1.9**	2.6	**3.0**	4.2
Honduras	Zn-rich rice	**35**	31	**165**	147
	Zn-rich beans	**46**	41	**81**	72
	Zn-rich maize	**32**	29	**853**	759
Nicaragua	Zn-rich rice	**73**	65	**337**	300
	Zn-rich beans	**116**	103	**225**	198
	Zn-rich maize	**55**	49	**604**	538
Mexico	bC-rich maize	**18**	39	**1,408**	2,792
Haiti	bC-rich cass.	**9.8**	8.9	**87**	79

Indeed, one of the main rationales for biofortification is the potential to realise economies of scale across countries. Therefore, analysing a biofortification programme at a disaggregated level, like above, may have its shortcomings, especially if a "fair" attribution of the overall programme costs to the individual countries or sub-regions is difficult. To address this issue, also more aggregated analyses were carried out, looking at the overall impact and cost-effectiveness of the selected biofortified crops in all chosen target countries. This approach yielded the above-mentioned result of 10-20 USD/DALY saved – under optimistic and pessimistic assumptions, respectively (Table 7). This result indicates that at the larger scale outliers of individual case studies are counterbalanced, thus showing that also in Latin America biofortification as such could be a viable micronutrient intervention. Moreover, while fortification and supplementation can become more expensive on a per-capita basis when the programmes are expanded and can reach costs of up to 50 cents per capita for a common intervention like vitamin A supplementation (Table 8), the costs per capita for biofortification do not exceed 1 cent per capita and remain stable across different scenarios (Table 7).This also shows that the funds necessary to implement biofortification are relatively minor and within the possibilities of the target countries.

Another issue related to the attribution of the central AgroSalud budget is the comprehensiveness of the costs considered in the initial analysis. The information on the costs that need to be incurred for the biofortified crops to have an impact were elicited from AgroSalud staff. However, this information was almost exclusively based on the AgroSalud budgets (for 2004-2009 and the one planned for 2011-2015). In the interviews with the breeders and other staff at CIAT, the cost data was complemented as good as possible with estimates for the in-country costs (without which no impact will be achieved as the in-country activities will be crucial to that the biofortified crops are adopted widely and speedily). However, it could still be that these future costs are underestimated, although, given discounting, the impact on the cost-effectiveness results may be small. Similarly, HarvestPlus has given funds to CIAT, CIMMYT and Embrapa to work on biofortification – and part of this work also benefits the biofortification efforts of AgroSalud. To assess the impact of more comprehensive costing of the AgroSalud crops, the cost-effectiveness analysis was repeated with cost estimates that included attributed shares of the HarvestPlus monies. For instance, while for rice and cassava virtually no additional costs were attributed to Latin America for the period 2004-10, for beans USD 700,000 were attributed and for maize even USD 2.25 million; minor costs were also attributed for coordination work and for Brazil-specific work by Embrapa. The results show that this consideration of more comprehensive work on biofortification does not affect the overall cost-effectiveness of the individual crops (Table 11). Only in the case of biofortified maize the cost-effectiveness changes to a greater extent – given that the attributed costs are somewhat greater while the assumed coverage, and thus the impact, is relatively small.

Table 11: Results with the attribution of HarvestPlus monies

		High impact scenario Cost per DALY (USD)		Low impact scenario Cost per DALY (USD)	
		initial results	extended costs	initial results	extended costs
NE-Brazil	Fe-rich rice	2.3	2.4	10	11
	Fe-rich beans	1.9	2.1	3.0	3.3
Honduras	Zn-rich rice	35	36	165	167
	Zn-rich beans	46	52	81	90
	Zn-rich maize	32	44	853	1,109
Nicaragua	Zn-rich rice	73	74	337	340
	Zn-rich beans	116	127	225	243
	Zn-rich maize	55	70	604	745
Mexico	bC-rich maize	18	22	1,408	1,662
Haiti	bC-rich cass.	9.8	11	87	95

