Managing the vitamin A program portfolio: A case study of Zambia, 2013–2042

John L. Fiedler and Keith Lividini

Abstract

Background. *Micronutrient deficiencies continue to constitute a major burden of disease, particularly in Africa and South Asia. Programs to address micronutrient deficiencies have been increasing in number, type, and scale in recent years, creating an ever-growing need to understand their combined coverage levels, costs, and impacts so as to more effectively combat deficiencies, avoid putting individuals at risk for excess intakes, and ensure the efficient use of public health resources.*

Objective. *To analyze combinations of the two current programs—sugar fortification and Child Health Week (CHW)—together with four prospective programs—vegetable oil fortification, wheat flour fortification, maize meal fortification, and biofortified vitamin A maize—to identify Zambia's optimal vitamin A portfolio.*

Methods. *Combining program cost estimates and 30-year Zambian food demand projections, together with the Zambian 2005 Living Conditions Monitoring Survey, the annual costs, coverage, impact, and cost-effectiveness of 62 Zambian portfolios were modeled for the period from 2013 to 2042.*

Results. *Optimal portfolios are identified for each of five alternative criteria: average cost-effectiveness, incremental cost-effectiveness, coverage maximization, health impact maximization, and affordability. The most likely scenario is identified to be one that starts with the current portfolio and takes into account all five criteria. Starting with CHW and sugar fortification, it phases in vitamin A maize, oil, wheat flour, and maize meal (in that order) to eventually include all six individual interventions.*

Conclusions. *Combining cost and Household Consumption and Expenditure Survey (HCES) data provides a powerful evidence-generating tool with which to understand how individual micronutrient programs interact and to quantify the tradeoffs involved in selecting alternative program portfolios.*

Key words: Cost-effectiveness, evidence-based policy, Household Consumption and Expenditure Surveys (HCES), household surveys, micronutrients, nutrition policy, portfolio analysis, vitamin A

Micronutrient deficiencies: Taking stock

Between 1990 and 2010, the global burden of micronutrient deficiencies fell by more than half (**table 1**). In many countries, however, and particularly in sub-Saharan Africa, micronutrient deficiencies remain major public health problems and still rank among the top causes of death and disability (**table 2**). The micronutrient disease burden is shouldered disproportionately by a highly vulnerable group in the most vulnerable countries in the world—children under 5 years of age in sub-Saharan Africa.

Over the past 15 years, there has been a steady and pronounced increase in the numbers and coverage of programs to combat micronutrient malnutrition. Although micronutrient supplementation and food fortification programs started in Switzerland, Great Britain, and the United States in the 1920s, it was not until the end of the 1980s that public health attention and resources began to be devoted to these interventions in lower- and middle-income countries [3]. The first large-scale efforts in less-developed countries consisted of vitamin A supplementation piggybacked on immunization campaigns. Since there was little knowledge of the importance of vitamin A in the general population at the time—and thus little demand for it—linking vitamin A supplementation to already existing, popular immunization programs was strategic and enabled substantial coverage rates to be quickly achieved. Piggybacking immunization programs also enabled

The authors are affiliated with HarvestPlus, International Food Policy Research Institute (IFPRI), Washington, DC.

Please direct queries to the corresponding author: John L. Fiedler, HarvestPlus, International Food Policy Research Institute (IFPRI), Washington, DC 20006, USA; e-mail: J.fiedler@cgiar.org.

