Expected economic benefits of meeting nutritional needs through biofortified cassava in Nigeria and Kenya

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Vitamin and mineral deficiencies are a significant health problem in much of the developing world, causing illness, disability, mortality and reduced productivity. Biofortification of staple food crops has been proposed as a cost-effective solution. This paper calculates disability-adjusted life years (DALYs) and economic surplus in order to analyze the potential health and economic benefits of cassava varieties developed to reduce vitamin A and iron deficiency in Nigeria and Kenya. Potential benefits from biofortification with vitamin A alone are estimated at $1,100 to $1,400 million in Nigeria and $67 to $81 million in Kenya, and from biofortification with both vitamin A and iron at $1,200 to $1,600 million in Nigeria and $105 to $110 million in Kenya. Costs per DALY saved are estimated at $4 to $6 for Nigeria, which compares very favorably with the costs for alternative methods such as fortification and supplementation. The estimated cost per DALY saved for Kenya is $56 to $87, which is similar to that for fortification and supplementation.

Keywords: vitamin A deficiency; iron deficiency; biofortified cassava; disability-adjusted life years (DALYs)

JEL classification: O13; O33; I10

Dans beaucoup de pays en voie de développement, la carence en vitamines et minéraux représente un problème de santé significatif, responsable des maladies, de l'infirmité, de la mortalité et de la réduction de la productivité. La biofortification de la nourriture de base a été proposée en tant que solution rentable. Cet article calcule l'espérance de vie corrigée de l'incapacité (EVCI – DALY en anglais) et le surplus économique afin d'analyser les bénéfices

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potentiels, en matière de santé et d'économie, des variétés de manioc destinées à réduire les carences en vitamine A et en fer, au Nigéria et au Kenya. Rien que pour la biofortification en vitamine A, on estime les bénéfices potentiels allant de $1,100 à $1,400 millions pour le Nigéria et de $67 à $81 millions pour le Kenya. Concernant la biofortification combinant la vitamine A et le fer, on parle de $1,200 à $1,600 millions pour le Nigéria et de $105 à $110 millions pour le Kenya. On estime l'épargne des coûts par EVCI à un montant allant de $4 à $6 pour le Nigéria, un chiffre très favorable comparé à celui des méthodes alternatives comme la fortification et la supplémentation. On estime l'épargne des coûts par EVCI à un montant allant de $56 à $87 pour le Kenya, similaire à celui obtenu pour la fortification et la supplémentation.

Mots-clés : *carence en vitamine A ; carence en fer ; manioc biofortifié; espérance de vie corrigée de l'incapacité (EVCI – DALY en anglais)*

Catégories JEL : *O13 ; O33 ; I10*

1. Introduction

Vitamin and mineral deficiencies affect more than two billion people worldwide, causing illness, disability and mortality. The problem is most severe in developing countries, where a third of the children under the age of five suffer from vitamin A deficiency and one fifth of maternal deaths are attributed to iron deficiency anemia during pregnancy (Micronutrient Initiative, 2009). The present study focuses on Nigeria and Kenya, where vitamin A deficiency and iron deficiency anemia are significant concerns. It is reported that 25% of children under the age of six in Nigeria and 70% in Kenya suffer from vitamin A deficiency, while 69% of children under five in Nigeria have iron deficiency anemia and 60% in Kenya (Micronutrient Initiative, 2004). Forty-seven percent of Nigerian women and 43% of Kenyan women aged 15 to 49 suffer from iron deficiency anemia. A study in western Kenya of children aged one to three found that 29% had severe VAD and 92% were anemic (Nabakwe & Ngare, 2004).

Vitamin A and iron deficiencies have several negative health and economic consequences, including early mortality and reduced productivity. Vitamin A deficiency (VAD) leads to nightblindness, corneal scarring and blindness in children under the age of five (Rice et al., 2004; Stein et al., 2005). Between 250,000 and 500,000 children are rendered blind by VAD each year, and children who have lost their vision due to VAD have a 50% chance of dying within a year (Caulfield et al., 2006). VAD also weakens the immune system, leaving its victims more susceptible to diseases such as measles and malaria, as well as increasing the severity of such diseases (Sommer & West, 1996; West & Darnton-Hill, 2001). VAD is a primary risk factor for early mortality, contributing to 630,000 deaths annually from infectious disease, and is associated with at least 20% of the mortality from measles, diarrhea and malaria (Rice et al., 2004).

Iron deficiency is the principal cause of anemia, which leads to reduced levels of energy, physical activity and productivity (Hallberg & Scrimshaw, 1981; Horton & Ross, 2003). Iron deficiency anemia (IDA) is also responsible for impaired mental development (Nokes & Bundy, 1997) and can cause irreversible neurological damage (Grantham-McGregor & Ani, 1999). Iron deficiency weakens the immune system, exacerbating the impact of infectious diseases (Caulfield et al., 2006). Finally, IDA leads to increased maternal mortality, contributing to 841,000 pregnancy-related deaths annually, as well as 134,000 deaths among children under the age of five (Rush, 2000; Stoltzfus et al., 2004).

