The potential impact of orange-fleshed sweetpotatoes on vitamin A intake in Sub-Saharan Africa

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The potential impact of orange-fleshed sweetpotatoes on vitamin A intake in Sub-Saharan Africa

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A recent ex ante impact assessment indicates that orange-fleshed sweetpotatoes can make a major contribution to alleviating vitamin A malnutrition in Sub-Saharan Africa. Replacing the white-fleshed varieties now grown by farmers with new high ß-carotene cultivars that meet local preferences would benefit an estimated 50 million children under age 6 who are currently at risk. The majority of children in Burundi, Rwanda and Uganda would benefit, as would about half of the children in Tanzania. Children in Ethiopia, Kenya and South Africa would also be affected, though to a lesser degree. The study did not take into account the benefits of the new cultivars to pregnant and lactating women, a population whose health is also likely to improve from the availability of the new plant types. Vitamin A deficiency is a major public health problem throughout the region and is responsible for tens of thousands of deaths annually among young children.

Introduction

During the past 20 years, nutritionists in several developing countries have assembled compelling evidence that many children (especially young ones) and adults lack adequate essential vitamins and minerals in their diets (United Nations, 1997). Deficiency in vitamin A is one of the most prevalent problems, particularly in Sub-Saharan Africa and South Asia. The functional consequences of vitamin A deficiency are dramatic: “Severe Vitamin A deficiency has very high fatality rates (60%) but even sub-clinical deficiency is associated with a 23% increase in preschooler mortality in areas with endemic Vitamin A deficiency” (McGuire, 1993).

Consequently, a massive international effort has been underway since the early 1990s to combat vitamin A deficiency. Emphasis in many countries was initially placed on supplementation programs, in the belief that distribution of vitamin capsules could solve the problem quickly. However, experience has shown that although supplementation can be cost-effective, it must be repeated every six months. Thus, in many countries with poorly developed health and

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road infrastructure, supplementation can be logistically difficult to implement, and has mostly been sustained only through continued financial support from outside donors.

A second approach, that of fortifying common foods with a micronutrient, has been used successfully in some instances. But in countries where markets for foods are not well developed, it has been difficult to identify appropriate foods to fortify in order to reach the consumers who are most at risk. Moreover, legal infrastructure has to be sufficiently strong to ensure that manufacturers comply with fortification laws.

A third approach is to improve dietary quality and quantity through diversification. The goal is to achieve and maintain an adequate intake of micronutrient-rich foods in the context of an adequate total diet (World Health Organization, 1996). Food-based approaches require an inter-sectoral perspective, which means providing agricultural and educational inputs, with an awareness of cultural, socio-economic, market and health conditions. Some components, such as home gardens and introduction of new crops, have not always measured up to expectations, but, in general, donors and governments have invested only limited resources in food-based approaches that may prove to be the most sustainable of the various interventions (Ruel and Levin, 2000).

In most countries, a mix of the three approaches is practiced. The focus of this paper is on the potential contribution in the medium term of one crop, sweetpotato, for increasing vitamin A intake in Sub-Saharan Africa as part of a food-based intervention.

Motivation for the assessment of expected benefits

Few foods are rich in vitamin A. Some animal foods, such as fish oils, liver, milk, eggs and butter, contain vitamin A in its true form (also called retinol) which can be used directly and easily by the human body. But the rural and urban poor in developing countries have only limited access to these expensive vitamin A-rich animal foods. Although plant foods and vegetables do not contain vitamin A as such, they do contain precursors, or pro-vitamin A – ß-carotene and other carotenoids – that the human body can convert to vitamin A. Considerable effort has therefore been made to promote improved pro-vitamin A intake through increased consumption and improved storage and preparation of a variety of suitable plant sources of these compounds.

Orange-fleshed sweetpotatoes have emerged as one of the most promising plant sources of ß-carotene (Hagenimana and Low, 2000). A 100-g serving (about half a cupful) of boiled roots can supply about 50% of the daily vitamin A requirement of a young child. Weight for weight, current varieties of orange-fleshed sweetpotatoes contain

20–30 times more ß-carotene than does Golden Rice® (Ye et al, 2000).

