ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 17 No. 2 April 2017
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

*Afr. J. Food Agric. Nutr. Dev*. 2017; **17(2):** 11848-11864 **DOI: 10.18697/ajfand.78.HarvestPlus01**

# CHAPTER 1

## AN OVERVIEW OF THE LANDSCAPE AND APPROACH FOR BIOFORTIFICATION IN AFRICA

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Volume 17 No. 2
April 2017
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ISSN 1684 5374

**ABSTRACT**

Mineral and vitamin deficiencies are a serious public health problem in Africa. The terrible consequences of these deficiencies are well known. Biofortification is the process of breeding nutrients into staple food crops. It is one cost-effective and sustainable agricultural investment that can help to reduce mineral and vitamin deficiencies, especially in the diets of the rural poor. This chapter discusses the key questions and impact pathway around which biofortification research has been oriented over the past 15 years, and sets the stage for subsequent chapters in this special issue on biofortification for the African Journal of Food, Agriculture, Nutrition, and Development.

**Key words:** Biofortification, Micronutrient deficiency, Agriculture, Nutrition, Micronutrient targets, HarvestPlus

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ISSN 1684 5374

## INTRODUCTION

Mineral and vitamin deficiencies are a serious public health problem in Africa. In general, dietary quality in Africa is poor, with high dependence on cereal and root staples for the bulk of dietary energy consumption, particularly among the poor [1]. Low incomes and high prices for non-staple foods such as vegetables, fruits, pulses, and animal products are the major constraints to improved dietary quality.

Non-staple foods are often dense in vitamin and minerals, and bioavailability is particularly high for animal products, yet animal products are the most expensive source of dietary energy. The poor eat large amounts of food staples to acquire dietary energy and to keep from going hungry.[1] While undernourishment has been reduced significantly for many African countries since the 1990s, accelerated improvements in diet quality and nutrition interventions are needed to reduce indicators of chronic undernutrition, including micronutrient deficiencies [2]. Because a significant portion (35 percent or more) of poor household income is spent on staple foods for energy, they have little income left to purchase vegetables, fruits and animal-based protein – dietary quality [3]. A similar story can be told for the poor in Asia and Latin America as well.

The health consequences of poor dietary quality are well known – high morbidity and infant mortality rates, compromised cognitive development for children, stunting, and low economic productivity. What people eat depends on many factors, including cultural, geographical, environmental, and seasonal factors. One of the key underlying causes leading to poor dietary quality is that current food systems do not provide minerals and vitamins in sufficient quantities at affordable prices for the poor. In non-emergency situations, poverty is a major factor that limits intake of adequate, nutritious food, which must be available, accessible, and affordable to the poor. Therefore, agricultural investments and policies that improve the availability and affordability of more nutritious foods, such as biofortification, must be made an important part of the solution.

Biofortification, the process of breeding nutrients into staple food crops, is a cost-effective and sustainable agricultural investment that can help to reduce mineral and vitamin deficiencies, especially in the diets of the rural poor. Sufficient resources to implement biofortification globally for several key staple food crops became available in 2003, which coincided with the approval of the Biofortification Challenge Program by the Technical Advisory Committee of the Consultative Group on International Agricultural Research (CGIAR).

The aim of this chapter is to describe the overall landscape and approach for biofortification in Africa and preview the chapters presented in this issue. The following chapters present both the complexity involved in implementing biofortification, and the scientific evidence that biofortification works. The plant breeding and human nutrition research to date has been largely successful and continues to generate new evidence. A

[1] Hunger, not having enough to eat to meet energy requirements, differs from malnutrition, a condition that results from a person's diet having inadequate nutrients for growth and maintenance, or poor absorption of food consumed.

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critical task is to scale up the production and use of biofortified crops that are now available to farmers, particularly by impoverished and malnourished rural households, and to embed biofortification as a mainstream approach to improved micronutrient adequacy in a number of institutions.

