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# Ex-Ante Evaluation of Nutrition and Health Benefits of Biofortified Cassava Roots in Nigeria: The Dalys Approach

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**Abstract:** Cassava is a major staple that supplies more than 50% of daily energy to more than 200 million persons in sub-Saharan Africa (SSA). Cassava roots are known to be low in micronutrients such as vitamin A, iron, and zinc. Micronutrient deficiencies threaten the lives of millions of poor households and those located in remote rural areas of SSA often not targeted by fortification programmes. This paper presents results from an ex-ante evaluation of nutrition and health benefits of increased vitamin A status of cassava roots through biofortification for at-risk-target-groups using the disability-adjusted life years (DALYs) approach. Results showed that Vitamin A deficiency (VAD) causes an annual loss of about 553,000 years of "healthy" life in Nigeria with children constituting more than forty percent. Biofortified cassava would reduce VAD by 4.42%, 11.73%, and 3.14% for children, pregnant women, and lactating women respectively in the pessimistic scenario. Results for the optimistic scenario are 28.79%, 76.39, and 20.45% respectively. The biofortification of cassava roots would result in annual gains of about 33,000 years of "healthy"life and avert 166 child deaths per year for the pessimistic scenario and about 220,000 years life and 1272 child deaths per year for the optimistic scenario. In economic terms, such a programme would bring gains amounting to about $10 million per year, which Biofortification, DALYs, Economics, Health, corresponds to an internal rate of return (IRR) as high as 92.4% in the pessimistic scenario. Results in the optimistic scenario are about $63 million per year and an IRR of 165.3%. A research and development effort aimed at the biofortification of cassava roots is a powerful strategy in the fight against hidden hunger from micronutrient deficiencies, which African governments at the national and local levels, and international investors should support to improve the standard of living of the people in SSA.
**Key words:** Cassava, Biofortification, DALYs, Economics, Health, Nigeria

## Introduction

Cassava is considered the most important root crop, which is grown in over 90 countries. It serves as a staple food for more than 500 million people worldwide. According to Scott et al. (2000), 172 million tonnes of cassava was produced worldwide in 2000. Africa accounted for 54%, Asia for 28%, and Latin America and the Caribbean for 19% of the total world production. Sub-Saharan Africa (SSA) produced more than 85 million MT yearly—about half of global production (FAO, 2003). This amount is about double sub-Saharan Africa's production of maize and almost triples its combined production of sorghum and millet.

Cassava provides food and livelihood for many resource poor and rural households in the developing world. The various forms in which cassava is consumed include raw, boiled, cooked and fried slices, flakes, fermented, flour, macaroni, fufu, and gari among others. Cultivated in many SSA countries, cassava is an especially important food crop in Nigeria, the Democratic Republic of the Congo, Tanzania, Ghana, Mozambique, Uganda, Madagascar, Angola, Côte d'Ivoire, Cameroon, Benin, and Kenya. However, many people in countries of sub-Saharan Africa are undernourished with high levels of micronutrient malnutrition threatening the lives of millions of poor households especially those located in remote rural areas often not targeted by fortification and pharmaceutical supplementation programmes.
Nigeria, with a population of more than 110 million and an annual growth rate of about 2.83% has a very low annual per capita income of US$290 in the 2001 period (World Bank, 2003). This, coupled with the high rate of inflation of about 27% in the economy has resulted in increased poverty among the people with more than 9 million people undernourished and consequently deficient in essential micronutrients (such as vitamin A, iron, and zinc) which are required for healthy growth and development (World Bank, 1994). Vitamin A deficiency (VAD) is a leading cause of early childhood death and a major risk factor for pregnant and lactating women with about 3 million African children under the age of five suffering from blindness as a result of VAD (UNACCSN, 1994). A recent study shows that 29.5% of children less than five years, 8.8% of pregnant women and 4.1% of lactating women are found deficient in VA (Maziya-Dixon et al., 2004). The condition can kill directly, but also causes different acute and chronic health problems, such as weakening the immune system and leaving its victims susceptible to deadly diseases like measles, malaria and diarrhoea (West and Darnton-Hill, 2001).