Sweetpotato varieties common in the USA have deep-orange flesh, but those grown in Sub-Saharan Africa have white flesh, and contain no pro-vitamin A. It is the prospect of going from nothing to a very sizeable something that fuels interest in orange-fleshed sweetpotato.

Traditionally, orange-flesh has been associated with low dry matter, but the strong preference in Sub-Saharan Africa is for types with higher dry matter. Sufficient progress has now been made via conventional plant breeding to break the link between flesh color and dry matter, and more orange-fleshed sweetpotato varieties with higher dry matter are becoming available (Dapeng Zhang, CIP, personal communication, 2001).

A high level of pro-vitamin A in a crop does not automatically confer improved nutritional status. Absorption depends on the health status of the individual (for example, persons infected with worms absorb less than those not infested), and the presence of inhibitors (such as fiber) and enhancers (such as fat) determines the effectiveness with which ß-carotene is converted into vitamin A (de Pee, 1999). Pro-vitamin A from dark-orange fleshy fruits and vegetables (such as ripe mango, papaya or sweetpotato, but not oranges), appears to be more bio-available (absorbed and utilized) than does pro-vitamin A from dark leafy greens (de Pee et al, 1995, 1998; Khan et al, 1997; Jalal et al, 1998).[1]

Because vitamin A is stored in the liver, measuring bio-availability is difficult. One of the few clinical trials undertaken in developing countries did use sweetpotatoes as a source of pro-vitamin A (Jalal et al, 1998). The trial (Figure 1) showed that incorporating orange-fleshed sweetpotatoes into the diet given to 3–6 year olds who were

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[1] Until recently, the commonly used conversion factors for estimating vitamin A intake reflected the higher bio-availability of animal sources of vitamin A over plant sources:

- 1 retinol equivalent (RE) = 1 µg retinol from animal sources
- 1 RE = 6 µg all-*trans* ß-carotene

In particular, the ß-carotene:retinol equivalency of purified ß-carotene in oil was about 2:1 and it was thought that 3 µg of dietary ß-carotene was equivalent to 1 µg of purified ß-carotene in oil (NRC, 1989).

Recent work among school children in Indonesia and breastfeeding women in Vietnam, which compared the increase in serum retinol resulting from feeding different types of foods, calculated the following apparent conversion factors:

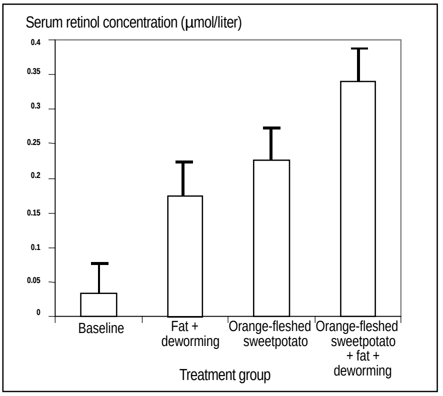
- Retinol-rich foods (animal sources): 1 RE = 1 µg retinol
- Fruits, pumpkin, orange-fleshed sweetpotatoes: 1 RE = 12 µg ß-carotene
- Dark-green leafy vegetables or carrots: 1 RE = 26 µg ß-carotene

In response to these new findings, in 2001 a new conversion unit – retinol activity equivalent (RAE) – was established, with a conversion rate of 1 RAE = 1 µg retinol = 12 µg ß-carotene (Institute of Medicine, Food and Nutrition Board, 2001). Not all evidence supports a lower conversion rate (Takyi, 1999).

Figure 1. Mean (± SEM) changes in serum retinol of children after supplementation

Children 3-6 years of age who were marginally deficient in vitamin A were supplemented with 750 RE of ß-carotene (two snacks + one main meal) six days a week for three weeks. Sweetpotato provided 80% of the ß-carotene consumed

Source: Jalal et al (1998)



marginally deficient in vitamin A significantly increased serum retinol concentrations (ie,. improved vitamin A status), by about the same amount as a treatment comprising a drug for worms and added fat in the diet. But a combination of improved ß-carotene intake, added fat and improved health had a greater effect than either of these treatments alone.