**THE AFRICAN LANDSCAPE FOR ADDRESSING MINERAL AND VITAMIN DEFICIENCIES**

While there is great national and regional variation in diets in sub-Saharan Africa, most are characterized by high staple food consumption, mainly cereal or root crops. Access to micronutrient-dense food sources, including animal-source protein, fruits, and vegetables, is a major challenge for many rural households. These foods are often inaccessible because of their relatively high cost, limited local availability, and distribution challenges [4].

Vitamin A, iron, and zinc deficiencies are recognized as the most severe mineral and vitamin public health problems throughout sub-Saharan Africa. Severe vitamin A deficiency among preschool children afflicts most countries, despite widespread vitamin A supplementation programs. The prevalence of vitamin A deficiency among preschool children ranges from 40% in West and Central Africa to about 25% in southern Africa [5]. Anemia affects about 40% of pregnant women and 62% of children in Africa, about half of which is estimated to be attributed to iron deficiency [6]. Anemia levels have not significantly improved over the last 20 years [7]. Data on zinc deficiency are limited, but recent estimates suggest that 24% of Africans have inadequate zinc intakes, with pregnant women and young children at the highest risk of deficiency [8].

Furthermore, half of children with vitamin and mineral deficiencies are suffering from multiple deficiencies [9]. Table 1.1 describes rates of micronutrient deficiencies in several African countries. Micronutrient deficiencies cause poor health, low cognitive development and thus low educational attainment, and decreased work capacity and earning potential, with far-reaching consequences for national socio-economic development for current and future generations.

Several options exist to combat micronutrient deficiencies, including supplementation and food-based approaches like fortification, dietary diversification, and biofortification. For children under two, breastfeeding, micronutrient powders, and nutrient-dense complementary foods can reduce the prevalence of micronutrient deficiencies.

Vitamin A supplementation is a targeted intervention that is considered to be one of the most cost-effective interventions for improving child survival [10]. Because it is associated with a reduced risk of all-cause mortality and a reduced incidence of diarrhea [11], programs to supplement vitamin A are often integrated into national health policies. Pharmaceutical doses of synthetic vitamin A, usually in the form of gelatin capsules, are provided every six months to children under five years of age. Between 1999 and 2005, the proportion of children 6-59 months of age receiving at least one high-dose vitamin A supplement increased more than fourfold. In 2012, estimated coverage rates were near 70 percent globally [12]. However, since the funding for these interventions depends largely on donors and international NGOs, coverage varies widely from year to year in many countries.

Commercial food fortification, where trace amounts of micronutrients are added to staple foods or condiments during processing, allows people to consume recommended levels of micronutrients. This type of fortification has been particularly successful for salt iodization: 71 percent of the world's population has access to iodized salt and the number of iodine-deficient countries has decreased from 54 to 32 since 2003 [13]. Common examples of fortification include adding B vitamins, iron, folic acid and/or zinc to wheat flour, and adding vitamin A to cooking oil and sugar. Fortification is particularly effective for urban consumers, who purchase foods that have been commercially processed and fortified. Fortification is less suitable for reaching rural consumers who often do not have access to or the incomes to afford commercially produced foods. To reach those most in need, such as poor, rural households, it may be necessary to subsidize fortified foods so that the poor do not buy cheaper non-fortified alternatives.

An alternative to commercial fortification is home, point-of-use fortification systems, in which micronutrient powders or lipid-based nutrient supplements are added to food prepared in the home. Evidence of the acceptability and efficacy of home fortification is growing [14, 15, 16], but concerns remain that it is difficult and costly to implement on a large scale. Home fortification is also subject to distribution and funding limitations.

Dietary diversity is strongly and positively associated with children's nutritional status and growth, even when controlling for socioeconomic factors [17]. In the long term, dietary diversification is likely to ensure a balanced diet that includes the necessary micronutrients. In the short term, however, investments will be required in the non-staple food and livestock sectors to increase production and reverse the trend of lower staple and higher non-staple food prices, which have made it difficult for the poor to meet their mineral and vitamin requirements through diverse diets. Investments in reducing food waste in low-income countries – by improving harvest techniques, farmer education, storage facilities, and cooling chains – are also likely to increase the availability and affordability of diverse diets [18].