Part of the differences in the cost-effectiveness of the various biofortified crops may also be due to the very different final adoption shares estimated by the breeders (Table 5). To assess the sensitivity of the results to changes in the assumed coverage of the micronutrient-rich crops, the initial calculations were re-run using the same coverage rates for all crops (50 percent in the high impact scenario and 20 percent in the low impact scenario) while keeping all other parameters unchanged (Table 12). As could be expected, the results for biofortified rice (for which before very high coverage rates were assumed) become less advantageous, in particular in the low impact scenario. On the other hand the maize results improve considerably – again most pronounced in the low impact scenario. (In the case of beta-carotene-rich maize in Mexico, the result for the low impact scenario even improves by one order of magnitude!) While it is justified to assume better acceptance of mineral-rich crops as they are not expected to be noticeably different from familiar varieties (unlike beta-carotene-rich crops, which take on a darker hue), this sensitivity analysis clearly shows the importance of the coverage rate of biofortified crops on the final outcome: Being too pessimistic in projecting the possible coverage rate will unduly worsen any assessment of biofortified crops, but being too optimistic will similarly bias the results and produce a partial assessment.

To elaborate on the finding of the importance of the coverage rate of the biofortified crops an additional analysis was carried out for the micronutrient-rich maize in the low impact scenario (the crop and scenario with the lowest assumed coverage rates in the initial analysis). As far as insufficient uptake of the biofortified crops is not due to inherent shortcomings in the germplasm that prevents farmers from adopting the crops, but rather due to less intense extension and marketing activities, greater investments in the dissemination of the crops are likely to be compensated by the bigger impact that can be achieved with greater coverage rates. Being conservative, it was assumed that a 10-fold increase in the costs for logistics and distribution only leads to a 5-fold increase in the coverage of the biofortified maize. Yet, as Table 13 shows, even with these cautious assumptions the additional investment into the dissemination of the crops pays off and increases impact and cost-effectiveness considerably.

Table 12: Results with the same consumption shares for all crops

		High impact scenario with 50 percent consumption share			**Low impact scenario with 20 percent consumption share**		
		DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**
NE-Brazil	Fe-rich rice	59	1,242	**2.9**	20	428	**20**
	Fe-rich beans	98	2,062	**1.9**	70	1,459	**3.9**
Honduras	Zn-rich rice	1.9	264	**54**	0.4	61	**555**
	Zn-rich beans	2.5	340	**45**	0.8	118	**193**
	Zn-rich maize	5.9	821	**14**	2.4	332	**90**
Nicaragua	Zn-rich rice	1.3	245	**100**	0.3	60	**971**
	Zn-rich beans	1.3	233	**115**	0.5	84	**474**
	Zn-rich maize	3.7	672	**30**	1.6	286	**178**
Mexico	bC-rich maize	16	148	**7.6**	2.2	21	**142**
Haiti	bC-rich cass.	11	1,091	**6.3**	2.3	229	**65**

Note: Consumption shares in NE-Brazil and Nicaragua are increased by 10 and 5 percent in the high and low impact scenarios, respectively, to take account of measures that are planned to market products made from biofortified crops.

Table 13: Sensitivity analysis for the dissemination costs of biofortified maize

		Low impact scenario			**Low impact scenario with cost & coverage increases ***		
		DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**
Honduras	Zn-rich maize	0.3	35	**844**	1.2	171	**232**
Nicaragua	Zn-rich maize	0.5	85	**599**	2.1	388	**165**
Mexico	bC-rich maize	0.2	2	**1,399**	1.1	11	**344**

Within the AgroSalud programme there are micronutrient deficiencies within one country that are targeted by several crops at the same time. This is not only the case for three zinc-rich crops, similar overlaps also exist for the iron-rich and the beta-carotene-rich crops (Table 1). In these cases the economic rationale for parallel biofortification of different crops with the same micronutrient for the same target countries could be questioned: As an exemplary analysis of all possible combinations of zinc-rich crops targeted at Nicaragua shows, any combination of two of the three crops virtually yields the same result as the biofortification of all three crops – but at lower costs (Table 14). While there may be good reasons to target different crops to reach different population groups, it may be worth considering to drop one crop and to used the freed funds to promote the dissemination of the remaining crops to obtain higher consumption levels of these. Similarly, in NE-Brazil iron biofortification of beans has effectively the same impact as iron biofortification of both beans and rice (Table 6, Table 7), i.e. in this case it could be more efficient to focus the biofortification efforts on beans only.