In addition, an 18-month village-level pilot study undertaken in western Kenya confirmed that potential exists to successfully substitute ß-carotene-rich sweetpotatoes for the white-fleshed sweetpotatoes in the diets of young children in that region (Low, et al, 1997; Hagenimana et al, 1999).

Introducing a marginal change in the diet (such as switching varieties) is likely to be easier than introducing a completely new food. Therefore, the potential medium-term impact of orange-fleshed sweetpotato in Sub-Saharan Africa is a function of the area currently under sweetpotato production[2] . This paper examines the potential to meet the intake needs of young children at risk of vitamin A deficiency in Sub-Saharan Africa, based on a spatial evaluation of where sweetpotatoes are being produced. In particular, we address the question: Is sweetpotato availability per person sufficiently large to warrant optimism that substituting orange-fleshed for white-fleshed varieties will result in significant improvements in pro-vitamin A intake? Because sweetpotato is widely perceived to be a secondary food crop that is produced seasonally in only parts of Sub-Saharan Africa, responses to this question are not trivial.

[2] In the longer run, sweetpotato is likely to expand into substantially larger areas of Sub-Saharan Africa. The crop is widely adaptable at altitudes ranging from 200 to 2200 m, and it yields well in marginal soils. Areas for expansion likely will be less affected by sweetpotato virus disease (SPVD) that may limit the scope for introducing exotic orange-fleshed materials in parts of Uganda and Kenya in the short term.

Assumptions and the GIS context

The calculation on the potential impact of orange-fleshed sweetpotato varieties on pro-vitamin A status is driven by supply and demand assumptions. The framework for analysis is a geographic information system (GIS) that permits a disaggregated spatial evaluation of per capita production of sweetpotato. The unit of observation is a grid cell of 2.5 x 2.5 arc-minutes (about 5 x 5 km).

The supply and demand assumptions are listed in Table 1. Population data were taken from the 2.5-minute *Global gridded population* database for the year 1995 (CIESIN, 2000). We used a global geo-referenced database of sweetpotato area for 1997–99 (Huaccho and Hijmans, 2000; Hijmans et al, 2001). For a uniform treatment across countries, this database (with a few exceptions)

Table 1. Assumptions for the simulation of the potential impact of substituting orange-fleshed for white-fleshed sweetpotato varieties in Sub-Saharan Africa

Variable	Assumption	Source
upply		
Area	74,000 ha[a]	FAO (2001)
ield	10 t/ha[a]	FAO (2001)
• Postharvest loss	10%	Woolfe (1992)
• Peeling loss	25%	Woolfe (1992)
et yield	6.5 t/ha	
Pro-vitamin A content		
Potential pro-vitamin A intake (orange)	350 RAE /100 g	Low et al (1997)
• Boiling loss (total)	20%	Woolfe (1992)
• Boiling loss (isomeric)	15%	Woolfe (1992)
Net gain after boiling	228 RAE /100 g	
easonal availability	5 months	Bashaasha et al (1995) Kapinga et al (1995)
emand		
opulation potentially at risk (children 6 months to 6 years)	20% of total population	Low et al (1997)
ercentage of population potentially at risk that has 'adequate' pro-vitamin A intake	20% of population potentially at risk	Low et al (1997)
opulation actually at risk	16% of total population	
DA	450 RAE	Low et al (1997)
ntake of sweetpotato by the population actually at risk	50% of that of other groups	Ryan et al (1984)

[a] Refers to Kenya for illustrative purposes

combines national total area estimates from the Food and Agriculture Organization of the United Nations (FAO) with more disaggregate information on the distribution of the relative sweetpotato growing area across administrative units or production zones[3]. The polygons from the sweetpotato database were transferred to the 2.5-minute grid. As these grid cells are rather small in relation to the precision of the sweetpotato database, the data were smoothed across the grid cells, to allow for the consumption of produce outside, but near to, production zones. For many households, particularly those located in towns and cities, purchasing sweetpotato in the market will be the principal means to tap the potential of the orange-fleshed varieties. By dividing the sweetpotato area and the population grids we obtained a new grid with the sweetpotato area per capita for each grid cell. From this new grid, the distribution of sweetpotato area per capita over the population was determined for each country.