Special considerations are needed for infants and young children. The transition period from breast milk or formula to solid foods is often accompanied by micronutrient deficiency in many developing countries. Food-based approaches can include additions or changes to complementary feeding practices during this period, including a focus on nutrient-dense foods and the use of specially formulated micronutrient powders. Recent Multiple Indicators Surveys and Demographic Health Surveys that have included diet diversity of children 6-23 months of age and women of reproductive age indicate that the diversity of diets for most children and mothers remain low [19, 20].

**Agriculture plays a role in mineral and vitamin deficiencies**

Traditionally, public research and development strategies have focused on increasing agricultural productivity in staple crops to reduce chronic calorie deficiency (undernourishment). The Green Revolution prioritized the development of high-yielding varieties of major staple crops and intensifying production, increasing the total output of

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Volume 17 No. 2 April 2017
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

staple food crops, thereby increasing their availability and affordability by reducing their prices. From the 1970s to the mid-1990s, the price of staple foods (like rice, wheat, and maize) decreased relative to the price of micronutrient-rich, non-staple foods (like vegetables, fruits, and pulses). The same level of investment for staple crops was not made in increasing the productivity of these non-staple foods. As a result, micronutrient rich foods became relatively less affordable, particularly to the poor [21, 22].

**Regional and multi-lateral organizations recognize the agriculture-nutrition link**

Nutrition starts with what people eat, food products from the agricultural sector. Following the food price crises of 2008 and The Lancet's first series on Maternal and Child Nutrition (2008), the link between agriculture and nutrition has garnered more attention on the international stage. For example, the Scaling Up Nutrition (SUN) movement was launched in September 2010, bringing together governments, civil society, the United Nations, donors, private businesses, and scientists in a collective action to improve nutrition. The SUN Framework for Action calls for intensifying research on biofortification as well as on improving yields of nutrient-rich foods to better address micronutrient deficiencies [23]. Fifty-five countries have now established goals to address immediate and underlying causes of malnutrition, including through agriculture. In 2012, the CGIAR initiated a research program on Agriculture for Nutrition and Health (A4NH). The Second International Conference on Nutrition (ICN2), organized by the FAO and WHO in 2014, resulted in a political commitment to address major nutrition challenges and transform food systems through coordinated public policies. At the regional level, the African Union's 2014 Malabo Declaration recommitted the member states to the Comprehensive Africa Agriculture Development Programme (CAADP) process and committed to ending hunger and improving nutrition by 2025. Biofortification is considered an important piece of the puzzle in each of these efforts to address agriculture and nutrition linkages.

## THE JUSTIFICATION FOR BIOFORTIFICATION

Biofortification provides a comparatively cost-effective, sustainable, and long-term means of delivering vitamins and micronutrients to households that might otherwise not have access to, or that cannot afford to have, a fully balanced diet. Biofortified staple food crops cannot deliver as high a level of minerals and vitamins per day as supplements or industrially fortified foods, but, based on current dietary patterns, they can help by increasing the daily adequacy of micronutrient intakes among individuals throughout the lifecycle [24]. Biofortification is not expected to treat micronutrient deficiencies or eliminate them in all population groups, but contribute to increased micronutrient intake. No single intervention will solve the problem of micronutrient deficiency, but biofortification complements existing interventions (discussed above) to provide micronutrients to the most vulnerable people in a comparatively inexpensive, cost-effective, and sustainable manner [25, 26, 27, 28, 29].