Table 14: Overview of the impact and cost-effectiveness of zinc-rich crops in Nicaragua

	High impact scenario			**Low impact scenario**		
	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**	DALYs saved ('000)	DALYs saved per 1m capita	**Cost per DALY (USD)**
Zn-rich rice	1.8	337	**73**	0.9	173	**334**
Zn-rich beans	1.3	233	**115**	1.0	178	**223**
Zn-rich maize	2.0	372	**54**	0.5	85	**599**
Zn-rich rice & maize	8.9	1,640	**30**	8.6	1,590	**64**
Zn-rich rice & beans	8.8	1,626	**30**	8.7	1,602	**61**
Zn-rich maize & beans	8.9	1,629	**30**	8.7	1,590	**62**
All	9.0	1,664	**44**	9.0	1,664	**89**

Another issue that could have an impact on the result of the present analysis are the micronutrient programmes existing in several Latin American countries (MI 2010, MOST 2005, Mora and Bonilla 2002, Mora et al. 2000). Because of these interventions the burden of the respective micronutrient deficiencies – and thus the additional impact of biofortified crops – is likely to be smaller than in settings where micronutrient deficiencies are not controlled. Yet even in these countries it could make sense to introduce biofortified crops: while the crops may not save many additional DALYs, they could help scale down more costly current micronutrient programmes, thus freeing scarce resources in the public health sector. For instance, in Mexico various food items are currently fortified with vitamin A (MOST 2005), which could help explain why vitamin A deficiency is a relatively small problem in Mexico (Table 4). Yet, vitamin A fortification costs 34-43 USD/DALY saved (Table 8), whereas even in the presence of such fortification, beta-carotene-rich maize may cost as little as 18 USD/DALY saved (Table 7). In this case, i.e. if wide-spread consumer acceptance of yellow maize can be achieved, the more costly vitamin A fortification could be scaled back and be replaced by the beta-carotene-rich maize – which then could save more DALYs without increasing costs (i.e.

the cost per DALY saved through the beta-carotene-rich maize would fall, the more vitamin A fortification is scaled back). On the other hand, where existing micronutrient programmes are not fully effective in controlling micronutrient deficiencies, biofortified crops could complement these measures and help reduce the burden of micronutrient deficiencies further. For instance, even with a comprehensive vitamin A supplementation programme, in Haiti the prevalence rate of vitamin A deficiency in pre-school children is still at 32 percent (MI 2010). Here biofortified crops could possibly help reach those population groups that so far have not been covered effectively – and do so at relatively lower costs than vitamin A supplementation (Figure 1, right panel). Also, once biofortified crops are introduced, the vulnerability of the population to external or internal shocks (whether natural disasters or political turmoil) is reduced as people do not rely on the more susceptible distribution of supplements or the processing of food to improve their micronutrient intake.

5.2 Individual assessment by micronutrient-crop combination

As Figure 1 clearly shows, both iron-rich rice and iron-rich beans are vastly more cost-effective than the alternative interventions. Moreover, as Table 7 shows and as has been discussed in the previous section, iron-rich beans on its own has virtually the same impact as iron-rich rice and iron-rich beans together while obviously being cheaper. Hence – given all shortcomings of a quantitative analysis based on aggregated and partly only estimated data and that moreover not even covers half of all micronutrient-crop-country combinations of the underlying programme – the most promising and economic crop to develop further are iron-rich beans. To what extent it is worthwhile to continue work on iron-rich rice, given that this is the only crop targeted at Bolivia, cannot be answered based on the current analysis.

On the other hand, all the zinc-rich crops are consistently less cost-effective than the estimated cost-effectiveness of zinc fortification and mostly also of zinc supplementation (Figure 1). However, with a combined introduction of all three crops in parallel, their cost-effectiveness improves somewhat (Table 7). And as the exemplary analysis for Nicaragua has shown, introducing a combination of two zinc-rich crops in parallel improves the cost-effectiveness even further (Table 14), in particular if a higher coverage rate of the zinc-rich maize can be achieved (Table 12). Yet, it seems zinc-rich crops will at best be at the same level of cost-effectiveness as industrial zinc fortification, i.e. their further funding would require convincing qualitative arguments in their favour – or the zinc biofortification efforts need to reach larger populations beyond those of small Central American countries and Caribbean islands (Table 1).

