Expert consultation on

Micronutrient deficiencies: can agriculture meet the challenge?

FAO Regional Office for the Near East, Cairo, 11-13 December 2007

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Cost-effectiveness of biofortification

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Abstract: Micronutrient deficiencies are a recognised public health problem in the Near East. Although this problem is often exacerbated through mineral-poor soils, so far agricultural interventions have attracted less attention as complementary approaches to current interventions like pharmaceutical supplementation or industrial fortification. Yet, especially biofortification – i.e. the use of plant breeding to accumulate essential micronutrients in staple crops – promises to offer a very cost-effective strategy to improve the micronutrient intake of poor population groups, particularly in remote rural areas. While achieving dietary diversity for all is a generally accepted objective, this is often only possible in the long run and the cost-effectiveness of this approach is still unclear. Therefore, where the diets of the poor are already monotonous and cereal-based, biofortified crops can replace these micronutrient-poor staples at a low cost, thus offering a potential remedy in the medium-term.

Introduction

Micronutrient deficiencies are a recognised public health problem in the region (chapter 1), where soils are also often poor in essential minerals (chapter 3). Currently certain micronutrient interventions – like pharmaceutical supplementation or industrial fortification – are being implemented in some countries (chapter 2), but they are limited in scope and require continuous funding. In this context, complementary agricultural approaches could be considered and need to be evaluated (chapters 3 and 4). First projections for countries in other regions of the world have shown that especially biofortification – i.e. the use of plant breeding to accumulate essential micronutrients in edible parts of staple crops – holds the promise of notable improvements in the micronutrient status at the population level at a very low cost (Stein et al. 2006, 2007; Stein, Sachdev & Qaim 2006, 2008; Meenakshi et al. 2007).

According to HarvestPlus, the global alliance of institutions working on this agricultural approach to improve human nutrition, biofortification takes advantage of the daily consumption of large amounts of staple crops by the poor in developing countries – and in doing so several advantages can be exploited: (i) After a one-time investment is made to develop biofortified seeds, recurrent costs are low and germplasm may be shared internationally, making biofortification a cost-effective strategy. (ii) Biofortification provides a means of reaching malnourished populations in relatively remote rural areas who have limited access to processed foods or the public health system. (iii) Biofortification may increase yields because a higher content in trace minerals can also help plants resist disease and other environmental stresses (HarvestPlus 2007).

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[1] Summary paper of a presentation on the cost-effectiveness of biofortification given at an expert consultation on "Micronutrient deficiencies: can agriculture meet the challenge?", organised by the FAO Regional Office for the Near East in Cairo on 11-13 December 2007 (http://www.ajstein.de/presentation/Stein_FAO_2007.pdf).

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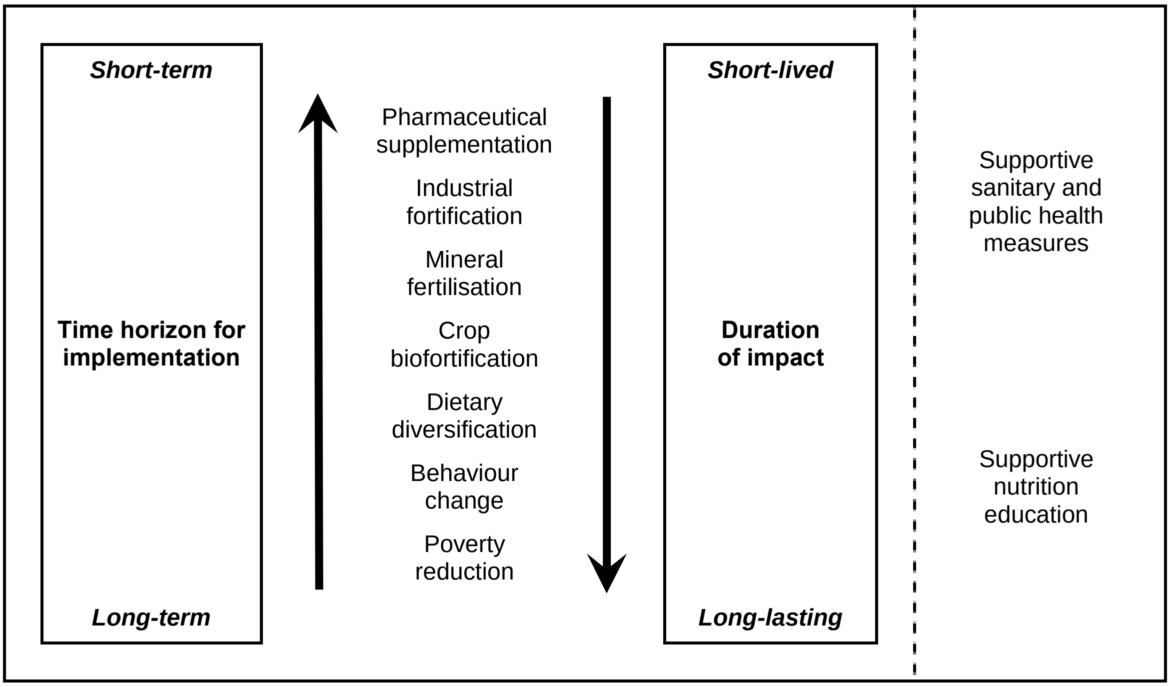
In this section the methodological rationale of economic analyses of biofortification is outlined and the first results of aforementioned ex ante analyses are presented and discussed.