Biofortification provides a feasible means of reaching malnourished populations who may have limited access to diverse diets, supplements, and commercially fortified foods. The biofortification strategy seeks to put the micronutrient-dense trait (such as for zinc, iron or vitamin A) in basic staple food crops that are being grown and consumed by


DOI: 10.18697/ajfand.78.Harvestplus01

people in developing countries and that have preferred agronomic traits, such as high yield. In contrast to complementary interventions, such as fortification and supplementation that begin in urban centers, biofortified crops reach consumers in rural areas first, since most rural farming households consume what they grow. As farmers produce and market surplus biofortified staple food crops, the intervention reaches urban areas.

Unlike the continual financial outlays required for supplementation and commercial fortification programs, a one-time investment in plant breeding can yield micronutrient-rich planting materials for farmers to grow for years to come. Biofortified varieties bred for one country can be evaluated for performance in, and adapted to, other countries and their agro-ecological growing conditions, thereby potentially multiplying the benefits of the initial investment. As seed producers incorporate biofortified crops into their product lines, biofortification becomes more sustainable over time, provided that regulatory mechanisms are in place to maintain standards and related claims. While recurrent expenditures are required for monitoring and maintaining these traits in crops, these are low compared to the cost of the initial development of the nutritionally improved crops and the establishment, institutionally speaking, of nutrient content as a legitimate breeding objective for the crop development pipelines of national and international research centers. Once established, the cost of maintaining biofortified traits represents a small portion of ongoing global investment in crop improvement.

There are three common approaches to biofortification: agronomic, conventional, and transgenic. Agronomic biofortification provides temporary micronutrient increases through fertilizers and/or foliar sprays. This approach is useful if the goal is to increase micronutrients that can be directly absorbed by the plant, such as zinc, but is less efficient and effective for micronutrients that are synthesized in the plant and cannot be absorbed directly [30]. Conventional plant breeding involves identifying and developing parent lines with high vitamin or mineral levels and crossing them over several generations to produce plants with the desired nutrient and agronomic traits. Transgenic plant breeding seeks to do the same in crops where the target nutrient does not naturally exist at the required levels. The chapters in this special issue focus only on conventionally-bred biofortified varieties of staple food crops and not on transgenic plant breeding, as the evidence base has been developed with conventionally-bred biofortified crops. Transgenic biofortified crops have not been released in any African country.

## UNPACKING THE STEPS TO SUCCESSFUL IMPLEMENTATION OF BIOFORTIFICATION

As with fortification, an initial question for biofortification was: what level of extra minerals and/or vitamins added to diets would be required to have a measurable public health impact? The answer is complex, depending on age- and gender-specific nutrient requirements, per capita consumption of a particular food, bioavailability of the nutrients, and nutrient retention – as shown in the equation below:

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Volume 17 No. 2
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PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

$$\frac{\text{Extra Nutrient Supplied Through Biofortification}}{\text{Nutrient Requirement}} = \text{Additional Percentage of Estimated Average Requirement Supplied, where}$$

Extra Nutrient Supplied By Biofortification =

| Per Capita Consumption of the Food Staple | X | Increment in Density of Mineral/Vitamin Due to Plant Breeding | X | Retention of Mineral/ Vitamin in Processing/ Storage/Cooking | X | Percent Bioavailability of Mineral/Vitamin as Consumed |
|---|---|---|---|---|---|---|
| (Term A) | | (Term B) | | (Term C) | | (Term D) |

A simple example provides clarity:

- An adult woman in a maize-eating society may consume, on average, the equivalent of 300 grams of shelled, dried maize per day (Term A).
- White maize has zero provitamin A. The plant breeding target for biofortified, orange maize is 15 mg of provitamin A carotenoids per kilogram of shelled, dried corn at harvest, units sometimes referred to as 15 parts per million (ppm). The ***increment*** due to plant breeding, therefore, is +15 ppm (Term B).
- 70% of provitamin A carotenoids may be lost during processing/storage/cooking; retention is, therefore, 30% (Term C).
- After ingestion, four units of provitamin A carotenoids are converted to one unit of absorbed retinol[2]; bioavailability, therefore, is 25% (Term D).