Beta-carotene-rich maize is only targeted at Mexico and Haiti (Table 3). While for an analysis of the latter not enough data was available, the results for Mexico do not send a clear message – because of the very wide range of possible outcomes. If a sufficient coverage rate of the maize can be achieved, which may be difficult given its colour, beta-carotene-rich maize in Mexico can be more cost-effective than alternative interventions (Figure 1, Table 12). In addition, as discussed in the previous section, it may represent a useful and economic intervention if its introduction allows scaling back more costly current measures. However, the uncertainty over its acceptance and the extremely poor cost-effectiveness in the low impact scenario make it a risky investment. (However, as Table 8 shows, also the cost-effectiveness of alternative vitamin A interventions varies considerably.) To reduce this uncertainty, it may be recommendable to carry out studies on the potential acceptance of this maize or to develop concrete measures that ensure its ultimate acceptance.

Finally, beta-carotene-rich cassava is only targeted at Haiti (with most of the cassava-related biofortification being done for Africa). Despite the lack of data for a sound analysis, an analysis has nevertheless been carried out based on various assumptions and extrapolations to obtain an idea of the possible orders of magnitude of the impact and cost-effectiveness of this crop. While the cost-effectiveness-range of the best alternative intervention is 155-169 USD/DALY for vitamin A fortification in high mortality Latin American countries (Table 8), the range for biofortified cassava in Haiti is 10-87 USD/DALY (Table 6). Moreover, as discussed in the previous section, introducing biofortified crops in Haiti could help reduce the population's vulnerability to shocks affecting the provision of alternative interventions. Yet, given the uncertain data base, also regarding the costs of establishing and disseminating new crop varieties in Haiti, a decision on the further development of beta-carotene-rich cassava for Latin America would benefit from more detailed in-country expertise confirming the scope of vitamin A deficiency and the feasibility of introducing biofortified cassava on a larger scale (even if in other respects it can perhaps "free-ride" on the work that is being done for Africa anyway).

In terms of targeting individual countries, it has become clear that for the biofortified crops to become cost-effective, they have to be consumed by a great number of potential beneficiaries, i.e. they need to be targeted also at populous countries where the respective micronutrient deficiency is a public health problem (like NE-Brazil). However, once the crops are developed for such a big country, smaller countries can "free-ride" on this development – this spreading of the benefits lies at the very heart of the economic rationale for carrying out biofortification. And while bigger and richer countries may be more likely to have the infrastructure and the means to disseminate the biofortified crops themselves, smaller and poorer countries may need more external support for dissemination activities to reach the coverage rates needed. (For instance, for differences in per-capita incomes of the countries analysed, please see Table 4). On the other hand, targeting biofortification efforts only at small countries may indeed result in not enough beneficiaries being reached for making the undertaking much more cost-effective than alternative interventions.

6 Conclusions

In this report the burden of micronutrient malnutrition in various Latin American countries has been quantified and the potential impact of biofortified crops that are currently being developed in the framework of the AgroSalud programme, which is coordinated at the Centro Internacional de Agricultura Tropical (CIAT), has been shown: In case of successful biofortification efforts and if a high degree of consumption can be achieved, the ex ante calculations indicate that biofortification can eliminate wide-spread mineral deficiencies and considerably reduce the burden of vitamin A deficiency. While there are some outliers, the analysis has shown that on average also in Latin America biofortification promises to be a cost-effective micronutrient intervention – in many cases even more cost-effective than other analyses project industrial fortification to be.