In the past, food fortification and pharmaceutical supplementation were the only known strategies used to reduce the health burden associated with micronutrient deficiencies. These approaches however, require continuous huge investments, with benefits limited to the few number of people who have access to and who could afford them, often in the urban centers. Further research revealed that improving the micronutrient content of major staples produced and consumed by rural and resource-poor households would go a long way in reducing the level of micronutrient deficiency among different categories of people in SSA. Recent efforts include the introduction of biofortified crops – varieties bred for increased mineral and vitamin content – through the biofortification challenge programme (known as HarvestPlus), which involves breeding staple food crops for enhanced micronutrient content. It is a new paradigm for agriculture and a tool for improving human health. Biofortification will complement existing strategies and provide a sustainable and low-cost intervention of reaching people with poor access to markets and formal health care systems (HarvestPlus 2004). This is aimed at improving the nutrition and health status of the undernourished in the developing countries (Alexander et al., 2004). Nigeria with 33 million tonnes of cassava roots in 2003 (the world's largest producer) would benefit greatly from such a biofortification programme.

However, as biofortified crops are not yet available, and in order to ascertain the extent of the nutrition and health benefits of a biofortification programme, this paper uses an ex-ante approach to evaluate the nutrition and health benefits of increased vitamin A status of cassava roots through biofortification for at risk target groups in Nigeria using the disability-adjusted life years (DALYs) approach. The paper is divided into three main sections after the introduction: the methodology, the results and discussion, and a summary and conclusion.

## Methodology

### Study area and data collection

The study covered Nigeria as a whole and is based mainly on secondary data.
Data collected include demographic, food intake, beta-carotene content in food, bio-conversion rate to vitamin A (VA), and health consequences of VAD. Demographic data (population composition and mortality rate) were obtained from UNICEF (2003) and Nigeria Ministry of Health (1999). The food consumption pattern (cassava intake, other food items) of the target group was generated from the database on 24-hour dietary recall undertaken during the Nigeria Food Consumption and Nutrition Survey (Maziya-Dixon et al., 2004). Data were validated from a 24-hour dietary recall among pregnant women, lactating women and their babies, as well as children of 5 years of lower in three communities of southwest Nigeria. The choice of these locations was based on criteria such as being major cassava producing locations where cassava consumption provides more than 50% energy/day for the people, and where secondary information on previous food studies could be obtained. The findings from the three communities were adapted to address the general food consumption patterns in Nigeria. Tables for food composition from various sources (Oguntona and Akinyele, 1995; Pennington, 1994; Prosper, 1987; West and Poortvliet, 1983; and FAO/USDHEWPHS, 1968) were used to calculate the supply of VA from food intake by each target group. Cassava breeders and economists provided information on the VA content of cassava (before and after bio-fortification) and on the duration and costs related to the development and diffusion of BC. The bio-conversion rate into VA was from Zimmermann and Qaim (2004). Data on prevalence/incidence rates of and number of people affected by VAD, disability weights and mortality rates, and health consequences of VAD were also collected from various sources (Maziya-Dixon et al., 2004; UNSSCN, 2004; UNICEF, 2003; West and Darnton-Hill, 2001; Murray and Lopez, 1996; World Bank, 1994; and Brenzel, 1993) and confirmed by local nutritionist and health experts.

### Data analysis

Data were analysed with descriptive statistics and the DALYs techniques. Descriptive statistics involve the use of percentages and means to summarize major parameters in the study. The social costs associated with health problems are quantified using the DALYs technique. The social costs are expressed in years of "healthy" life lost, and are calculated on an annual basis. DALYs measure both the disease and death condition resulting from a micronutrient deficiency, and the total number of DALYs lost, following World Bank (1993) and Murray and Lopez (1996), is expressed as:

$\text{DALYs}_{\text{Lost}}$=YLL + YLDtemp. + YLDperm.…………………………………… (1)