TABLE 1. Evolution in the micronutrient-related, global burden of disease

	Deaths		DALYs (1000s)	
	1990	2010	1990	2010
Iron	39,409	32,287	168,084	119,608
Vitamin A	181,151	63,291	349,934	119,762
Zinc	143,518	52,390	275,590	97,330
3 Nutrients	364,078	147,968	793,608	336,700
Total	46,514,000	52,770,000	2,502,601	2,490,385
Iron	0.08%	0.06%	6.72%	4.80%
Vitamin A	0.39%	0.12%	13.98%	4.81%
Zinc	0.31%	0.10%	11.01%	3.91%
3 Nutrients	0.78%	0.28%	31.71%	13.52%
Total	100.00%	100.00%	100.00%	100.00%
Changes in deaths and DALYs				
Iron		−18.07%		−28.84%
Vitamin A		−65.06%		−65.78%
Zinc		−63.50%		−64.68%
3 Nutrients		−59.36%		−57.57%
Total		13.45%		−0.49%

Source: Derived from Wong et al. [1], Lim et al. [2]. DALYs, disability-adjusted life-years

TABLE 2. Nutrition-related risk factor rankings by burden of disease, 2010, from among 43 risk factors

Region	Childhood underweight	Iron deficiency	Vitamin A deficiency	Zinc deficiency
South Asia	4	9	30	31
Southern SSA	9	10	17	21
Eastern SSA	1	4	11	13
Central SSA	1	4	7	10
Western SSA	1	4	8	14
Global	8	13	29	31

Source: Derived from Lim et al. [2]. SSA: Sub-Saharan Africa.

vitamin A supplementation costs to be kept low and facilitated planning, while minimizing organizational and administrative requirements, thereby making this new activity more politically acceptable and financially sustainable than it would otherwise have been.

The first commonly adopted intervention—the campaign-based vitamin A supplementation—has now generally been transformed into what are commonly called Child Health Days (CHDs). CHDs are generally large-scale, campaign-style events undertaken semiannually that provide an integrated package of services. The size and composition of the service package varies by country (and usually within a country as well), but all CHDs include vitamin A and most include anthelminths and some immunizations. Although their initial development owes in large part to supply-related considerations, their high and generally sustained popularity owes in large part to the fact that they provide mothers with more readily accessible "one-stop shopping" for many services for all of their young children, thereby reducing households' direct and indirect costs (with lower opportunity costs of time and lower direct costs of travel) to obtain these services. The growing popularity of CHDs is manifested in the substantial increases in coverage rates they have posted over most of the past decade (**fig. 1**).

Starting in the early 2000s, the number of people and the percentage of national populations eating fortified staple foods have been growing at a brisk pace in low- and middle-income countries. The most rapid growth has been in wheat flour and vegetable oil fortification. Between 2004 and 2013, as the percentage of the world's total wheat flour produced in large roller mills grew from 18% to 31%, the number of countries fortifying in either mandatory or voluntary programs grew from 30 to 76 [5, 6]. No similar data are available on the other key vehicles, but piecemeal data suggest that a similar trend has characterized vegetable oil and, to a lesser extent, sugar and maize flour [7].*

Biofortification—the breeding of new varieties of staple foods for higher macro- and micronutrient content—is the latest intervention strategy, having emerged in just the past 5 years [8–10]. **Figure 2** shows the accelerating pace of progress that HarvestPlus, a global consortium co-led by the International Food

*Personal communication, James P. Wirth, May 14, 2012, reporting his analysis of the Global Alliance for Improved Nutrition (GAIN) Projects Database, Geneva.

Unpublished consultancy report: Trarore T. Regional harmonization for sustainable food fortification program. Economic Community of West African States (ECOWAS) regional feasibility study. A study for the West African Health Organization (WAHO), Helen Keller International (HKI), African Development Bank (ADB). Human Development Department. Health Division. HKI, WAHO, ADB, 2008.

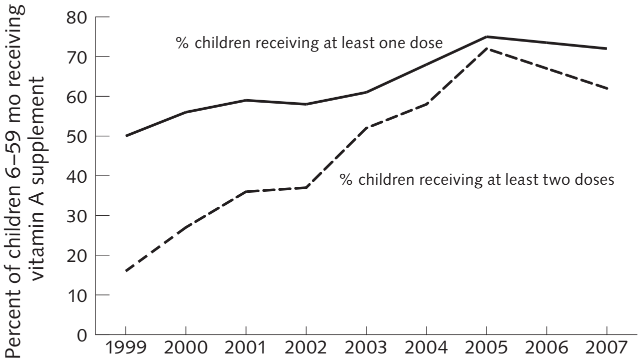

FIG. 1. Evolution of vitamin A supplementation coverage in the 103 UNICEF vitamin A priority countries. Source: Micronutrient Initiative [4]. 2006 data are interpolated from 2005 and 2007

Policy Research Institute (IFPRI) and the International Center for Tropical Agriculture (CIAT), has made in promoting seven biofortified crops.