The analysis has also shown that biofortification is more cost-effective if it is done in the framework of a bigger programme at the international level, covering several countries and thus realising economies of scale; focusing efforts on smaller countries or countries with only a small malnourished sub-population yields less clear-cut results. Results can also be optimised by avoiding parallel biofortification of too many crops with the same micronutrient for the same target countries. However, the single most important factor to improve impact and cost-effectiveness is increasing the coverage of the biofortified crops, which justifies higher investments in agricultural extension and social marketing of the crops, where necessary. (The underlying rationale is that the health gains arising from higher consumption rates of biofortified crops more than compensate the costs that need to be incurred to achieve these rates.)

In countries where other micronutrient programmes already exist the results for the impact and cost-effectiveness of biofortification can be biased. Judging from the overall results for biofortification, the introduction of micronutrient-rich crops also in these countries could be sensible if it subsequently helps to scale back more costly micronutrient interventions that are currently in place – and thus frees scarce resources in the public health sector. Similarly, the introduction of biofortified crops, if successful, could decrease the population's vulnerability to shocks affecting alternative interventions.

Of the individual crops evaluated in this report, those targeting iron deficiency are the most cost-effective ones. The crops targeting vitamin A deficiency also have some potential, however, uncertainties about their acceptance or the underlying data base of the analysis do not allow an unequivocal statement. Finally, while not necessarily being expensive, either, the crops aimed at controlling zinc deficiency are at best as cost-effective as industrial zinc fortification is projected to be. Hence, a more careful and qualitative analysis on a case-by-case basis may be required to decide which of the alternative interventions is preferable – or to determine to what extent they complement each other.

Overall, various sensitivity analyses that probed the impact of changes to key parameters showed that the results are very robust; only changes in the coverage rates of the crops have the potential to influence the outcomes considerably. This corresponds to the underlying economic rationale of biofortification, which is the exploitation of economies of scale. In this context the main limitation for AgroSalud is the relative smallness of its target countries (e.g. compared to much more populous countries in Asia for which previous analyses of biofortification were carried out). Where possible, more international coordination of basic biofortification efforts, beyond Latin America, could address this more structural problem. Otherwise the use of potential synergies in the execution of the in-country activities, with concomitant cost reductions at the national levels, could help improve the economics of the AgroSalud crops.

References

Baltussen R, Knai C, Sharan M (2004). Iron fortification and iron supplementation are cost-effective interventions to reduce iron deficiency in four subregions of the world. Journal of Nutrition 134: 2678-2684. http://jn.nutrition.org/cgi/content/abstract/134/10/2678

Bouis HE (2002). Three criteria for establishing the usefulness of biotechnology for reducing micronutrient malnutrition. Food and Nutrition Bulletin 23: 351-353. http://foodandnutritionbulletin.org/FNB/index.php/FNB/article/view/372

Cakmak I (2008). Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant and Soil 301: 1-17. http://dx.doi.org/10.1007/s11104-007-9466-3

CIAT (2010). Files with applications of the MAIN to various crops and countries were obtained while visiting CIAT, 3-9 March. Cali: Centro Internacional de Agricultura Tropical. http://www.ciat.cgiar.org/ (Also see García Castro et al. (2008). These files contained health and nutrition data needed to carry out the analyses; this data was taken from the files and only updated and corrected where necessary before being used for own calculations. The Excel files used for the own calculations are made available to the International Food Policy Research Institute (Washington, DC) under Contract No. 2010X012STE.)

Dawe D, Robertson R, Unnevehr L (2002). Golden Rice: What role could it play in alleviation of vitamin A deficiency? Food Policy 27: 541 560. http://dx.doi.org/10.1016/S0306-9192(02)00065-9

Dessalines M (2008). The role of sweet potatoes in the diet and nutrition of rural Haitian families. MSc Thesis. Storrs, CT: University Of Connecticut. http://www.agrosalud.org/index.php?option=com_docman&gid=10

DHS (1997). Brasil: Pesquisa Nacional Sobre Demografia e Saúde, 1996. Calverton, MD: Macro International. http://www.measuredhs.com/pubs/pub_details.cfm?ID=119

FAO (2009). FAOSTAT: Food Supply. Online database. Rome: Food and Agriculture Organization of the United Nations. http://faostat.fao.org/site/345/default.aspx