Where, YLL is the number of years of life lost due to mortality, and YLDtemp and YLDperm are years of life lost due to temporary and permanent disability respectively. In order to add up disability (temporary and permanent) and death, the sum of YLD are weighted according to the level of "severity" or "disability" ranging from 0 to 1, with zero connoting perfect health condition while 1 is a health status equal to death. Thus, based on the different levels of severity of disease types among targeted groups in a population, the complete $\text{DALYs}_{\text{Lost}}$ model is expressed as:

$$DALYs_{Lost} = \sum_j T_j M_j \left( \frac{1 - e^{-rL_j}}{r} \right) + \sum_i \sum_j T_j I_{ij} D_{ij} \left( \frac{1 - e^{-rd_{ij}}}{r} \right) + \sum_k \sum_j T_j I_{kj} D_{kj} \left( \frac{1 - e^{-rL_j}}{r} \right) \quad \dots (2)$$

This model follows from Murray (1996), Alexander et al. (2004) and Zimmermann and Qaim (2004). $\Sigma_j$ is the sum for all target group j, $T_j$ is the number of people in target group j (where j = children, pregnant women or lactating women). $M_j$ is the mortality rate associated with VAD, $L_j$ is the average remaining life expectancy in the same group, r is the discount rate of future life, $I_{ij}$ is the incidence rate of temporary disease I in group j, $D_{ij}$ is the corresponding disability weight, $d_{ij}$ is the duration of the temporary disease, and k represents conditions for the permanent disease.

It is assumed that VAD related diseases and associated costs would be reduced if BC were consumed regularly. This can be accounted for by a decrease in the prevalence rates of these diseases in each target group. Following Brenzel (1993), the reduced prevalence rates can be calculated as:

$$Pn_{ij} = [1 - [E_j \times C)] \times P_{ij} \quad \text{………………………………………………..…} \ (3)$$

Where the new prevalence rate of disease i (or incidence rate of disease k) in group j ($Pn_{ij}$) is a function of the initial prevalence rate ($P_{ij}$), the group-specific efficacy rate ($E_j$) which is a function of the characteristics of BC, and the technology coverage rate (C) of BC which depends on its accessibility and acceptance. The new prevalence rates are now inserted into equation (2) to obtain the number of $\text{DALYs}_{\text{Lost}}$ with BC.

The health impact of BC is measured by computing the difference between the numbers of $\text{DALYs}_{\text{Lost}}$ "without BC" and the number of $\text{DALYs}_{\text{Lost}}$ "with BC". The difference is expressed as the number of "disability-adjusted life years" gained (i.e. DALYs gained). DALYs gains are computed under two scenarios: pessimistic and optimistic. Parameters for both scenarios under the original assumptions are shown in Table 1. A sensitivity analysis was conducted on some key parameters such as post harvest losses, technology coverage rate, and the amount of beta-carotene in BC based on the optimistic scenario in the original assumptions (Table 1). The economic implications of DALYs gained from BC are assessed on the basis of the cost per DALY as recommended by World Bank (1994).

## Results and Discussion

The effect of VAD among the target population studied is shown in Table 2. The mortality rate is highest among children, particularly infants and deaths associated with VAD are very important. Of all the children below 5 years, infants mortality account for 60.1%. The average age at which blindness (a permanent disability resulting from VAD) sets in among children is about 2.5 years (Newman 1993). According to this author, breast-fed infants have body stores of VA, which prevents eye symptoms unless depleted. Corneal xerophthalmia (that leads to blindness) is usually high between the age of 2 and 3 years for children and thirty years for pregnant and lactating women (Newman, 1993; West and Darnton-Hill, 2001). This implies that intervention programmes aimed at reducing the mortality rate associated with VAD among children should be targeted to pregnant and lactating women through extended periods of exclusive breastfeeding. Thus, if BC were consumed regularly the same way cassava is currently being consumed by resource poor rural households, it would help to alleviate this health problem.

Both clinical and sub-clinical manifestations of VAD are reported in Table 3. Serum retinal levels are accounted for by sub-clinical VAD, while clinically evident ocular manifestation of VAD (xerophthalmia) constitutes the clinical manifestations. This includes night blindness, Bitot's spot, corneal ulceration, corneal scars, and blindness. Sub-clinical VAD is most predominant in children of less than 5 years with the highest prevalence rate, and accounts for 91.0% of the number of people affected in the three target groups. Pregnant and lactating women respectively account for 6.4% and 2.6% of the sub-clinical VAD. Night blindness is the most important clinical manifestation, followed by Bitot's spot, corneal ulceration, blindness, and corneal scars in that decreasing order of importance. Again children of les than 5 years old, are the most affected compared to pregnant and lactating women.