There are other interventions as well, including dietary change (promoting diversity and complementary feeding, and direct, nutrition–agriculture focused efforts) and micronutrient powders, which are not considered in this study. The fact that they are not considered here should not be construed as their being regarded as inferior or less promising. There was a need to delimit the study, and fortification and supplementation interventions were chosen to compare with biofortification because they are more common and long-established programs.

Why the dearth of studies comparing micronutrient program costs and effectiveness?

Up until just a few years ago, the traditional, key micronutrient policy issue was most commonly depicted as a simple, dichotomous one: which was better—more cost-effective—supplementation or fortification? It has slowly become apparent that this response was too simple and that micronutrient deficiency concerns could not be adequately addressed with just an either/or proposition. Most cost-effectiveness studies of fortification and supplementation find fortification to be the more cost-effective intervention. The few such studies that have compared the relative levels of coverage of the two approaches, however, have also found that the fortification programs have left "too many" micronutrient-deficient persons, i.e., persons whose deficiency was not addressed or was inadequately addressed by the fortification program [11, 12].

Although there is growing recognition that identifying the "optimal" portfolio mix entails more than simply a cost-effectiveness analysis [13, 14], the micronutrient programming evidence base remains scant. One of the reasons for the dearth of evidence is a practical constraint, namely, that one cannot run randomized, controlled trials on fortification. Another reason is that the individual programs themselves are quite distinct, making for many noncomparabilities. They vary, for instance, in terms of target populations,

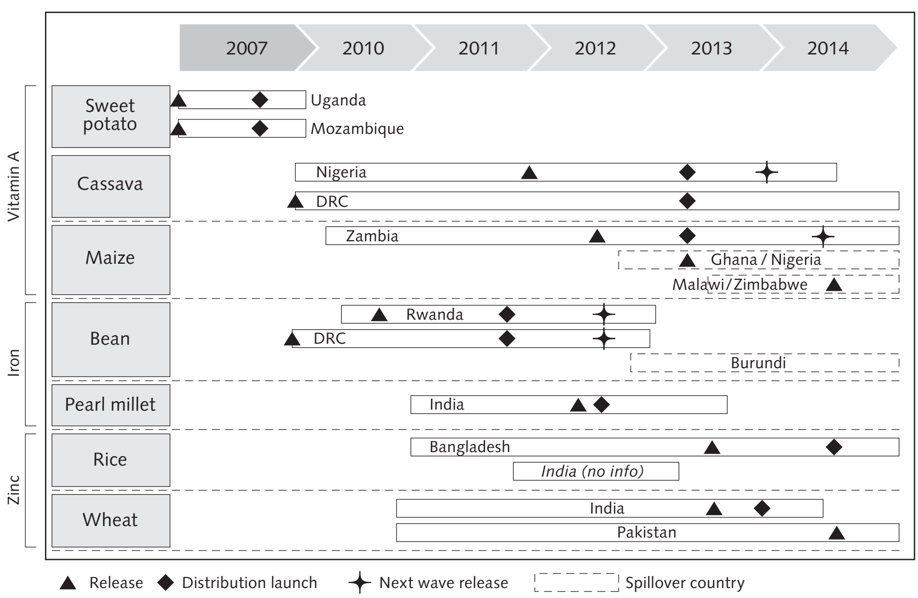

FIG. 2. HarvestPlus's releases and planned releases of biofortified crops, 2007–14. Source: Saltzman et al. [12]

implementing agencies, public and private sector roles, the nature of their technology, the extent to which they are government-implemented versus market-based, the size and nature of the costs, their sources of financing, the incidence of the costs, the extent to which their clients need to be aware of the benefits of the program and be active to obtain them, and, more generally, the nature and the cost of behavioral change that is required to become a participant in a program.