Consuming biofortified maize on any given day, a one-for-one substitution for white maize, then adds:

300 grams X +15 mg/kg provitamin A carotenoids X 30% X 25% = +0.34 mg of absorbed retinol per day.

The estimated average requirement (EAR) for absorbed retinol (vitamin A) for adult women is 0.85 mg retinol per day. Therefore, biofortification would provide an extra 40% of the EAR per day.

The numbers used in the above example are realistic, based on research described in Chapters 2, 3, and 4. However, educated guesses had to be made for each of these magnitudes when plant breeding was initiated. Plant breeders, for example, concluded in 2005 that there was a reasonable probability that they could develop maize varieties with 15 ppm provitamin A carotenoids in high-yielding backgrounds, but they could not be sure. Today, some experimental maize lines, not yet in high-yielding backgrounds, have more than 30 ppm provitamin A carotenoids. Moreover, nutritionists surmised in 2005 that an additional 40 percent of the EAR for vitamin A in diets would have a positive public health impact, but, similarly, nutritionists could not be sure. Economists and nutritionists used these numbers to calculate, on an ***ex-ante*** basis, the cost-effectiveness

[2] When consumed, provitamin A carotenoids are metabolized by the body to retinol, the absorbable form of vitamin A. Bioavailability of provitamin A carotenoids is measured by retinol activity equivalents (RAE). In the case of orange maize, research demonstrated that 1 RAE was converted for each 4 mg/kg of provitamin A carotenoids consumed.

of biofortification under various farmer adoption rates in selected developing countries. The methodologies used and calculations, which showed biofortification to be highly cost-effective, are discussed in Chapters 13 and 14. These calculations provided the quantitative evidence for donors to make and sustain investments in biofortification for the ten years that it took to develop, test, and release biofortified staple food crop varieties in a significant number of developing countries.

Yet provitamin A in maize is only one example of biofortified crop success. Table 1.2: Revised Assumptions and Target Levels, shows the magnitudes used for the terms in the equation above for a number of biofortified crops in setting plant breeding targets, and for making decisions as to what crop-nutrient combinations were selected for investment and eventual deployment. Originally set using limited data on consumption patterns, as well as nutrient stability and retention in the biofortified crops, nutrient targets have been validated and updated for specific target populations as more data became available. These revised assumptions are reported in Table 1.2 and further described in Chapters 2, 3, and 4. The provitamin A levels in orange sweet potato are sufficiently high that 100 percent of the EAR is met for both target groups listed in Table 1.2. The micronutrient target levels initially set in 2005 were later increased for zinc-biofortified crops, but on-going research showed that targets were adequate for vitamin A and iron-biofortified crops. Nutritionists continue to monitor and evaluate results and they revise assumptions and targets as new evidence emerges.

After initially setting nutrient targets, researchers identified three broad questions to be addressed in order for biofortification to be successful:

- Can breeding increase the micronutrient density in food staple crops to target levels that will have a measurable and significant positive impact on nutritional status?
- When consumed under controlled conditions, will the extra nutrients bred into the food staple crops be absorbed and utilized at sufficient levels to improve micronutrient status?
- Will farmers be willing to grow the biofortified varieties and will consumers be willing to buy and eat them in sufficient quantities?

To answer these questions, researchers carried out a series of activities classified in three phases of discovery, development, and delivery, as shown in Figure 1.1: Biofortification Impact Pathway, below. Since 2012, biofortification has moved significantly into the delivery phase in several African countries.