Biofortification in the context of other micronutrient interventions

In general four different interventions to combat micronutrient deficiencies can be differentiated: pharmaceutical supplementation, industrial fortification, biofortification and dietary diversification. Moreover, to introduce dietary diversity it may be necessary to change the target group's behaviour to some extent to make people accept new food or different dishes; this is also the case for biofortification with beta-carotene, when people have to accept familiar but somewhat different-looking food. And next to biofortification, the micronutrient content in crops may also be increased through mineral fertilisation, which thus represents another agricultural approach in this context (chapter 3). In the long run poverty reduction can be considered a further, overarching strategy to help control micronutrient deficiencies. Finally, where the sanitary and health situation of the target population is poor, corresponding supportive measures are necessary before any micronutrient intervention can be successful; in the longer run nutrition education is needed to raise awareness and to support food-based micronutrient interventions.

These various micronutrient interventions can be ranked according to the time horizon within which they can be implemented and according to the duration of their impact. By and large an intervention's performance in one of these fields is negatively correlated to its performance in the other (Figure 1). This indicates already that each intervention has its strengths and weaknesses and that more integrated and combined strategies are needed to address the issue of micronutrient deficiencies effectively and comprehensibly.

Figure 1: Overview of micronutrient interventions



Source: Based on Stein, Sachdev & Qaim (2006, online supplement).

From a nutrition point of view what matters in this context is that an intervention works, i.e. that it can reduce the prevalence and severity of micronutrient deficiencies. Although it is still being investigated to what extent biofortification can be effective in this regard, first results are positive (Haas et al. 2005; Tang et al. 2007). But while above mentioned mineral fertilisation to improve human nutrition – as opposed to plant nutrition – is similar to biofortification, clarification may be needed as to how the required inputs can reach farmers (especially poor farmers in remote areas), how much the mineral content of the target crops can be increased and where the additional trace elements accumulate in the crops.

Economic assessment of biofortification

In the previous paragraph it has been highlighted that micronutrient interventions need to work if they are to be assessed in a positive way. However, in a world of limited resources it is not only the effectiveness of an intervention that matters, also its costs are important – both in absolute and in relative terms: Can the costs of the intervention be covered from available funds? And if they can, does spending them on this particular intervention generate the biggest possible impact – or effect – compared to using the funds for alternative interventions? It is exactly these questions that have to be answered in an economic assessment, and discussing the "cost-effectiveness of biofortification" is the topic of this contribution.

Measuring the costs of an intervention is relatively straightforward, but in the case of micronutrient interventions benefits consist in better nutrition and, ultimately, better health of the (previously) malnourished. Hence, this health effect needs to be measured to carry out a cost-effectiveness analysis of biofortification.

Measuring nutrition and health benefits

Common ad hoc measures of malnutrition are prevalence rates of a deficiency, deficiency-related mortality rates, or the percentage of individuals who are at risk of insufficient intakes of a particular micronutrient. While such figures can give an idea of how many individuals are affected by a deficiency, these measures are incomplete in that they ignore the severity of a deficiency – for instance, individuals affected by vitamin A deficiency (VAD) can suffer from permanent blindness or "only" from temporary night-blindness. Similarly, these measures cannot be used to compare different deficiencies – for instance, iron deficiency (FeD) has "relatively" mild negative health outcomes, while some of the functional outcomes of VAD or zinc deficiency (ZnD) are more severe.