García Castro JA, González MC, Johnson N (2008). MAIN: a model for assessing the impact of nutritional interventions to reduce deficiencies of vitamin A, iron, and zinc. Cali: Centro Internacional de Agricultura Tropical. http://webapp.ciat.cgiar.org/impact/main.htm

Jacobsen AB (2008). Ex-ante economic impact assessment of introducing cassava or maize biofortified with pro-vitamin A in four Latin American countries. Copenhagen: University of Copenhagen. http://www.agrosalud.org/descargas/Thesis_2008_Anne_Balling_Jacobsen_8Dec%202008_resumen.pdf

Javelosa JC (2006). Measuring the potential payoffs from biofortification: the case of high-iron rice in the Philippines. Dissertation No. AAT 3228739. Gainesville, FL: University of Florida. http://proquest.umi.com/pqdlink?did=1196409241&Fmt=7&clientId=79356&RQT=309&Vname=PQD

Ma G, Jin Y, Li Y, Zhai F, Kok FJ, Jacobsen E, Yang X (2007). Iron and zinc deficiencies in China: what is a feasible and cost-effective strategy? Public Health Nutrition. 11: 632-638. http://dx.doi.org/10.1017/S1368980007001085

Meenakshi JV, Johnson NL, Manyong VM, DeGroote H, Javelosa J, Yanggen DR, Naher F, Gonzalez C, García J, Meng E (2009). How cost-effective is biofortification in combating micronutrient malnutrition? An ex ante assessment. World Development 38: 64-75. http://dx.doi.org/10.1016/j.worlddev.2009.03.014

MI (2010). Haiti Country Profile. Website. Ottawa: Micronutrient Initiative. http://www.micronutrient.org/english/View.asp?x=600

Montagnac JA, Davis CR, Tanumihardjo SA (2009). Nutritional value of cassava for use as a staple food and recent advances for improvement. Comprehensive Reviews in Food Science and Food Safety 8: 181-194. http://dx.doi.org/10.1111/j.1541-4337.2009.00077.x

Mora JO, Bonilla J (2002). Successful vitamin A supplementation in Nicaragua. Sight and Life 3: 75-79. http://www.sightandlife.org/publications/sight-and-life-magazine-archive

Mora JO, Dary O, Chinchilla D, Arroyave G (2000). Vitamin A sugar fortification in Central America: experience and lessons learned. Arlington, VA: MOST, the USAID Micronutrient Program. http://www.mostproject.org/pubs2.htm#USAID/Roche

MOST (2005). Choosing a vehicle. Fortification Basics No. 45. Arlington, VA: MOST, the USAID Micronutrient Program. http://www.mostproject.org/pubs2.htm#USAID/Roche

Nestel P, Bouis HE, Meenakshi JV, Pfeiffer W (2006). Biofortification of staple food crops. Journal of Nutrition 136: 1064-1067. http://jn.nutrition.org/cgi/content/abstract/136/4/1064

Pachón H (2010). Personal communication in March and April. Coordinator, AgroSalud Project. Cali: International Center for Tropical Agriculture. http://www.ciat.cgiar.org/aboutus/people/pages/profile_helena_pachon.aspx

Pérez Suárez S (2010). Disability-Adjusted Life Years (DALYs), a methodology for conducting economic studies of food-based interventions such as biofortification. In: Combating micronutrient deficiencies: food-based approaches, forthcoming.

Qaim M, Stein AJ, Meenakshi JV (2007). Economics of biofortification. Agricultural Economics 37: 119-133. http://dx.doi.org/10.1111/j.1574-0862.2007.00239.x

Sandler, BJ (2005). Biofortification to reduce vitamin A deficiency: a comparative cost-benefit analysis of Golden Rice and orange-fleshed sweet potato. Thesis. Stanford, CA: Stanford University.