While several factors contribute to micronutrient deficiencies in the developing world, including inadequate health care and sanitation, poor diet is the primary cause. People consume a disproportionate amount of staple food crops, which are relatively low in micronutrients, and consume an insufficient amount of the fruits, vegetables and animal products that provide the micronutrients essential for good health (Micronutrient Initiative, 2009). One such staple food is cassava, which is important in the diet of most of the populations in Nigeria and Kenya. Cassava is the most important crop in Africa, by weight and value of production, with more than 100 million metric tons being produced annually (FAOSTAT, n.d.). Nigeria is the largest producer, averaging more than 40 million metric tons per annum from 2005 to 2007. Kenya is also an important cassava producer (FAOSTAT, n.d.). Cassava is a major source of calories, especially for the poor, and is a relatively dependable crop even in the face of erratic rainfall and poor soils. While millions of poor households rely on cassava for half of their daily energy, the crop contains only small amounts of micronutrients such as vitamin A and iron. Approximately 20% of Nigerian children get more than 12.5% of their energy from cassava, and 11.9% obtain more than 25% of their energy from that staple crop (author estimates). In Kenya, cassava accounts for more than 50% of the diets of 16% of the population, or 7.1 million people (author estimates).

Given the central place of cassava in the diets of people suffering from vitamin and mineral deficiencies, biofortification – or genetic improvement to increase nutritional content – has been identified as a potential intervention to reduce micronutrient malnutrition. Biofortification can be carried out through field-based breeding or through transgenic modification. It is expected to be particularly effective in combating micronutrient deficiencies among poorer households, those who are unable to afford a wide variety of foods and consume a diet based on a relatively large proportion of one or two staple crops (Nestel et al., 2006), as well as among people living in remote areas that are seldom targeted by processed food fortification and vitamin supplement programs (Manyong et al., 2004).

Several studies have analyzed the probable impact of biofortified staple crops. Meenakshi et al. (2007) published the results of an extensive study of staple crop biofortification that examined six crops and three micronutrients across 11 countries in Africa, Asia and Latin America. Another comprehensive survey, conducted by Qaim et al. (2007), highlighted the potential benefits of biofortification aimed at important staple food crops, specifically rice and wheat with higher pro-vitamin A and iron content for cultivation in India. Both studies found that biofortification compared favorably with fortification and supplementation in terms of cost and effectiveness.

A biofortification program, BioCassava Plus (BC+), was initiated in 2005 and was aimed at developing and distributing improved cassava varieties, one for Nigeria and one for Kenya, to reduce the incidence of the micronutrient deficiencies in these countries.[1] The BC+ varieties being developed for cultivation in these countries are designed to have significantly increased levels of beta carotene (pro-vitamin A) and iron. The variety being developed for Nigeria is based on a farmer-preferred cultivar resistant to cassava mosaic disease (CMD), and the cultivar for Kenya will be engineered for resistance to both CMD and cassava brown streak

[1] The project, 'Improving Cassava for Nutrition, Health, and Sustainable Development', is being carried out by researchers at the Donald Danforth Plant Science Center, with funding from the Bill and Melinda Gates Foundation, Global Health Program.

disease (CBSD).[2] An additional benefit of enhancing vitamin A content is the extension of the shelf life of cassava roots. Fresh cassava roots deteriorate within a few days and shelf life may be extended for up to three weeks, although field trials are ongoing to confirm this trait. If it is confirmed, both varieties should exhibit delayed post-harvest physiological deterioration (PPD), a major cause of lost revenue in cassava production (Wenham, 1995). Because biofortifying cassava will not increase yield, reduce production costs, or mitigate risk, the degree to which farmers adopt the new biofortified varieties will depend on the extent to which they also experience a reduction in the per-unit cost of production. One means of lowering that cost, while potentially providing more carbohydrates and protein, is to biofortify and release varieties that reduce disease problems and post-harvest losses.

This paper presents an assessment of the benefits of cassava biofortification with vitamin A and iron in Nigeria and Kenya. The assessment includes an evaluation of the likely health effects and the likely increase in economic benefits associated with the new cassava varieties. Economic benefits are combined with the costs of developing and disseminating the varieties in a benefit-cost analysis.

2. Methods

The economic impact assessment of the new cassava varieties for Nigeria and Kenya consists of three steps: (1) quantifying the projected health benefits from the new varieties, (2) calculating the expected economic surplus benefits from the new varieties, and (3) using benefit-cost analysis to compare the total benefits from steps 1 and 2 with the costs of developing and disseminating the new varieties.

2.1 Health benefits: Reduction in DALYs lost

Quantifying the expected health benefits of biofortified cassava involves an assessment of the current ill health effects of vitamin A and iron deficiencies in Nigeria and Kenya – including disability, morbidity and mortality – and an assessment of the likely change in health problems that would result from developing and adopting the BC+ cassava varieties. In addition, the analysis involves assessing the economic value of the health changes associated with the micronutrient deficiencies. Previous studies have attempted to assess these factors, using a measure called disability-adjusted life years (DALYs), which was first devised by Murray and Lopez (1996) as a means of capturing health effects in a single index that combines the number of years of life lost and the number of years lived with temporary or permanent disability due to a given health problem.

Zimmermann and Qaim (2004) were the first to calculate the economic value of DALYs saved in the context of biofortification when they applied the method to project the benefits of golden rice in the Philippines. They estimated that annual losses to vitamin A deficiency (VAD) without biofortified rice are $144 million for children, $50 million for pregnant women and $84 million for lactating women for a total loss of $278 million. They projected that golden rice would reduce the total loss by $88 million. They also estimated the costs of

[2] CBSD is a devastating disease of cassava that is spreading rapidly in east and central Africa. The disease had been an endemic problem in the East African coastal region for decades and was not causing much damage to the crop. Recently, however, the disease moved to the higher altitude areas of the east central regions such as western Kenya, southwestern Uganda, and northwestern Tanzania. where it is causing as much as 50% yield loss.

developing and disseminating the biofortified rice and calculated a rate of return of 66 to 133%, depending on assumptions.