National yield estimates are also taken from the FAO production database. Because sweetpotato does not store well once harvested, and throughout Sub-Saharan Africa is usually eaten in boiled form after peeling, post-harvest and peeling losses have to be factored into the calculation. For example, for the case of Kenya with an estimated national yield of 10 t/ha, the net yield available for the supply of pro-vitamin A is assumed to be 6.5 t/ha (Table 1).

The assumptions made in Table 1 about the pro-vitamin A content of orange-fleshed sweetpotato and about demand are based largely on the aforementioned pilot project focusing on the introduction of orange-fleshed varieties to women's groups in rural South Nyanza, western Kenya (Low et al, 1997). We assume that the orange-fleshed varieties supply 350 RAE (retinol activity equivalents) per 100 g fresh matter. This is equivalent to about 4200 µg of ß-carotene per 100 g fresh matter, which is about 50% of the ß-carotene content of cooked sweetpotato in the USA (Holden et al, 1999). Cooking losses further reduce the pro-vitamin A content of the orange-fleshed varieties. Therefore, we assume that the net supply of pro-vitamin A available from orange-fleshed varieties is 228 RAE per 100 g of edible matter (Table 1).

The other supply-related element in Table 1 is seasonal availability. Sweetpotato is a perishable secondary crop of seasonal importance

[3] Data collection on sweetpotato by national systems is weak and production is typically under-reported in countries where it is a secondary food crop (most of southern Africa, for example), especially when it is intercropped. For instance, most of what figures as potato in Malawi is really sweetpotato. In 2000 or 2001, FAO revised upward the estimated sweetpotato-growing area in Nigeria in the late 1990s, from 5000 to 378,000 ha! In Mozambique, the first census of agriculture shows that about 45% of rural farm households cultivate some sweetpotato; the existing national data show an area of only 8000 ha. Typically, data are most reliable in countries where sweetpotato is a major staple. Therefore, results outside East Africa should be interpreted with caution.

in many regions of Sub-Saharan Africa. Piecemeal harvesting is a common practice that increases the length of the availability of the crop to the farm household. Piecemeal harvesting of the improved varieties begins two–three months after planting and often continues for five–seven months. In bimodal rainfall areas two cropping seasons are common, and in parts of the East African highlands where rainfall is less seasonally distributed sweetpotato can be cultivated throughout the year. Even in relatively isolated rural markets seasonal availability may be more than five months. Like several of the supply-related assumptions in Table 1, this one is judged to be conservative.

Because of the lack of information on the geographic incidence of vitamin A deficiency, we address the issue of adequacy more generally, from the perspective of percentage of recommended dietary allowance (RDA) for the most vulnerable group: children aged between six months and six years. We assume that young children make up 20% of the population in each grid cell. Using the Helen Keller method as an approximation, Low et al (1997) found that about 20% of young children were judged to have an 'adequate' intake of vitamin A; the vulnerable group is therefore 80% of young children, or 16% of the total population. Finally, we assume that vitamin-A-malnourished young children consume half as much sweetpotato per day than do other age groups.[4]

Collectively, the assumptions in Table 1 result in the summary relationship between per capita production of sweetpotato and pro-vitamin A intake (relative to RDA) that is described in Figure 2. With the full replacement of white-fleshed varieties with orange-fleshed ones, the increasing per capita production of sweetpotato linearly contributes to vitamin A adequacy until production reaches about 30 kg/person. This 'full-impact' level satisfies about 40% of the annual RDA. Beyond 30 kg/person the attainment of adequacy bumps up against the seasonal constraint of five-month availability.[5]