Estimates of DALYs lost due to VAD without BC is shown in Table 4. The total DALYs lost annually due to VAD related mortality and disability conditions is 1,403,609. Children suffer most: DALYs lost represent 78% of the total while women account for 11% for each target group. Mortality constitutes 67% of all the DALYs lost while loss due to disability accounts for 6% temporal and 26% for permanent. Adding loss due to mortality and that due to permanent disability makes the social impact of VAD even greater. Persons affected by a permanent disability or death cannot contribute fully to the economy of a country. These high consequences of VAD in Nigeria constitute an additional reason for a new strategy to fight VAD through biofortification. Children should be the major beneficiaries of the new biofortification programmes of crops, in particular to address the consequences on death. Out of the total DALYs lost for children, the proportion due to mortality accounts for 86.1%. For the children to benefit more from this new strategy, they need to eat more of the new cassava. Educational campaigns will be needed to increase the awareness among mothers in the choice of the type of cassava to be fed to their kids. In monetary terms, the total $\text{DALYs}_{\text{Lost}}$ per annum amounting to 1,403,609 is about US$1,403.6 million. Thus, the cost of VAD is quite huge and requires immediate strategies of intervention.

With BC, annual gains of 98,770 years of healthy life are estimated in the pessimistic scenario (Table 5). Children account for 49.6% of this estimate, while pregnant and lactating women account for 26.7% and 23.7% respectively. Reduced disability accounts for 13.9% of the total DALYs gained among children while all gains for pregnant and

lactating women were due to reduced disability. About 57.3% of the total estimated DALYs gained in the pessimistic scenario is due to reduced disability, while 42.70% accounts for reduced mortality. Cassava biofortification can avert a total of 1,651 child deaths per year in the pessimistic scenario. In monetary terms, the health gain is about US$98.8 million per year, corresponding to an internal rate of return (IRR) of as high as 185.9% (Bamire et al., 2004). In the optimistic scenario, the biofortification of cassava can result into annual gains of about 295,539 years of healthy life, with children, pregnant and lactating women accounting for 59.1%, 21.0% and 19.8% respectively. About 49.1% of the health gain is attributed to disability, while reduced mortality accounts for about 50.9%. The biofortification of cassava roots can avert 5,886 child deaths in the optimistic scenario, which translates into an annual gain of US$295.5 million with a high IRR of about 243.8% (Bamire et al., 2004).
The potential annual benefits correspond to the reduction in the health burden of about 7% for the pessimistic scenario and 31% for the optimistic scenario. The investments required to make that reduction in the social cost of VAD lead to high economic returns between about $100 m and $300 m annually depending on the type of scenarios. The corresponding high IRRs indicate that investment in the biofortification of cassava is indeed very profitable. This shows that tremendous health gains could be achieved through BC roots.

Although the health and nutrition benefits are quite high to justify an investment in the biofortification of cassava roots, the above results also show the new cassava under the original assumptions would not be able to fully resolve the social costs associated with VAD.

A sensitivity analysis was conducted on key parameters to define the minimal conditions under which the new BC will fully address the estimated social costs of VAD for the cassava consumers in Nigeria. Three separate strategies emerged.

The first is on the reduction of post-harvest losses to 22%. Maintaining other parameters constants under the optimistic scenario (i.e. beta-carotene at 15µg/g and technology coverage rate at 40%), the reduction in post-harvest losses to 22% will eliminate the health burden and result in a bonus of 4445 DALYs. Reduction of post-harvest losses to 22% would require the consumption of cassava roots as fresh and boiled only. This would be a complete change in the consumption habits of the target population, which is unlikely to happen because cassava is usually eaten processed into lafun, fufu, eba, gari in Nigeria. Food technologists should come up with new processing methods that retain most of the VA in the processed cassava products.