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ISSN 1684 5374

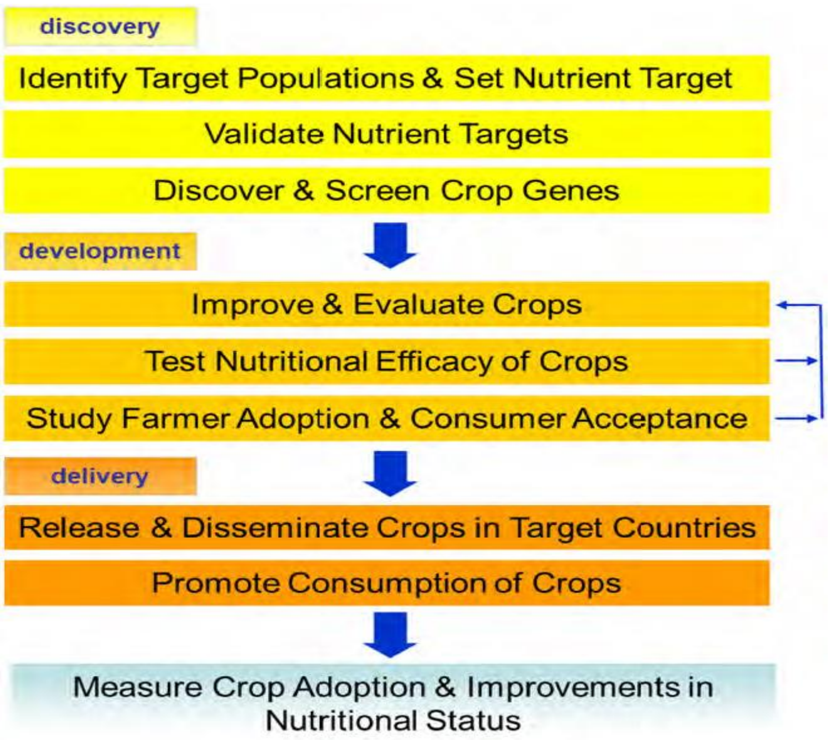


**Figure 1.1: Biofortification Impact Pathway**

Within the final steps of the impact pathway, new areas for inquiry have emerged, including the role of processors and private sector actors in the marketing of biofortified varieties. With strong proof-of-concept for biofortification, moving towards scale will require increased public and private sector investment in crop development and seed systems to sustain the pipeline of biofortified varieties. The following chapters review the evidence developed to date along the impact pathway and chart the path for future research and scaling.

## ORGANIZATION OF THE CHAPTERS IN THIS VOLUME

Developing and delivering biofortified crops has required donor buy-in and investment, evidence of the potential to address the targeted micronutrient deficiencies, and promoting adoption and sustainability at the country level. For biofortification to successfully address micronutrient deficiencies, the given micronutrients must be present in sufficient amounts, adequately retained during processing and storage, and bioavailable for absorption. Chapters 2, 3, and 4 address these aspects, presenting summaries of the nutrition and food science research undertaken to date on consumption levels of staple food crops, nutrient retention, bioavailability, and efficacy. In Figure 1.1: Biofortification Impact Pathway, this research corresponds to the first two steps under discovery, and the second step under development.

Crop development requires effective screening and testing of varieties. Chapters 5 and 6 discuss the progress in crop development using conventional plant breeding methods.

Investments in crop development have first focused on the most widely consumed food staple crops, and more than 150 varieties of biofortified crops have been developed and released in more than 30 countries (Chapter 5). In Chapter 6, measurement of minerals and vitamins in the edible portions of biofortified crops and foods made from such crops are discussed, including innovations in high throughput, low-cost analytical methods. These correspond to step 3 under discovery, step 1 under development and step 1 of delivery in the Biofortification Impact Pathway.

Chapters 7-12 primarily address the third step under development in the Biofortification Impact Pathway, and both steps under delivery, but include some findings related to discovery as well. Chapters 7, 8, 9, and 10 are crop specific – discussing the range of discovery-development-delivery experiences to date in Africa for four biofortified crops – orange sweet potato across the continent, vitamin A orange maize in Zambia, vitamin A yellow cassava in Nigeria, and iron beans in Rwanda, respectively. General marketing and branding issues are discussed in Chapter 11. Integrating biofortified crops into existing international development projects is explored in Chapter 12, which focuses on the use of biofortified crops in World Vision International’s programs.