In health economics more standardised measures of poor health are used. However, some of these measures tend to be inequitable in that poor health among the more productive or richer members of society weighs more in principle because the measures build on foregone earnings or affordability considerations (e.g. cost of illness or willingness-to-pay approaches) (c.f. Stein & Qaim 2007).

A more comprehensive measure, which is supported by the World Bank or the World Health Organisation (WHO), are “disability-adjusted life years” or DALYs (Murray & Lopez 1996). While slightly different methodologies are in use, DALYs are generally quantified based on the duration, frequency *and* the severity of an adverse health outcome and expressed in common units of health that are lost (DALYs lost) due to a disease or injury. DALYs are standardised by weighting each different health outcome relative to death (100 percent loss of health) and perfect health (no health loss). Thus DALYs can be used to measure both morbidity and mortality and they can also be summed up across different health outcomes. For instance, the DALYs that are lost specifically due to VAD-related adverse health outcomes (measles, corneal scars, blindness, mortality) can be added up to obtain the burden of VAD – and the burdens of VAD, FeD, ZnD, etc. can be added up to obtain the burden of micronutrient deficiencies. A more detailed explanation of the DALY approach for measuring the health loss due to micronutrient deficiencies is given by Stein et al. (2005), Stein (2006) and Stein et al. (forthcoming).

DALYs can be used to measure the health effect of a micronutrient intervention by calculating the number of DALYs that are currently lost within a target population due to the corresponding micronutrient deficiency and by calculating the (smaller) number of DALYs that would be lost if the intervention was implemented. The difference between these two numbers is the impact of the intervention expressed in the number of DALYs that could be saved.

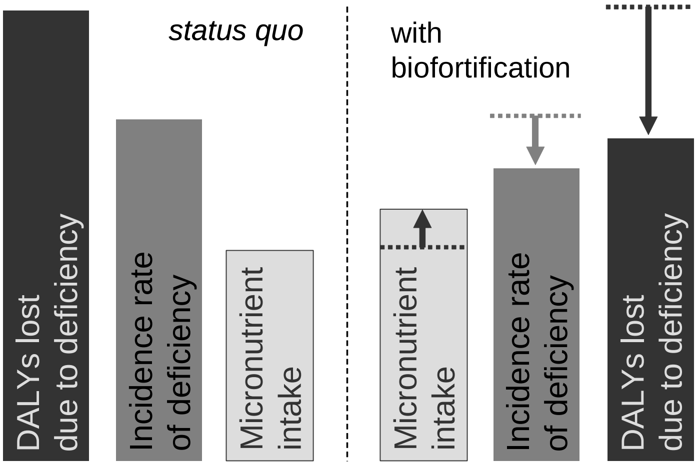
Linking health, nutrition and biofortification

In order to calculate the number of DALYs that are lost with biofortification, a link needs to be established between the micronutrient content that can be bred into a crop and the incidence of the micronutrient deficiency within the target population that enters the DALYs calculation: the higher micronutrient content in the crop, together with the share of biofortified crops in the overall consumption of the crop and the post-harvest loss of the micronutrient due to storage and food preparation determines the additional amount of the micronutrient in people's diets. This additional amount of the micronutrient and its bioavailability then determine the additional uptake of the micronutrient, which in turn improves the micronutrient status in deficient subjects and, thus, their overall health status. In the aggregate this finally leads to a lower incidence rate of the micronutrient deficiency at the population level – which reduces the number of DALYs that are lost due to the micronutrient deficiency. Figure 2 gives a simplified illustration of this link; a more detailed explanation can be found in Stein et al. (2005) and Stein (2006).

Projected impact of biofortification in the case of India

The approach outlined above has been applied to project the impact of various crops that are being biofortified with various micronutrients in various countries. The most comprehensive and thorough analyses to date have been carried out for India for rice that is biofortified with iron, zinc or beta-carotene and wheat that is biofortified with iron or zinc (Stein et al. 2006, 2007; Stein, Sachdev & Qaim 2006, 2008).

Figure 2: Simplified illustration of the link between biofortification, nutrition and health



Source: Based on Stein (2004).