The second strategy would be to increase the beta-carotene content to 58.5µg/g, other parameters kept constants under the optimistic scenario (i.e. post-harvest losses at 80% and technology coverage rate at 40%). This amount should be the target for breeders through conventional breeding and/or engineering. The potentials for acceptance of the new cassava are higher because consumers will still use cassava in the known forms as lafun, fufu, eba, gari as long as the new BC meets other consumers' preferences such as color, taste, stickiness, starch content, yield, resistance to pests and diseases, etc. Increasing the beta-carotene to a minimum of 58.5µg/g will eliminate the health burden and also result in a bonus of 4445 DALYs. The only issue from this second strategy as a stand-alone strategy is that 80% of the gains in beta-carotene content from the breeding programmes are lost. In other words, consumers have to waste 4/5th of the beta-carotene generated that supplies more than 50% of daily energy and use only 1/5th of it.

The third strategy is a simultaneous change that result in the reduction of post-harvest losses, an increase in the beta-carotene content, and expansion in the use of the technology by both producers and consumers. Results show post-harvest losses of 66%, beta-carotene of 35µg/g and technology coverage of 45% would completely eliminate the social costs due to VAD (Table 6). Other alternative combinations could be tested. By all means, increasing the total coverage alone to 100% could not totally reduce the health burden under the original optimistic scenario, as it was the case for the first and second strategy. Implementing this third strategy implies that an integrated approach that brings together food technologists, cassava breeders, extension services, economists, etc. will totally pay for the losses due to VAD. Thus, a multi-facet research and development effort aimed at the biofortification of cassava roots is imperative to reduce the growing trend of death cases and disabilities resulting from micronutrient deficiencies in SSA.

## Summary and Conclusion

This paper evaluated the nutrition and health benefits of cassava biofortification among children, pregnant and lactating women in Nigeria using the DALYs approach. Results showed that more than 1.4 million years of healthy life are lost annually due to VAD amounting to a huge monetary loss of about US$1,403.6 million. The conservatively estimated annual health gains associated with BC roots range between 98,770 and 295,539 years of healthy life respectively in the pessimistic and optimistic scenarios depending on the underlying assumptions. This translates into an internal rate of return as high as between 185.9% and 243.8%. A large positive health effect is obtained with increasing levels of coverage of the technology and beta-carotene content, and reducing post harvest losses. The results imply that deaths and related health effects associated with VAD among resource poor households in developing countries would be substantially reduced with the biofortification programme, particularly through an integrated approach. Thus, a research and development effort aimed at the biofortification of cassava roots is imperative for African governments at the national, state and local levels as well as international investors to embark upon to reduce the growing trend of death cases resulting from VAD in SSA. This would help to meet the food and nutrition challenges of the people and improve their standard of living.

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**Table 1: Key parameters used in computing DALYs "with" biofortified cassava**

| Parameter | Original Assumption | |
|---|---|---|
| | Pessimistic Scenario | Optimistic Scenario |
| Post-harvest losses (%) | 90.0 | 80.0 |
| Technology coverage rate (%) | 30.0 | 40.0 |
| Amount of beta-carotene (μg/g) | 10 | 15 |
| Bioconversion rate to VA (x:1) | 12 | 12 |
| Cost per DALYs (US$) | 1,000 | 1,000 |

Source: West and Darnton-Hill, 2001; World Bank, 1994; Cassava Breeder and Nutritionist (personal communication)

**Table 2: Mortality due to vitamin A deficiency among the target population**

| Group | Population | Mortality rate | Mortality due to VAD | Total Deaths | # Deaths from VAD | Average age of onset of blindness |
|---|---|---|---|---|---|---|
| Infants | 8,005,300 | 11.0% | 2.53% | 880,583 | 22,279 | |
| Children | 12,062,700 | 7.3% | 1.68% | 880,577 | 14,794 | |
| Children (<5 years) | 20,068,000 | 18.3% | | 1,761,160 | 37,072 | 2.5 |
| Pregnant women | 4,702,000 | 0.80% | | 37,616 | 0 | 30 |
| Lactating women | 4,176,000 | 0.80% | | 33,408 | 0 | 30 |

Source: UNICEF, 2003; West and Darnton-Hill, 2001; Nigeria Ministry of Health, 1999; Newman, 1993; and own calculations.