Subsequent studies have applied the method to vitamin A, iron and zinc for several other crops and countries. For example, Manyong et al. (2004) applied the method to estimate the benefits of vitamin A fortified cassava in Nigeria. They estimated that VAD in that country caused annual losses of $1,100 million to children, $155 million to pregnant women and $148 million to lactating women – a total of $1,403 million. They projected that biofortified cassava would reduce these losses by $49 to $175 million in children, $26 to $62 million in pregnant women and $23 to $59 million in lactating women – a total benefit of $98 to $296 million.

The number of DALYs lost to disease are calculated as the sum of years of life lost due to preventable death (YLL) and years lived with illness or disability from a preventable disease or health condition (YLD). To calculate the DALYs lost for a particular micronutrient deficiency in a specific country we identify functional outcomes (e.g. night blindness, increased child mortality) associated with the deficiency as well as the affected target groups (e.g. children under the age of five, lactating women) and the size of these groups (Stein et al., 2005). DALYs are quantified using the formula

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

where Tj is the total number of people in target group j, Mj is the mortality rate associated with the deficiency in target group j and Lj is the average remaining life expectancy for target group j. Iij equals the incidence rate of each disease i in target group j, or the percentage who suffer from the disease or health condition. Dij is the disability weight for disease i in target group j – that is, the associated degree of disability of each health outcome, which can vary from 1 for someone who dies to a small fraction for a somewhat minor disability – and dij equals the duration of disease i in target group j (for chronic diseases dij equals the average remaining life expectancy Lj). Finally, r is the discount rate for future life years, which is applied in order to account for the fact that losses that occur closer to the present are worth more than those occurring later (Stein et al., 2005).

The current health impacts of vitamin A deficiency and iron deficiency in Nigeria and Kenya – that is, the number of DALYS presently lost because of the deficiencies – were estimated using target group sizes, functional outcomes, incidence rates, disability weights, a discount rate and disease durations gathered from published data on the two target countries (Murray & Lopez, 1996; Stein et al., 2005; US Census Bureau, 2010). Once the numbers of DALYs currently lost in each country were calculated, the projected reduction in DALYs lost, if the new BC+ cassava varieties are developed and adopted for cultivation, was calculated as a percentage of the current DALYs lost. This percentage depends on the assessment of new incidence rates for the nutrient deficiency-related diseases. These new incidence rates in turn depend on the nutrient quantity and bioavailability in the new crop varieties, the effect of the added available nutrients on the functional health outcomes, and the quantity of the new cassava varieties consumed.

The new cassava varieties are fortified with bioavailable nutrients such that those individuals who receive 25% of their daily energy from the new varieties will obtain the minimum daily allowance of vitamin A and iron (author estimates). Therefore, the health impacts of the new crops will depend on the quantity consumed, which is determined by both the quantity of cassava currently consumed and the adoption rates for the new varieties. In Nigeria, approximately 25% of children under five and 25% of pregnant and lactating women (the target groups for vitamin A and iron deficiencies) receive 25% of their daily energy from cassava and would have their incidence rate of disease and disability from vitamin A and iron deficiency reduced to zero if there were 100% adoption of the new variety (author estimates). This 25% of children and pregnant women is multiplied by the maximum adoption rate of 24% to estimate a projected 6% reduction in DALYs lost per year at the point of peak adoption in Nigeria. And in Kenya 18% of children under age five and 18% of pregnant and lactating women (target groups for vitamin A and iron deficiencies) consume an adequate amount of cassava to benefit from an incidence rate of zero for the related health problem (author estimates). Therefore, at peak adoption, there would be a projected 3% reduction in DALYs lost per year – that is, the maximum expected adoption rate of 16% multiplied by 18%.

The difference between the number of DALYs lost with and without biofortified cassava represents the health impact of the biofortification project. There are multiple ways to assign an economic value to the DALYs saved through biofortification. Discounting (at 3%) and summing the DALYs saved from the year of variety release until 2030, and dividing that sum by total expenditures on research and development, provides the cost per DALY saved, which can be compared to alternative means of meeting the nutrient requirements (Stein et al., 2005). Alternatively, each DALY saved could be assigned a subjective value such as $1,000 in order to determine the total value of lives saved and disability avoided due to the micronutrient enhanced varieties.[3]

2.2 Economic surplus analysis

Besides providing health benefits, the new cassava varieties are expected to provide economic benefits due to a productivity change that shifts out the supply curve of cassava. It is assumed that incorporating vitamin A into cassava imparts a degree of delayed PPD to the roots, resulting in a yield gain (losses avoided) that is partly offset by a small increase in input costs for those who adopt the new varieties. In Nigeria, vitamin A enhancement will be incorporated into a variety resistant to CMD, although the new biofortified variety will not contribute additional CMD resistance. However, the delayed PPD trait will add value to that from biofortification and will increase adoption. In Kenya, the biofortified varieties also add value from delayed PPD as well as from combining resistance to cassava brown streak disease (CBSD) and cassava mosaic disease (CMD). This combined disease resistance in the new BC+ (Serere) variety is new and increases yield compared to current varieties. In addition, both delayed PPD and disease resistance will boost adoption rates in Kenya.