Stein AJ, Meenakshi JV, Qaim M, Nestel P, Sachdev HPS, Bhutta ZA (2008a). Potential impacts of iron biofortification in India. Social Science & Medicine 66: 1797-1808. http://dx.doi.org/10.1016/j.socscimed.2008.01.006

Stein AJ, Meenakshi JV, Qaim M, Nestel P, Sachdev HPS, Bhutta ZA (2005). Analyzing the health benefits of biofortified staple crops by means of the Disability-Adjusted Life Years approach: a handbook focusing on iron, zinc and vitamin A. HarvestPlus Technical Monograph 4. Washington, DC: International Food Policy Research Institute. http://www.harvestplus.org/content/analyzing-health-benefits-biofortified-staple-crops-means-disability-adjusted-life-years-app

Stein AJ, Nestel P, Meenakshi JV, Qaim M, Sachdev HPS, Bhutta ZA (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 AJ, Sachdev HPS, Qaim M (2006). Potential impact and cost-effectiveness of Golden Rice. Nature Biotechnology 24: 1200-1201. http://dx.doi.org/10.1038/nbt1006-1200b

Stein AJ, Sachdev HPS, Qaim M (2008b). Genetic engineering for the poor: Golden Rice and public health in India. World Development 36: 144-158. http://dx.doi.org/10.1016/j.worlddev.2007.02.013

Tanumihardjo SA, Bouis H, Hotz C, Meenakshi JV, McClafferty B (2008). Biofortification of staple crops: an emerging strategy to combat hidden hunger. Comprehensive Reviews in Food Science and Food Safety 7: 329-373. http://dx.doi.org/10.1111/j.1541-4337.2008.00049.x

UNICEF (2010). Information by country: statistics. Website. New York: United Nations Children's Fund. http://www.unicef.org/infobycountry/index.html

White PJ, Broadley MR (2009). Biofortification of crops with seven mineral elements often lacking in human diets – iron, zinc, copper, calcium, magnesium, selenium and iodine. New Phytologist 182: 49-84. http://dx.doi.org/10.1111/j.1469-8137.2008.02738.x

WHO (2009). Global prevalence of vitamin A deficiency in populations at risk 1995-2005: WHO Global Database on Vitamin A Deficiency. Geneva: World Health Organization. http://www.who.int/vmnis/vitamina/prevalence/

WHO (2010). CHOosing Interventions that are Cost Effective (CHOICE): cost-effectiveness results. Website. Geneva: World Health Organization. http://www.who.int/choice/

World Bank (2010). Data: countries. Online database. New York: The World Bank. http://data.worldbank.org/country

Zimmermann R, Ahmed F (2006). Rice biotechnology and its potential to combat vitamin A deficiency: a case study of Golden Rice in Bangladesh. Discussion Papers on Development Policy 104. Bonn: Center for Development Research. http://www.zef.de/dp_2006.html

Zimmermann R, Qaim M (2004). Potential health benefits of Golden Rice: a Philippine case study. Food Policy 29: 147-168. http://dx.doi.org/10.1016/j.foodpol.2004.03.001

The potential of biofortification of rice, beans, cassava and maize throughout Latin America

International Food Policy Research Institute, Washington, DC
Contract No. 2010X012STE

AgroSalud is a project coordinated at the Centro Internacional de Agricultura Tropical and aims to increase nutrition security in Latin America through biofortification – i.e. through plant breeding with the objective of increasing the micronutrient content in staple crops. Thus AgroSalud should help prevent the negative economic and health consequences of micronutrient malnutrition. The objective of the present study was to evaluate the cost-effectiveness of current AgroSalud crops to inform funding priorities for biofortification.

For this ex ante evaluation the commonly used methodological framework of "disability-adjusted life years" (DALYs) was used. The data for the analysis was mostly taken from previous work of AgroSalud and from personal interviews with the experts involved in the project. For nine case studies enough data could be compiled to carry out an assessment.

The analysis determined the burden of micronutrient deficiencies in various countries in the region and showed that in case of successful biofortification efforts and if a high degree of consumption of the crops can be achieved, biofortification can eliminate wide-spread mineral deficiencies and considerably reduce the burden of vitamin A deficiency. Furthermore the analysis has shown that on average also in Latin America biofortification promises to be a cost-effective micronutrient intervention – and in many cases even more cost-effective than alternative or complementary interventions. The single most important factor for success is the coverage rate of the biofortified crops. Thus given the smaller number of potential beneficiaries, results for crops targeted at smaller countries only are less clear.

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