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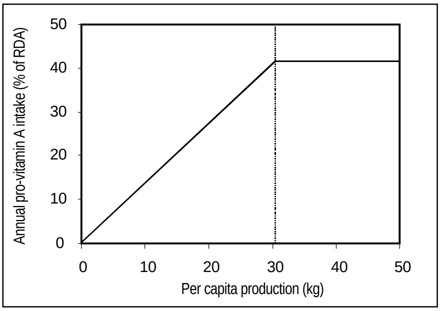
[4] We are not aware of dietary surveys on individuals in Sub-Saharan Africa that show age by gender consumption of sweetpotato. Our assumption is based on Ryan et al (1984) who conducted dietary surveys on a sample of 240 households in six villages on the Deccan Plateau of India. Across about 15 commodity groups, the per capita intake per day of young children aged 1–6 was about 50% of that of older children, adolescents, and adults.

[5] Only a full substitution scenario is specified to assess potential. It is unrealistic to think that orange-fleshed varieties will replace all white-fleshed varieties now grown by farmers. However, farm surveys have shown that varietal change is very dynamic as even subsistence producers are rapidly turning over native varieties. One variety, called Tanzania, has spread throughout East Africa and is also penetrating into southern Africa. Partial adoption scenarios could be specified but with the existing information they would not be that informative and merely fractions of the full adoption scenario. More definitive analysis of expected benefits must await the completion of more pilot-site or larger intervention projects.

Figure 2. Relationship between annual per capita sweetpotato production and pro-vitamin A intake relative to recommended dietary allowance (RDA)



Estimates of potential impact

The above calculation was carried out for the five countries (Ethiopia, Kenya, South Africa, Tanzania and Uganda) invited to participate initially in the Vitamin A for Africa (VITAA) Partnership that focuses on orange-fleshed sweetpotato in a food-based approach (CIP, 2001). Rwanda and Burundi were also included because they have the highest per capita production of sweetpotato in Sub-Saharan Africa. Per capita production is also high in Uganda. In Kenya, Tanzania and Ethiopia, sweetpotato is regionally important, but in Ethiopia, according to FAO, production levels are very low – considerably less than government data suggest. South Africa has the lowest per capita production.

As expected, per capita production in Burundi, Rwanda and Uganda is sufficiently high to make a large dent in the problem of vitamin A deficiency. The pro-vitamin A intake approaches a full-impact 40% of RDA in each of the three countries (Table 2).[6] In Tanzania, about half of the population at risk attains the full-impact outcome. In Kenya, the bulk of the population at risk still benefits somewhat from the replacement of the white-fleshed with the orange-fleshed varieties. In Ethiopia and South Africa, the mean intake increases by only a modest 2% of RDA; however, about one-third of the population at risk in each country experiences a rise in intake. Across the seven countries, about one-third of the population at risk receives the

[6] As a point of reference, the average estimates of simulated impact for the countries in Table 2 can be compared with somewhat similar estimates for the replacement of existing rice varieties with Golden Rice cultivars (Robertson et al, 2001). This application centers on the island of Cebu in the Philippines and is based on a longitudinal health and nutrition survey. Both rice and white flint maize are important staples in Cebu. Full replacement of ordinary rice with Golden Rice (with a future potential level of 200 µg ß-carotene per 100 g rice) results in an improved pro-vitamin A intake of about 6% of RDA for the bottom asset quintile of children aged 10–12 that were followed in the longitudinal survey. Because richer households eat proportionally more rice than do poorer households, the increase in %RDA (of about 13%) was highest for the top quintile. The impact of switching from white to yellow maize was an increase of 4% of RDA for the low quintile and of less than 2% for the top quintile.