Economic surplus analysis was used to calculate the expected economic benefits from the BC+ varieties associated with the supply increases caused by the higher yields. A closed economy model was assumed in the analysis since little cassava is traded internationally. Change in economic surplus was projected for the 16 years after variety release The formula

[3] Annual per capita income has been suggested as a possible value for a DALY, but that implies that a year of life for a person in Kenya and Nigeria would differ if their per capita incomes differed. Others have suggested a standard $1,000 value to circumvent that problem while still being within a plausible range.

for the change in total economic surplus (TS) for a closed economy with linear demand and supply and a parallel research induced supply shift is:

$$\Delta TS = P_0Q_0 K (1+ 0.5Zn)$$

where P_0 and Q_0 are initial equilibrium price and quantity, respectively; Z = Ke/(e+ n) is the relative reduction in price due to the supply shift; e = supply elasticity; n = demand elasticity (absolute value); and K = shift of the supply curve as a proportion of the initial price (Alston et al., 1995). The latter is calculated as

$$K = [(E(Y)/e) – E(C)/(1+E(Y))] p A (1-d)$$

where E(Y) is the expected proportionate yield increase per hectare after adoption of the new technology, E(C) is the expected proportionate change in variable input cost per hectare, p is the probability of success with the research, A is the adoption rate for the technology and d is the depreciation rate of the new technology (Alston et al., 1995). No depreciation was assumed in this analysis. The formulas for calculating benefits, and their net present value, were incorporated into spreadsheets for the calculations.

The added net benefits of the projected yield and cost changes were estimated using economic surplus analysis incorporating the assumptions shown in Table 1. Estimates of yield and cost changes, adoption rates, and probabilities of success were obtained through interviews with scientists and from data on previous varietal adoption rates in the countries. Benefits were assumed to begin in year 13 (for Nigeria) and year 14 (for Kenya), after the research and regulatory processes are complete, and assumed to continue for 16 years after release. Adoption occurs gradually as cuttings are multiplied, and peak adoption of 24% (Nigeria) and 16% (Kenya) is reached in the 10th year after varietal release. The estimated peak adoption rate for Nigeria was based on a December 2009 survey of the cassava varieties under cultivation in eight of the country's primary cassava-producing states (Akoroda, 2010). The survey results indicate relatively high current adoption rates for the cassava variety serving as the base cultivar for the new biofortified BC+ variety.[4] A conservative estimate of 24% adoption was assumed on the basis of the current distribution of the base cultivar throughout Nigeria and the expected maximum adoption rate in key cassava producing states after biofortification.[5] Adoption rates of new cassava varieties in Kenya have varied widely due to the effect of periodic outbreaks of cassava mosaic disease (CMD), with farmers exhibiting greater willingness to adopt disease resistant varieties following significant occurrences of CMD. For example, the Kenya Agriculture Research Institute (KARI) estimated an adoption rate as high as 50% in some parts of western Kenya following a CMD crisis in the 1990s.

[4] Current adoption rates for the base cultivar (TME7) range from 20 to 60%.

[5] The a) current percent adoption and b) projections of peak adoption after biofortification, for important cassava-growing states, are as follows: Oyo state, a) 26.63%, b) 40%; Ondo state, a) 19.97%, b) 30%; Benue state, a) 23.33%, b) 40%; Kogi state, a) 58.42%, b) 75% (Akoroda, 2010, for (a) and author estimates for (b)).

Given the wide variation in adoption rates, a conservative estimate of 16% was assumed, a rate applicable to a period that is unaffected by a major CMD outbreak.

It is assumed that the research has a 50% chance of succeeding and will result in a yield improvement (savings in losses) of 10 to 15% for adopters in Nigeria due to delayed PPD and 20 to 35% for adopters in Kenya due to delayed PPD and combined resistance to CMD and CBSD. Plant scientists indicate that current PPD losses are approximately 20%. The new varieties should delay PPD as long as the roots are undamaged at harvest. Approximately 95% of the rainy season crop and 50% of the dry season crop are undamaged at harvest. Eighty percent of the total crop is harvested during the rainy season and 20% during the dry season (author estimates). Therefore, the savings in losses due to PPD were calculated as: 0.95 * 0.8 + 0.5 * 0.2 = 0.86. With a 20% PPD loss currently, the final estimate of PPD loss averted is 0.86 * 0.2 = 0.17. Therefore, the new varieties will increase the net product by approximately 17% due to delayed PPD. Analysis in this paper assumed a conservative gain of 10 and 15% in Nigeria. Yield improvement from combined CMD and CBSD resistance in Kenya was estimated by scientists to be 10 to 20%.[6] Thus, the total gain in Kenya from delayed PPD and from disease resistance was 10 to 15% plus 10 to 20%, or a total 20 to 35%. Finally, a 5 to 10% increase in input costs per hectare was assumed, with the additional costs resulting from procurement of cassava cuttings for the first year of cultivation of the new varieties.

Table 1: Basic assumptions in models to estimate economic benefits of GM cassava varieties with resistance to CMD and delayed PPD in Nigeria and Kenya and resistance to CBSD in Kenya

Parameter	Nigeria	Kenya
Production (million tons)	40	0.6
Price per ton (US$)	75	95
Percent yield gain	10 – 15	20 – 35
Percent cost increase per ha	5 – 10	5 – 10
Maximum adoption rate (%)	24	16
Years to max after first adoption	10	10
Years to first adoption	13	14
Years of benefits	20	20
Probability of success (%)	50	50
Elasticity of supply	1	1
Elasticity of demand	.43	.3
Discount rate (%)	3	3
Market	No international trade	No international trade

2.3 Benefit-cost analysis

The final step in the analysis was to combine the health and economic surplus benefits and compare them with the research and distribution costs of the project in a benefit-cost analysis

[6] Recent crop losses to CBSD in East Africa indicate that this estimate may be conservative.

using a discount rate of 3%. Health benefits equaled the number of DALYs saved due to the biofortified varieties, valued at $1,000 per DALY. Total research and dissemination costs were estimated at $12,159,000, and were assumed to be distributed equally between Nigeria and Kenya.