Chapters 13, 14, and 15 focus on economic analysis. Chapter 13 summarizes the Theory of Change and how the nutritional impact of biofortified crops is measured and maximized. Chapter 14 examines complementarities and tradeoffs among a range of micronutrient interventions – supplementation, fortification, and biofortification -- in three countries. This analysis is also ex-ante. Chapter 15, however, is a summary of ***ex-post*** findings of the pilot delivery of orange sweet potato to white sweet potato-growing farm households in Mozambique and Uganda – using a randomized, control testing design.

The importance of advocacy to build stakeholder and policy support for scaling up farmer adoption and the sustainable mainstreaming of biofortification is discussed in Chapter 16, including recommendations for a forward-looking advocacy strategy at the national level. Several countries where biofortified crops are available (including Rwanda, Zambia, Mozambique, and DRC) have incorporated biofortification into their national nutrition strategies. Biofortification programs are increasingly supported by national governments, particularly in China, India, and Brazil, as well as several other countries in Latin America. The specific policy approaches to incorporating biofortified crops into regional and national nutrition strategies are discussed in this chapter. Finally, Chapter 17 evaluates lessons learned from all previous chapters and charts a proposed way forward for accelerating the integration of biofortified crops in African diets.

**ACKNOWLEDGEMENTS**

The editors of this special issue would like to acknowledge all contributing authors and all other scientists and practitioners who continue to dedicate their efforts to developing and delivering biofortified crops.

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ISSN 1684 5374

**Table 1.1: Micronutrient Deficiency Status of Select African Countries**

| Country | Total Pop ('000) | Proportion of pre-school age children with anemia (Hb<110 g/L) | Proportion of non-pregnant women with anemia (Hb<120 g/L) | Proportion of pre-school age children with vitamin A deficiency (serum retinol <0.70 µmol/l) | Proportion of population at risk of inadequate intake of zinc | Proportion of children <5 stunted | Total Population with Iron Deficiency (Considered 1:1 ratio with Anemia) ('000) | Total Population with Vitamin A Deficiency ('000) | Total Population with Inadequate Zinc Intake ('000) | Total population at risk of Micronutrient Deficiency with Anemia and Stunting ('000) |
|---|---|---|---|---|---|---|---|---|---|---|
| Nigeria | 175,288 | 71.0 | 47.3 | 29.5 | 12.8 | 36.4 | 50,573 | 9,124 | 22,436 | 70,263 |
| Ethiopia | 90,178 | 49.5 | 18.9 | 46.1 | 21.7 | 44.2 | 12,575 | 6,227 | 19,568 | 24,131 |
| Congo, Dem. Rep. | 73,291 | 67.1 | 49.0 | 61.1 | 57.5 | 43.5 | 20,904 | 8,040 | 42,142 | 34,434 |
| Tanzania | 50,705 | 60.8 | 38.2 | 24.2 | 22.9 | 34.8 | 12,369 | 2,241 | 11,611 | 17,755 |
| Uganda | 37,923 | 56.2 | 25.6 | 27.9 | 23.8 | 33.7 | 7,352 | 2,116 | 9,025 | 11,858 |
| Ghana | 26,721 | 76.1 | 55.9 | 75.8 | 21.0 | 22.7 | 8,519 | 2,859 | 5,611 | 12,216 |
| Mozambique | 25,590 | 66.5 | 43.7 | 68.8 | 60.5 | 43.1 | 6,665 | 2,818 | 15,482 | 11,215 |
| Malawi | 16,953 | 65.6 | 27.6 | 59.2 | 34.2 | 47.8 | 3,698 | 1,899 | 5,798 | 7,099 |
| Zambia | 14,767 | 57.7 | 28.2 | 54.1 | 38.0 | 45.8 | 3,076 | 1,577 | 5,611 | 5,958 |
| Rwanda | 11,950 | 37.6 | 17.1 | 6.4 | 39.8 | 44.3 | 1,530 | 167 | 4,756 | 2,620 |

Hb: Hemoglobin
ID: iron deficiency
IZI: inadequate zinc intake
VAD: vitamin A deficiency
Source: Authors' calculations based on WHO (2009), WHO (2015), Hotz (2004), and IFPRI (2014).