**Table 3: Prevalence rates and number of people affected by VAD**

| Clinical manifestation | Disability weights | Children (<5 years) | | Pregnant women | | Lactating women | |
|---|---|---|---|---|---|---|---|
| | | Prevalence rate (%) | Number of affected (thousand) | Prevalence rate (%) | Number of affected (thousand) | Prevalence rate (%) | Number of affected (thousand) |
| Sub-clinical VAD | 0.00 | 29.50 | 5,920.06 | 8.80 | 413.78 | 4.10 | 171.22 |
| Night blindness | 0.15 | 0.69 | 138.47 | 0.86 | 40.44 | 0.77 | 32.16 |
| Bitot's spot | 0.25 | 0.17 | 34.12 | 0.58 | 27.27 | 0.60 | 25.06 |
| Corneal ulceration | 0.50 | 0.09 | 18.06 | 0.43 | 20.22 | 0.43 | 17.96 |
| Corneal scars | 0.50 | 0.00 | 0.00 | 0.21 | 9.87 | 0.26 | 10.86 |
| Blindness | 0.50 | 0.05 | 9.03 | 0.32 | 15.05 | 0.34 | 14.41 |

Source: Maziya-Dixon et al., 2004; UNSSCN, 2004; UNICEF, 2003; West and Darnton-Hill, 2001; Murray & Lopez, 1996; World Bank, 1994; Brenzel, 1993; Nutritionist (personal communication)

**Table 4: DALYs lost due to vitamin A deficiency without biofortified cassava**

| **Loss** | **Lost** | **Children** | **Pregnant Women** | **Lactating Women** | **Total** |
|---|---|---|---|---|---|
| Due to mortality | YLL | 947,324 | 0 | 0 | 947,324 |
| Due to temporary disability | $YLD_{temp}$ | 37,761 | 27,515 | 25,116 | 90,392 |
| Due to permanent disability | $YLD_{perm}$ | 115,381 | 127,974 | 122,538 | 365,893 |
| Total due to disability | $YLD_{Total}$ | 153,142 | 155,489 | 147,654 | 456,285 |
| Total | $DALY_{Lost}$ | 1,100,466 | 155,489 | 147,654 | 1,403,609 |
| In monetary terms (million US$) | | 1,100.5 | 155.5 | 147.7 | 1,403.6 |

YLL= years of life lost; $YLD_{temp}$ = years of life due to temporary disability; $YLD_{perm}$ = years of life due to permanent disability; $YLD_{Total}$ = years of life due to disability
Source: own calculations

**Table 5: Potential annual benefits of biofortified cassava (DALYs gained) based on the original assumptions**

| **Gain** | **Pessimistic Scenario** | | | | **Optimistic Scenario** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Children** | **Pregnant Women** | **Lactating Women** | **Total** | **Children** | **Pregnant Women** | **Lactating Women** | **Total** |
| Due to reduced mortality | 42,178 | 0 | 0 | 42,178 | 150,406 | 0 | 0 | 150,406 |
| Due to reduced disability | 6,818 | 26,330 | 23,444 | 56,592 | 24,314 | 62,165 | 58,654 | 145,133 |
| Total | 48,996 | 26,330 | 23,444 | 98,770* | 174,720 | 62,165 | 58,654 | 295,539** |
| In monetary terms (million US$) | 49.0 | 26.3 | 23.4 | 98.8 | 174.7 | 62.2 | 58.7 | 295.5 |
| Child deaths averted by biofortified cassava | 1,651 | | | | 5,886 | | | |

Note: *Internal Rate of Return (IRR) = 185.9%; **IRR = 243.8%
Source: own calculations

**Table 6: Impact of key parameter variations on DALYs with biofortified cassava under the optimistic scenario**

| **Parameter** | **DALYs gained with BC** | **Percent reduction in health burden**[1] |
|---|---|---|
| Original assumptions | 295,539 | 21.1 |
| Post-harvest losses (22%) | 1,408,054 | 100 |
| Technology coverage rate (100%) | 736,184 | 52.5 |
| Amount of beta-carotene (58.5μg/g) | 1,408,054 | 100 |
| Simultaneous changes in the three parameters | 1,432,495 | 102.1 |

[1] DALYs lost due to VAD without BC is 1,403,609, Source: own calculations