3. Results

The estimated DALYs lost due to vitamin A deficiency and iron deficiency in Nigeria and Kenya are presented in Tables 2 to 5, along with the projected DALYs saved due to biofortified cassava. In Nigeria, pro-vitamin A fortified cassava is estimated to reduce total DALYs lost due to the health problems associated with VAD by 6%. Most of the DALYs saved are the result of a reduction in child mortality. In Kenya, cassava enhanced with pro-vitamin A is estimated to reduce DALYs lost due to VAD by about 3%. Again, most of the DALYs saved are due to a reduction in child mortality.

Table 2: DALYs lost to Vitamin A deficiency in Nigeria and saved by biofortified cassava

Functional outcome	Target group (million) (Tj)	Incidence rate (Iij)	Disability weight (Dij)	DALYs lost/yr before bio-fortification (thousand)	DALYs saved/yr with biofortified cassava at max adoption (thousand)
Night blindness	23.4	.00387	.05	4.5	0.3
Corneal scarring	23.4	.00057	.2	66.5	4.0
Blindness	23.4	.00057	.5	166.4	10.0
Measles	23.4	.012097	.35	2.7	0.2
Measles with complications	23.4	.012097	.7	10.8	0.6
Increased child mortality	23.4	.0054	1	3,152.2	189.1
Total DALYS	23.4			3,403.2	204.2

Sources: A. US Census Bureau (2010); B. Stein et al. (2005); C. Murray & Lopez (1996)

Target groups (Tj) obtained from A; mortality rates (Mj) calculated on the basis of B, using WHO mortality country fact sheets online; average remaining life expectancy (Lj) calculated based on B, using average life expectancy data from A; incidence rates (Iij) taken from C's global health statistics, where available (where only prevalence rates were available, incidence rates were calculated as prevalence/duration – duration from B); disability weights (Dij) taken from B; disease duration (dij) calculated using average onset of disease from B and average life expectancy from A.

Table 3: DALYs lost to Vitamin A deficiency in Kenya and saved by biofortified cassava

Functional outcome	Target group (million) (Tj)	Incidence rate (Iij)	Disability weight (Dij)	DALYs lost/yr before bio-fortification (thousand)	DALYs saved/yr by biofortified cassava at max adoption (thousand)
Night blindness	6.6	.00387	.05	1.3	0.04
Corneal scarring	6.6	.00057	.2	20.6	0.6
Blindness	6.6	.00057	.5	51.5	1.5
Measles	6.6	.012097	.35	.8	0.02
Measles with complications	6.6	.012097	.7	3.1	0.1
Increased child mortality	6.6	.0024	1	433.6	12.5
Total DALYS	6.6			510.8	14.7

Sources: A. US Census Bureau (2010); B. Stein et al. (2005); C. Murray & Lopez (1996)

Target groups (Tj) obtained from A; mortality rates (Mj) calculated on the basis of B, using WHO mortality country fact sheets online; average remaining life expectancy (Lj) calculated based on B, using average life expectancy data from A; incidence rates (Iij) taken from C's global health statistics, where available (where only prevalence rates were available, incidence rates were calculated as prevalence/duration – duration from B); disability weights (Dij) taken from B; disease duration (dij) calculated using average onset of disease from B and average life expectancy from A.

Iron biofortified cassava is estimated to reduce DALYs lost due to the health problems associated with iron deficiency by 6% in Nigeria and by 3% in Kenya. Most of the DALYs saved result from a reduction in maternal mortality caused by IDA. DALYs saved due to vitamin A enhancement are significantly greater than those saved due to iron enhancement.

Table 4: DALYs lost to iron deficiency in Nigeria and saved by biofortified cassava

Functional outcome	Target group (million) (Tj)	Inci-dence rate (Iij)	Disability weight (Dij)	DALYs lost/yr before bio-fortification (thousand)	DALYs saved/yr with biofortified cassava at max adoption (thousand)
Impaired physical activity (moderate)					
Children < five	23.4	.057444	.011	62.2	3.7
Women 15+	42.9	.003137	.011	30.5	1.8
Impaired physical activity (severe)					
Children < five	23.4	.003578	.087	30.7	1.8
Women 15+	42.9	.000372	.09	29.6	1.8
Impaired mental (moderate)					
Children < 5	23.4	.00347	.006	11.6	0.7
Impaired mental (severe)					
Children < 5	23.4	.00207	.024	27.8	1.7
Maternal mortality due to IDA					
Women 15–49	35.2	.0004[a]	1	187.7	11.3
Stillbirth accompanying maternal mortality due to IDA	.0141[b]	.3[c]	1	106.5	6.4
Child mortality accompanying maternal mortality due to IDA	.0141[b]	.0396	1	13.9	0.8
Total DALYS				500.5	30

Sources: A. US Census Bureau (2010); B. Stein et al. (2005); C. Murray & Lopez (1996)

Target groups (Tj) obtained from A; mortality rates (Mj) calculated on the basis of B, using WHO mortality country fact sheets online; average remaining life expectancy (Lj) calculated based on B, using average life expectancy data from A; incidence rates (Iij) taken from C's global health statistics, where available (where only prevalence rates were available, incidence rates were calculated as prevalence/duration – duration from B); disability weights (Dij) taken from B; disease duration (dij) calculated using average onset of disease from B and average life expectancy from A.

Notes:

[a] IDA causes 5% of maternal mortality. Maternal mortality is 0.8% in Nigeria. Therefore Iij = 0.05 *0.008 = 0.0004.

[b] The target group for stillbirths, and for child mortality that accompanies maternal mortality caused by IDA, is childbearing women who die in childbirth due to IDA; 35.2 * 0.0004 = 0.0141.

[c] 30% of maternal mortality results in stillbirths.