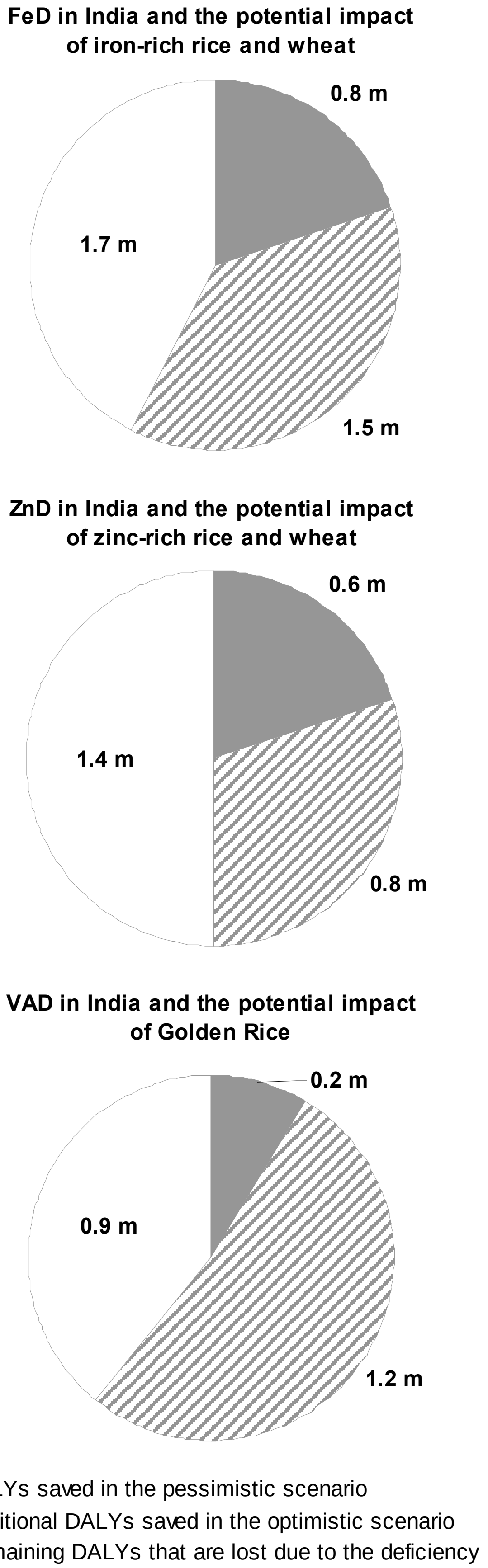
According to these analyses the current burden of FeD in India amounts to an annual loss of 4 million DALYs; the current burden of ZnD in India amounts to an annual loss of almost 3 million DALYs and the loss in the case of VAD amounts to over 2 million DALYs. Depending on the underlying assumptions of the projections for pessimistic and optimistic scenarios for the cultivation and consumption of the biofortified cereals, iron-rich rice and wheat could reduce the burden of FeD in India by about 20-60 percent, zinc-rich rice and wheat could reduce the burden of ZnD in India by about 20-50 percent, and beta-carotene-rich or "golden" rice could reduce the burden of VAD in India by 10-60 percent (Figure 3).

For instance in the case of VAD, where the mortality share in the overall disease burden is relatively high, also the number of avoidable deaths may help to illustrate both the current burden of this deficiency and the impact of biofortification: over 70,000 children die each year in India due to VAD; with Golden Rice about 5,000-40,000 of these lives could be saved.

Cost and cost-effectiveness of biofortification in India

As already explained above, in a world of scarcity effectiveness cannot be the only criterion when assessing an intervention; costs also matter. The discounted average annual costs of iron biofortification or zinc biofortification of rice and wheat amount to US$ 80,000-180,000; those of Golden Rice amount to US$ 500,000-800,000 (Stein et al. 2006, 2007; Stein, Sachdev & Qaim 2006, 2008). In absolute terms these figures could, for instance, be compared to the total cost of US$ 5.2 million for the annual supply of iron tablets – only the actual pills – that would be needed if the Indian anaemia prevention programme would reach 50 percent of its target population (Stein 2006). This comparison illustrates that the cost of biofortification is not out of scope.

Figure 3: The burden of FeD, ZnD and VAD in India and the potential impact of biofortification



Source: Data from Stein et al. (2006 and 2007) and Stein, Sachdev & Qaim (2006).