Table 2. Impact of the full substitution of white-fleshed sweetpotato varieties with orange-fleshed ones in selected countries of Sub-Saharan Africa

ountry	Population at risk (millions of children aged 6 months to 6 years)	Consequence of replacing white-fleshed with orange-fleshed sweetpotatoes – % of population actually at risk who receive: No benefit	Partial benefit[a]	Full benefit[b]	Average annual increase in pro-vitamin A intake[c] (% RDA)
urundi	1.01	0	9.6 (22.4)	90.4	38.3
thiopia	8.89	65.8	32.4 (5.0)	1.8	2.3
enya	4.47	8.9	72.6 (14.5)	18.5	17.9
wanda	0.87	0	4.6 (26.1)	95.4	39.4
outh Africa	5.98	63.2	36.1 (5.0)	0.7	2.1
Tanzania	4.96	9.9	41.6 (13.8)	48.5	25.1
ganda	3.30	0	15.5 (17.1)	84.5	34.1

Figures in parentheses show average increases in pro-vitamin A intake (as a percentage of RDA) for the children receiving partial benefit

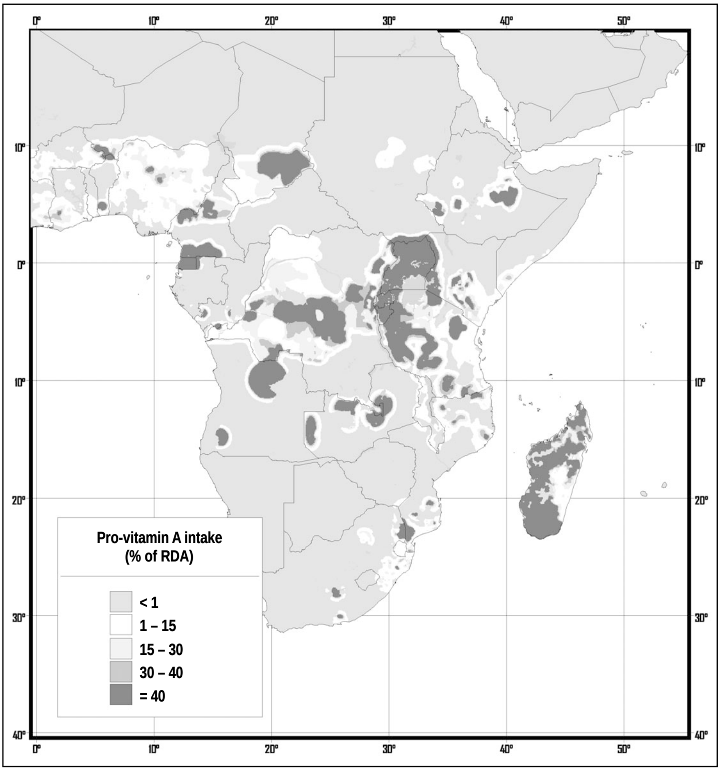
Full impact is equivalent to an increase in pro-vitamin A intake to 40% of RDA

Assuming a maximum availability of five months

increase to 40% of RDA, one-third receives a partial benefit, and one-third does not benefit from the switch to orange-fleshed varieties.

Unless covered by supplementation or fortification programs, much of this increase in intake will accrue to children who have only very low levels of pro-vitamin A intake. Results from dietary surveys, such as Ryan et al (1984), indicated that it is rare for an individual in semi-arid tropics in India to have an intake exceeding 50% RDA.

Applying the same ‘back-of-the-envelope’ calculation to all of Sub-Saharan Africa shows that the potential of orange-fleshed varieties to contribute to solving the problem of vitamin A deficiency is greatest in the Lake Victoria region of the East African highlands (Map 1). We would also expect positive results in Madagascar and parts of southern Africa, and even in some areas of West Africa. About 10 million children (about 10% of the population at risk in Sub-Saharan Africa) would receive the full benefit of an increase in pro-vitamin A



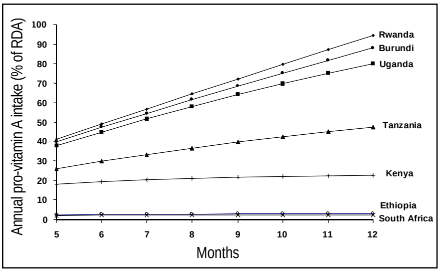
Map 1. Potential impact of replacing white-fleshed varieties of sweetpotato with orange-fleshed materials on pro-vitamin A intake in Sub-Saharan Africa

intake to 40% of RDA. Another 40 million children would be 'partial' beneficiaries.