The cost per DALY saved is found by dividing the total cost of developing and disseminating the biofortified varieties by the discounted sum of the DALYs saved from the year of variety release until 2030. In Nigeria, the cost per DALY saved of vitamin A enhanced cassava is estimated at $5, while a variety biofortified with both vitamin A and iron costs about $4 per DALY saved. In Kenya, a variety biofortified with vitamin A alone is estimated to cost about

Table 5: DALYs lost to iron deficiency in Kenya and saved by biofortified cassava

Functional outcome	Target group (million) (Tj)	Incidence rate (Iij)	Disability weight (Dij)	DALYs lost/yr before biofortification (thousand)	DALYs saved/yr with biofortified cassava at max adoption (thousand)
Impaired physical activity (Moderate)					
Children < five	6.6	.057444	.011	17.6	0.5
Women 15+	11.3	.003137	.011	9.4	0.3
Impaired physical activity (Severe)					
Children < five	6.6	.003578	.087	8.7	0.3
Women 15+	11.3	.000372	.09	9.1	0.3
Impaired mental (moderate)					
Children < 5	6.6	.00347	.006	3.7	0.1
Impaired mental (severe)					
Children < 5	6.6	.00207	.024	8.7	0.3
Maternal mortality due to IDA					
Women 15–49	9.4	.0005[a]	1	89.3	2.6
Stillbirth accompanying maternal mortality caused by IDA	.0047[b]	.3[c]	1	38.7	1.1
Child mortality accompanying maternal mortality due to IDA	.0047[b]	.0216	1	2.8	0.1
Total DALYS				188.0	5.4

Sources: A. US Census Bureau (2010); B. Stein et al. (2005); C. Murray & Lopez (1996)

Target groups (Tj) obtained from A; mortality rates (Mj) calculated on the basis of B, using WHO mortality country fact sheets online; average remaining life expectancy (Lj) calculated based on B, using average life expectancy data from A; incidence rates (Iij) taken from C's global health statistics, where available (where only prevalence rates were available, incidence rates were calculated as prevalence/duration – duration from B); disability weights (Dij) taken from B; disease duration (dij) calculated using average onset of disease from B and average life expectancy from A.

Notes:

[a] IDA causes 5% of maternal mortality. Maternal mortality is 1% in Kenya. Therefore Iij = 0.05 *0.01 = 0.0005.

[b] The target group for stillbirths, and for child mortality that accompanies maternal mortality caused by IDA, is childbearing women who died during childbirth due to IDA; 9.4 * 0.0005 = 0.0047.

[c] 30% of maternal mortality results in stillbirths.

$77 per DALY saved, while cassava enhanced with both vitamin A and iron is estimated to cost $56 per DALY saved. These estimates are comparable to those in previous studies of biofortified crops. For example, Meenakshi et al. (2007, 2010) applied a similar method to estimate the benefits of vitamin A fortified cassava in Nigeria, the DRC and northeast Brazil; vitamin A fortified maize in Ethiopia and Kenya; vitamin A fortified sweet potato in Uganda; and iron and zinc fortified beans in Honduras, Nicaragua and northeast Brazil; rice in Bangladesh and India; and wheat in India and Pakistan. Their estimated ranges were wide due to varying assumptions, but for cassava in Nigeria they estimated the costs per DALY saved through biofortification at $8 to $137 and for maize in Kenya at $18 to $113. They note that the World Health Organization estimated the cost per DALY saved in Africa through vitamin A fortification at $41 and for supplementation at $52 (WHO, 2010).[7]

Attaching a value of $1,000 per DALY saved to the numbers in Tables 2 to 5, the annual DALYs saved through biofortification are worth $204 million for vitamin A alone and $234 million for both vitamin A and iron in Nigeria (Table 6). This number is about the mid-point of the range estimated by Manyong et al. (2004). For Kenya, the annual DALYs saved for vitamin A and iron biofortification together are estimated at $20 million, with $14.7 million due to vitamin A.

The annual undiscounted value of the delayed PPD in Nigeria after full adoption is estimated at $3.3 million for the 10% loss yield reduction and a 10% increase in input costs. The numbers for a 15% yield loss reduction and a 5% increase in input costs is $38.4 million. For Kenya, the annual undiscounted value for the delayed PPD in combination with resistance to CMD and CBSD is $0.53 million, under the assumption of a 20% yield gain and a 10% increase in input costs. With a 35% yield gain and a 5% increase in input costs, the value is $1.4 million. The total discounted benefits minus costs from the time period when research costs were first incurred through the first 16 years of adoption are $14 to $221 million in Nigeria and zero to $2.3 million in Kenya.

The numbers in Table 6 underestimate the real value of the delayed PPD and the CBSD resistance because these traits are important drivers in the adoption of the biofortified cassava. Adoption would be lower without the visible yield effects. However, once adoption does occur, most of the economic benefits are derived from the biofortification as opposed to the yield change. If we add the value of vitamin A enhanced cassava to the value of the yield changes, the total annual undiscounted value is $207 to $242 million in Nigeria and $15 to $16 million in Kenya. For cassava enhanced with both vitamin A and iron, the total annual undiscounted value is $237 to $272 million in Nigeria and $20 to $21.5 million in Kenya. The discounted net benefits minus costs from the year when research costs were first incurred through the first 16 years of adoption for the combined yield changes and biofortification with vitamin A are $1200 to $1400 million in Nigeria and $76 to $81 million in Kenya. The corresponding values are $1400 to $1600 million in Nigeria and $105 to $110 million in Kenya when both vitamin A and iron enhancement are included.

The benefits of disease resistance in Table 6 may appear low because we assume that the counterfactual is a set of cassava varieties with some added resistance to CMD and CBSD that will be released by other institutions (using conventional or marker-assisted breeding). Hence the yield advantage over those other varieties is relatively small.