Yet, costs cannot be the only criterion either when evaluating an intervention from an economic point of view: once the effectiveness of an intervention has been determined and it has been ascertained that its costs can be met in principle, the necessary conditions for a positive assessment of the intervention are fulfilled. The final, sufficient condition is that the intervention is also cost-effective, i.e. that the impact of the intervention can be achieved at a low cost (relative to alternative interventions or relative to given benchmarks).

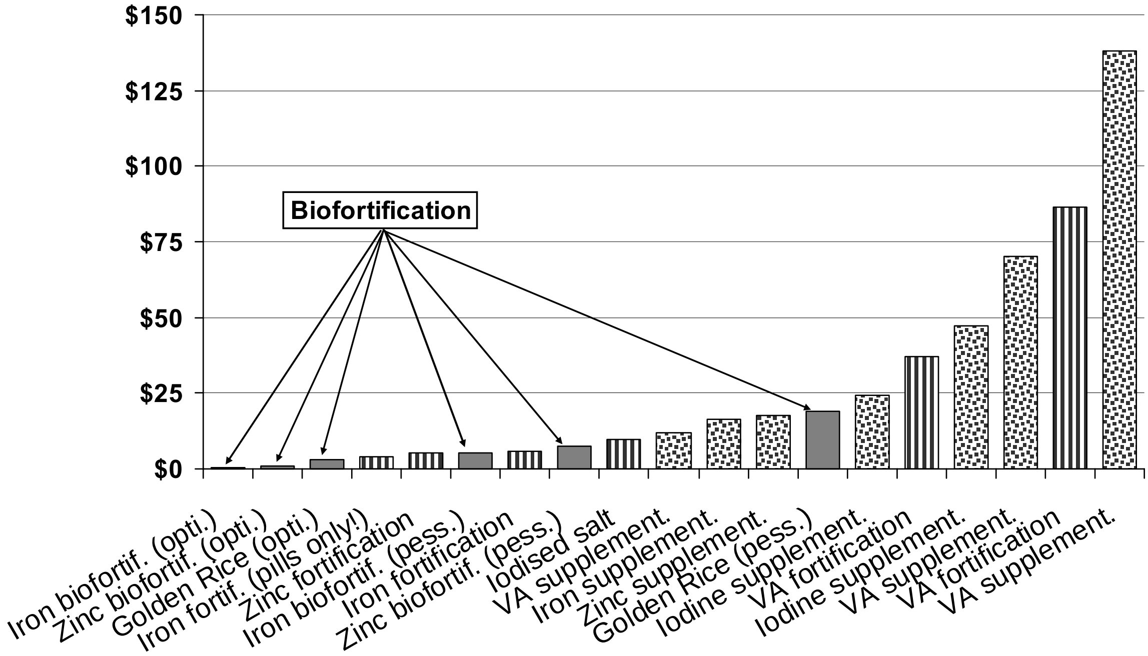
In the case of biofortification in India, the cost of saving one DALY through iron-rich rice and wheat is US$ 0.5-5.4, for zinc-rich rice and wheat the figure is 0.7-7.3 US$/DALY saved and with Golden Rice one DALY can be saved at a cost of US$ 3.1-19. This compares favourably with costs of 5-15 US$/DALY saved for other iron interventions, with a cost of 15 US$/DALY saved for zinc fortification in the region or with costs of 85-600 US$/DALY saved for other vitamin A (VA) interventions. These cost-effectiveness ratios are also far below international benchmarks set by the World Bank or the WHO, which use ranges of about 60-200 US$/DALY saved or, in the case of India, even 620-1860 US$/DALY saved as thresholds to determine whether a public health intervention is cost-effective (Stein et al. 2006, 2007; Stein, Sachdev & Qaim 2006, 2008). This overall tendency – that biofortification can be more cost-effective than industrial fortification and still more cost-effective than pharmaceutical supplementation – can also be discerned from Figure 4. Similarly, mineral interventions tend to be more cost-effective than VA interventions. A conclusive comparison with dietary diversification and nutrition education is not possible because corresponding cost-effectiveness studies are sparse (Ruel 2001); some studies suggest that these interventions are more costly, though (World Bank 1994; Tan-Torres Edejer et al. 2005).