How sensitive are these results to the assumptions made in Table 1? We have not explored this issue thoroughly, but we carried out a sensitivity analysis for two of the important variables: the assumptions that seasonal availability is five months, and that the pro-vitamin A content of orange-fleshed varieties is 350 RAE/100 g.

The seasonal availability assumption could be unduly restrictive so we relaxed this assumption by considering longer periods including all 12 months of the year. If sweetpotato is available (or can be made available) for a longer period in the high per capita production countries of Rwanda, Burundi and Uganda, then the potential role played by orange-fleshed varieties is substantially greater than our calculations indicate (Figure 3). Seasonally smoothing the existing level of production in these sweetpotato-dense countries (and to a

Figure 3. The effects of reducing the seasonality of sweetpotato production from a five-month baseline



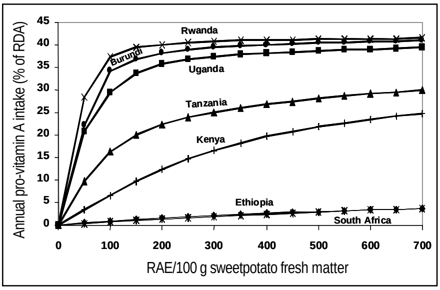
lesser extent in Tanzania) will substantially improve vitamin A nutrition. In the other three countries, production per capita is not sufficiently high to derive gains from extending seasonal availability without increasing production.

In contrast, the goal of increasing the pro-vitamin A content of the orange-fleshed varieties will generate more benefits to groups at risk in regions with moderate production levels than to similar groups in geographic areas with high per capita production (Figure 4). But even for the 'intermediate' countries of Tanzania and Kenya, returns to investing in breeding to improve pro-vitamin A content of orange-fleshed materials are diminishing. The data in Figure 4 suggest that 150–200 RAE/100 g fresh matter is a critical threshold level that cultivars require if they are to have much impact, particularly in high per capita production regions. Figure 4 is good news to plant breeders because it shows that levels of pro-vitamin A in orange-fleshed materials do not have to be that high to have potential for impact.

Conclusions

These preliminary calculations demonstrate the promise for orange-fleshed sweetpotatoes to contribute to a food-based approach to tackling the problem of vitamin A deficiency in Sub-Saharan Africa. In many parts of Sub-Saharan Africa there is sufficient per capita production of sweetpotato to be optimistic about the potential of

Figure 4. Annual pro-vitamin A intake (% of RDA) and pro-vitamin A content of orange-fleshed sweetpotato



orange-fleshed varieties to leverage positive nutritional outcomes by replacing the white-fleshed materials presently grown by farmers.

These estimates also suggest that increasing the availability of sweetpotato across seasons of the year will be more effective in improving nutritional status than will augmenting the pro-vitamin A content of orange-fleshed sweetpotato. Indeed, it seems that orange-fleshed materials do not have to be that 'orange' to make practical impact.

These calculations can be refined in several ways. Other vulnerable groups, such as pregnant and lactating women, can be considered in the population at risk. Agronomic knowledge can be brought to bear in a GIS-format to sharpen responses to issues regarding the seasonality of production. The nexus between production and market availability could be modeled. However, the pay-off to refinement is largely conditioned by the reliability of area estimates from state statistical reporting agencies.

Finally, our estimates indicate only potential. One or more highly focused bio-availability studies are needed to confirm that potential. Investments in breeding, in adaptation and in education programs about orange-flesh sweetpotatoes also need to be viewed in the larger context of more costly direct interventions, such as supplementation and fortification. Ultimately, tapping the potential of orange-fleshed sweetpotatoes hinges on a sustained effort in multi-locational varietal testing featuring participatory varietal selection.

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