[7] Meenakshi et al. (2007) also estimated that the cost per DALY saved by reducing iron deficiency in South Asia through biofortified rice and wheat was $1 to $18. Baltussen et al. (2004) estimated it at $27 for Africa. Meenakshi et al. (2007) estimated that the cost per DALY saved to reduce zinc deficiency in South Asia through biofortified rice and wheat was less than $11, and noted that the WHO estimated the cost per DALY saved in Africa at $82 for crop biofortification as compared to $120 for supplementation. The benefits of rice and wheat biofortified with iron and zinc and of rice biofortified with vitamin A in India were projected by Qaim, Stein, and others in a series of papers (Stein et al., 2005; Stein, Qaim et al., 2006; Stein, Sachdev et al., 2006; Stein et al., 2007; Qaim et al., 2007). They projected the cost per DALY saved due to iron biofortification in rice and wheat to be $1 to $5 and for zinc biofortification to be $1 to $9. They projected the cost per DALY saved due to vitamin A biofortification in rice to be $3 to $19.

Table 6: Projected economic benefits of biofortified and disease resistant cassava in Kenya and Nigeria under base assumptions (million US$)

	Nigeria	Kenya
Annual undiscounted benefit of cassava with delayed PPD after maximum adoption	3.3–38.4	
Annual undiscounted benefit of cassava after full adoption with delayed PPD and with CMD and CBSD resistance		0.5–1.4
Net present value of benefits minus costs of cassava with delayed PPD from first research through 16 years after adoption begins	14–221	
Net present value of benefits minus costs of cassava with delayed PPD and CBSD resistance from first research through 16 years after adoption begins		0–2.3
Annual undiscounted benefit of cassava with delayed PPD and biofortification with Vitamin A after maximum adoption	207–242	
Annual undiscounted benefit of cassava with delayed PPD and biofortification with Vitamin A and Iron after maximum adoption	237–272	
Annual undiscounted benefit of cassava after full adoption with delayed PPD, CMD and CBSD resistance, and biofortification with Vitamin A		15–16
Annual undiscounted benefit of cassava after full adoption with delayed PPD, CMD and CBSD resistance, and biofortification with Vitamin A and Iron		20–21.5
Net present value of benefits minus costs of cassava with delayed PPD and biofortification with Vitamin A from first research through 16 years after adoption begins	1,200–1,400	
Net present value of benefits minus costs of cassava with delayed PPD and biofortification with Vitamin A and iron from first research through 16 years after adoption begins	1,400–1,600	
Net present value of benefits minus costs of cassava with delayed PPD, CBSD resistance and biofortification with Vitamin A from first research through 16 years after adoption begins		76–81
Net present value of benefits minus costs of cassava with delayed PPD, CBSD resistance and biofortification with Vitamin A and iron from first research through 16 years after adoption begins		105–110

Sensitivity analysis was conducted to determine the effect of altering the assumption about the number of years to first adoption. This assumption was modified to account for the possibility of delayed adoption due to delays in the regulatory approval process or reluctance on the part of potential adopters. In the modified scenario, adoption was assumed to be delayed by another four years. The same shape for the adoption profile was assumed, with initial adoption beginning after 17 years in Nigeria and after 18 years in Kenya.

Given these altered assumptions, cost per DALY saved for Nigeria was estimated to be between $5 and $6, and for Kenya to be from $64 to $87. The discounted net benefits minus costs for cassava biofortified with vitamin A were estimated at $1,100 to $1,300 million in Nigeria and $67 to $71 million in Kenya. In the case of biofortification with both vitamin A and iron, the corresponding values were estimated at $1,200 to $1,400 million for Nigeria and $93 to $97 million for Kenya. As expected, delayed adoption would increase costs per DALY saved while reducing net benefits.

4. Conclusions

Biofortified cassava in Nigeria and Kenya is a cost effective means of reducing health problems associated with vitamin A and iron deficiency. The $4 to $87 estimated cost per DALY is low compared to alternative means for addressing these problems. The World Development Report for 1993 reviewed many public health interventions and found that interventions costing less than $150 per DALY averted were highly cost effective. The World Health Organization estimates the cost per DALY saved in Africa through other means of vitamin A fortification to be $41 and for supplementation to be $52 (WHO, 2010). Most of the benefits from vitamin A biofortification result from reduced mortality of children under the age of five, while most of the benefits from iron biofortification are derived from reductions in maternal mortality.

Economic returns from biofortification are high; in fact higher than the benefits from the yield improvements due to delays in post-harvest physiological deterioration and to CBSD resistance. However, without the addition of at least one of these traits the benefits of biofortification would probably be significantly lower due to a lower rate of varietal adoption by farmers.

The potential benefits of biofortification have now been documented in numerous studies examining a variety of crops, nutrients and regions. Further research is needed to confirm these findings as well as to consider the factors that will determine the relative long-term effectiveness of biofortification as compared to other approaches to combating malnutrition. One area for future research is to assess the acceptance of biofortified crops by consumers. There has been some resistance in Africa to genetically modified crops. Understanding the nature and extent of this resistance will be vital if biofortification is to have a real impact on micronutrient deficiencies and the related health problems.

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References

Akoroda, M, 2010. Distribution of cassava varieties in Nigeria. Unpublished survey, International Institute of Tropical Agriculture, Nigeria.

Alston, J, Norton, G & Pardey, P, 1995. Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Cornell University Press, Ithaca, NY.

Baltussen, R, Knai, C & Sharan, M, 2004. Iron fortification and iron supplementation are cost-effective interventions to reduce iron deficiency in four sub-regions of the world. Journal of Nutrition 134, 2678–84.