While expressing the cost-effectiveness of public health interventions in terms of US$/DALY saved is preferable for comparisons across different deficiencies or diseases, expressing the cost-effectiveness of an intervention in terms of dollars per death averted may be more illustrative if taken per se. (Comparisons are not possible because, for instance, the mortality rate of FeD is much lower than that of ZnD or VAD.) With this caveat, and keeping in mind that the average Indian per capita income in 2004 was US$ 620, saving one life through Golden Rice costs US$ 54-358 and saving one life through zinc biofortification of rice and wheat costs US$ 12-115 only.

Comparison of results for India with results of other studies

Apart from the above described in-depth studies on the potential cost-effectiveness of biofortification of cereals in India, other, smaller ex ante studies were carried our for various biofortified crops in various countries that all followed a consistent methodological framework (Meenakshi et al. 2007). The results of these studies show that – while biofortification is in most cases a very cost-effective intervention if assessed by the World Bank's US$ 200 threshold – there can nevertheless be a considerable variation of results (Figure 5).

Figure 4: Cost-effectiveness of micronutrient interventions (in South Asia, US$/DALY saved)

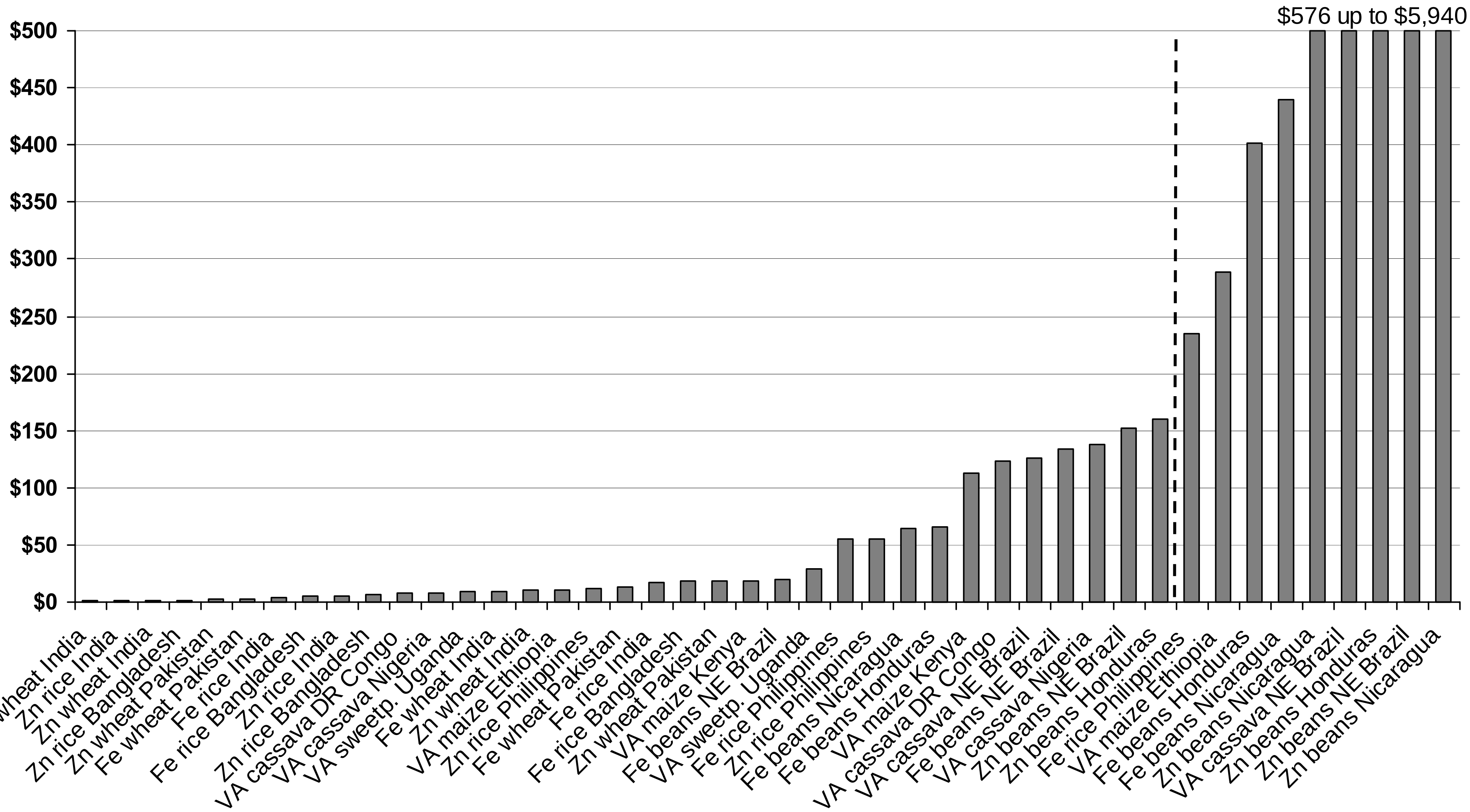


Source: Data from Stein (2006); Stein et al. (2006, 2007); Stein, Sachdev & Qaim (2006); Tan-Torres Edejer et al. (2005); Gillespie (1998) and World Bank (1994). Notes: biofortification = grey, fortification = striped, supplementation = spotted; values expressed in US$ of 2004.

However, this picture seems to be mainly influenced by the low cost-effectiveness of zinc-rich beans; micronutrient-rich cereals and tubers promise to be more cost-effective. Similarly, according to this study, biofortified crops seem to be less cost-effective in Central and South America, whereas results are more promising for South Asia and Sub-Saharan Africa. (Yet, with a cost of 20 US$/DALY saved under optimistic assumptions, iron-rich beans may be very cost-effective in Northeast Brazil.) These findings are in line with results from Tan-Torres Edejer et al. (2005) who find substantial variations in the cost-effectiveness also of other micronutrient interventions across different global regions.

Such variations suggest that more detailed analyses are needed to design national strategies to fight micronutrient malnutrition: while some factors, like the number of people suffering from a micronutrient deficiency in one particular region or the prevalence and severity of the deficiency, may influence the cost-effectiveness of all micronutrient interventions, other factors are more specific to biofortification. For instance the amount of additional micronutrients that can be accumulated in a crop (i.e. the breeding success), the spread and speed of adoption of a biofortified crop, the import or export of a biofortified crop (although the assumption is that biofortification primarily benefits subsistence farmers), the importance of a biofortified crop in the daily diets of the target population, or the bioavailability of the accumulated micronutrients and their net uptake by individuals may all affect the extent to which a biofortified crop can have an impact on a micronutrient deficiency. Similarly, the availability of free germplasm that can be used in national breeding programmes or the number of crop varieties that need to be biofortified to reach the target group to a sufficient extent will influence the cost of biofortification.