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ISSN 1684 5374

**Table 1.2: Revised Assumptions and Target Levels, 2016**

*Based on research on intake, bioavailability, and retention for biofortified crops*

| **Assumptions (revised)** | **IRON** | | **ZINC** | | **VITAMIN A** | |
|---|---|---|---|---|---|---|
| Age/physiological status group | Non-pregnant, non-lactating women | Children 4-6 yr of age | Non-pregnant, non-lactating women | Children 4-6 yr of age | Non-pregnant, non-lactating women | Children 4- 6 yr of age |
| Daily physiological requirement ($\mu$g/day)[1] | 1,460µg | 500µg | 2,960µg | 1,390µg | 500µg REA[2] | 275µg REA[2] |
| | **Pearl Millet (whole grain flour) India** | | **Wheat (whole grain flour) India** | | **Maize (whole to maize meal) Zambia** | |
| Intake (g/day) | 222 | 87 | 258 | 71 | 287 | 172 |
| Micronutrient retention after processing (%) | 90 | | 95 | | 37 | |
| Bioavailability (%) | 7.5 | | 15 | | 17 (6:1)* | |
| Baseline micronutrient content ($\mu$g/g) | 47 | | 25 | | 0.5 | |
| Additional content required ($\mu$g/g) | +30 | | +18 | | + 15 | |
| Total final content ($\mu$g/g) | 77 | | 43 | | 15.5 | |
| **% of the requirement contributed by biofortification** | 30 | 35 | 22 | 13 | 54 | 59 |
| **% of the requirement contributed by entire micronutrient content of staple (baseline + biofortification) (%)** | 79 | 90 | 53 | 31 | 56 | 61 |
| | **Beans (boiled thick broth) Rwanda** | | **Rice (polished parboiled) Bangladesh** | | **Cassava (fresh weight to cassava meal) Nigeria** | |
| Intake (g/day) | 198 | 107 | 422 | 159 | 940 | 348 |
| Micronutrient retention after processing (%) | 90 | | 90 | | 35 | |
| Bioavailability (%) | 7 | | 25 | | 20 (5:1)* | |
| Baseline micronutrient content ($\mu$g/g) | 50 | | 16 | | 0 | |
| Additional content required ($\mu$g/g) | +44 | | +12 | | +15 | |
| Total final content ($\mu$g/g) | 94 | | 28 | | 15.0 | |
| **% of the requirement contributed by biofortification (%)** | 38 | 59 | 39 | 31 | 197 | 133 |
| **% of the requirement contributed by entire micronutrient content of staple (baseline + biofortification) (%)** | 80 | 127 | 90 | 72 | 197 | 133 |

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| **Assumptions** | **Vitamin A** | |
|---|---|---|
| Age/physiological status group | Non-pregnant, non-lactating women | Children 4-6 yr of age |
| Estimated average requirement ($\mu$g/day)[a] | 500µg REA | 275µg REA |
| | **Orange-fleshed sweet potato (Uganda)** | |
| Intake (g/day) | **167** | **101** |
| Retention, boiled (%) | **80** | |
| Bioavailability (%) | 8 | |
| Baseline micronutrient content ($\mu$g/g) | 0 | |
| Additional content required ($\mu$g/g) | +70 | |
| Total final content ($\mu$g/g) | 70 | |
| **% of the requirement contributed by biofortification (%)** | 160 | 176 |
| **% of the requirement contributed by entire micronutrient content of staple (baseline + biofortification) (%)** | 160 | 176 |

*beta carotene equivalent to retinol bioconversion ratio
[1]Physiological requirements are derived from the IOM 2001 Dietary Reference Intakes for iron; from EFSA Journal 2014 for zinc; and from IOM 2001 for vitamin A.
[2]Retinol activity equivalents

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ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 17 No. 2 April 2017
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

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