Caulfield, L, Richard, S, Rivera, J, Musgrove, P & Black, R, 2006. Stunting, wasting, and micronutrient deficiency disorders. In Jamison, D, Breman, J, Measham, A, Alleyne, G, Claeson, M, Evans, D, Jha, P, Mills, A & Musgrove, P (Eds), Disease Control Priorities in Developing Countries. Oxford University Press, New York.

FAOSTAT (Food and Agriculture Organization), (n.d.). Statistical databases & data-sets. Production. http://faostat.fao.org/site/339/default.aspx Accessed 15 November 2009.

Grantham-McGregor, S & Ani, C, 1999. The role of micronutrients in psychomotor and cognitive development. British Medical Bulletin 55(3), 511–27.

Hallberg, L & Scrimshaw, N (Eds), 1981. Iron Deficiency and Work Performance. Nutrition Foundation, Washington, DC.

Horton, S & Ross, J, 2003. The economics of iron deficiency. Food Policy 28, 51–75.

Manyong, V, Bamire, A, Sanusi, I & Awotide, D, 2004. Ex ante evaluation of nutrition and health benefits of biofortified cassava roots in Nigeria: The DALYs approach. Paper presented at the Inaugural Symposium of the African Association of Agricultural Economists, 6 December, Nairobi, Kenya.

Meenakshi, J, Johnson, N, Manyong, V, De Groote, H, Javelosa, J, Yanggen, D, Naher, F, Gonzalez, C, Garcia, J & Meng, E, 2007. How cost-effective is biofortification in combating micronutrient malnutrition? An ex-ante assessment. Harvest Plus Working Paper No. 2, International Food Policy Research Institute (IFPRI), Washington, DC.

Meenakshi, J, Johnson, N, Manyong, V, De Groote, H, Javelosa, J, Yanggen, D, Naher, F, Gonzales, C, Garcia, J & Meng, E, 2010. How cost-effective is biofortification in combating micronutrient malnutrition? An ex ante assessment. World Development 38(1), 64–75.

Micronutrient Initiative, 2004. Vitamin and mineral deficiency: A global damage assessment report. www.micronutrient.org/vmd/CountryFiles/Sub-SaharanAfricaVMD.pdf Accessed 2 March 2011.

Micronutrient Initiative, 2009. Investing in the future: A united call to action on vitamin and mineral deficiencies. Global Report 2009. www.unitedcalltoaction.org/documents/Investing_in_the_future.pdf Accessed 2 March 2011.

Murray, C & Lopez, A (Eds), 1996. The Global Burden of Disease. Volumes I and II. Harvard University Press, Cambridge, MA.

Nabakwe, E & Ngare, D, 2004. Health and nutritional status of children in western Kenya in relation to vitamin A deficiency. East African Journal of Public Health 1, 1–5.

Nestel, P, Bouis, H, Meenakshi, J & Pfeiffer, W, 2006. Biofortification of staple food crops. Journal of Nutrition 136 (2006), 1064–67.

Nokes, K & Bundy, D, 1997. Iron and Cognition. ILSI (International Life Sciences Institute) Press, Washington, DC.

Qaim, M, Stein, A & Meenakshi, J, 2007. Economics of biofortification. Agricultural Economics 37(S1), 119–33.

Rice, A, West, K & Black, R, 2004. Vitamin A deficiency. In Ezzati, M, Lopez, A, Rodgers, A & Murray, C (Eds), Comparative Quantification of Health Risks: Global and

Regional Burden of Disease Attributable to Selected Major Risk Factors. World Health Organization, Geneva, Switzerland.
Rush, D, 2000. Nutrition and maternal mortality in the developing world. American Journal of Clinical Nutrition 72, 212S–240S.
Sommer, A & West, K, 1996. Vitamin A deficiency: Health, survival, and vision. Oxford University Press, New York.
Stein, A, Sachdev, H & Qaim, M, 2006. Potential impact and cost-effectiveness of golden rice. Nature Biotechnology 24, 1200–1.
Stein, A, Meenakshi J, Qaim, M, Nestel, P, Sachdev, H & Bhutta, Z, 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. Harvest Plus Technical Monograph No. 4, International Food Policy Research Institute (IFPRI) and International Center for Tropical Agriculture, US and Colombia.
Stein, A, Nestel, P, Meenakshi, J, Qaim, M, Sachdev, H & Bhutta, Z, 2007. Plant breeding to control zinc deficiency in India: How cost-effective is biofortification? Public Health Nutrition 10(5).
Stein, A, Qaim, M, Meenakshi, J, Nestel, P, Sachdev, H & Bhutta, Z, 2006. Potential impacts of iron biofortification in India. Research in Development Economics and Policy Discussion Paper No. 04/2006, University of Hohenheim, Germany.
Stoltzfus, R, Mullany, L & Black, R, 2004. Iron deficiency anemia. In Ezzati, M, Lopez, A, Rodgers, A & Murray, C (Eds), Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors. World Health Organization, Geneva.
US Census Bureau, 2010. International database. www.census.gov/ipc/www/idb/ Accessed 30 January 2010.
Wenham, JE, 1995. Post-harvest deterioration of cassava: A biotechnology perspective. FAO (Food and Agriculture Organization of the United Nations), Rome.
West, K & Darton-Hill, I, 2001. Vitamin A deficiency. In Semba, R & Bloem, M (Eds), Nutrition and Health in Developing Countries. Humana Press, Totawa, NJ.
WHO (World Health Organization), 2010. Choosing interventions that are cost effective (WHO-CHOICE).
www.who.int/choice/en/ Accessed 30 January 2010.
Zimmermann, R & Qaim, M, 2004. Potential health benefits of golden rice: A Philippine case study. Food Policy 29(2), 147–68.