Figure 5: Cost-effectiveness of biofortification of various crops with various micronutrients in various countries (US$/DALY saved)



Source: Data from Meenakshi et al. (2007).

Conclusions and recommendations

Micronutrient deficiencies are a recognised public health problem in the Near East. Although this problem is often exacerbated through mineral-poor soils, so far agricultural interventions have attracted less attention than other interventions like pharmaceutical supplementation or industrial fortification. Yet, first ex ante studies of biofortification in other regions of the world indicate that biofortification – i.e. the use of plant breeding to accumulate essential micronutrients in the edible parts of staple crops – promises to have a noticeable impact on the burden of micronutrient deficiencies in target populations, particularly in remote rural areas. Moreover, these projections show that biofortification can be a very cost-effective micronutrient intervention, both compared to other micronutrient interventions and compared to commonly used cost-effectiveness benchmarks.

While achieving dietary diversity for all is a generally accepted objective (Bouis 2002), this is often only possible in the long run and the cost-effectiveness of this approach is still unclear. Therefore, where the diets of the poor are already monotonous and primarily based on cereals, biofortified crops can replace these micronutrient-poor staples at a low cost, thus offering a potential remedy in the medium-term. However – given variations in the projected cost-effectiveness of different biofortified crops in different regions of the world and, also, variations in the cost-effectiveness of other micronutrient interventions in different parts of the world – prior to designing a micronutrient strategy for any country or region, a more specific assessment of the potential cost-effectiveness of the various micronutrient interventions in that particular country or region is advisable in order to put together not only an effective but also an efficient mix of interventions.

In as far as cereals have an important share in the diets of a substantial part of the population in the Near East, the comparison of the results of the analysis of different biofortified crops in different countries indicates that biofortification may indeed be a cost-effective intervention to help controlling micronutrient deficiencies in the region. Therefore the potential of this agricultural intervention for the Near East should be explored further.

Given economies of scale – i.e. a decrease in attributed average costs as production increases because the initial research and development costs of the germplasm can be divided – initial work on biofortification should be co-ordinated across countries and undertaken on a regional or international scale.

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This summary paper draws on other publications by the author (below); see there for more references.

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