How, for instance, does one compare a vitamin A supplementation program that targets only under-five children and a fortification program that will probably primarily benefit persons 5 years of age or older? What opportunities are there to analyze a biofortification program (which is likely to be implemented by the national agricultural research organization, the ministry of agriculture, and perhaps a private seed company), a vitamin A supplementation program (operated by the ministry of health), and a fortification program (which may be a purely voluntary, private sector program or may be monitored by a government bureau of standards, or the ministry of health, the ministry of industry, or some combination of government agencies)? Who would be interested in comparing the costs of these disparate programs when no one administrative or managerial domain includes all of them? Moreover, the beneficiaries, the implementers, and the stakeholders of these programs are a disparate lot. It is hardly surprising, therefore, that there have been few comparative analyses of these interventions [11–13, 15–19], and that there are even fewer references to micronutrient program portfolios.

Undertaking an analysis of the micronutrient program portfolio requires analyzing and addressing nutrition from a more general, social perspective, rather than from a program-by-program, micronutrient-by-micronutrient, or government agency-by-government agency approach. It requires comparative analyses of the costs, coverage, and impacts of supplementation, fortification, and biofortification from a more inclusive, societal perspective. Such an approach requires a database that enables these diverse measures to be compared and that employs common methodologies for measuring implementation costs, coverage, and impact. Those databases have not been readily available.

An even more fundamental data constraint has been the general lack of nationally representative data with which to “simply” measure usual dietary intake. Only a handful of countries in the world have nationally representative dietary assessment data that are from what nutritionists generally regard as the preferred food consumption methodologies—observed-weighed food records (OWFR) or 24-hour recall (24HR) surveys—because they are expensive and difficult to conduct [20–22].

The principal database for this case study is the 2006 Zambian Living Conditions Monitoring Survey (LCMS) [23]. The LCMS is one of a family of multipurpose surveys—collectively referred to as Household Consumption and Expenditure Surveys (HCES)—that can fulfill many of the data requirements for undertaking a portfolio analysis. Most fundamentally, they contain a wealth of information about household food acquisition and consumption behaviors. They collect data on the quantity of food purchased and/or consumed and how food was acquired, differentiating whether it was purchased, home-produced, or received free of charge (e.g., from friends, from relatives, from a social program, or as payment in-kind).* HCES also contain agricultural production data that can be used to simulate the adoption, production, marketing, and consumption of biofortified foods [24]. Many HCES also contain information about participation in other programs, including CHD or social safety net programs, that might serve as platforms for more targeted distribution of supplements or of fortified or biofortified foods [25].

Other, more general characteristics of HCES that are appealing include that they are available for more than 115 countries [26]; they are generally based on large samples of households and are statistically representative at the national level and almost always at a subnational (regional or state) level [27]; they are conducted routinely, and updated periodically, generally once every 3 to 5 years; and using them to analyze food and nutrition issues involves modest incremental cost compared with the alternatives.**

In stark contrast, the only country in the world that routinely conducts an individual-based, nationally representative 24-hour recall survey is the Philippines, which has conducted them once every 5 years since about 1970.

HCES are not, however, the be-all and end-all for conducting portfolio analyses. They do not provide information about program costs or about the structure of the food industry (i.e., number and size of food plants), which is likely to be important for modeling fortification. Moreover, the data they do contain have significant shortcomings: most importantly, they mix consumption and purchases, and they report

*It is essential to take into account food sources in modeling the coverage of micronutrient programs, their additional nutrient intakes, and their impacts. For example, in modeling the coverage of fortified maize flour in Zambia, the analysis uses exclusively purchases of maize flour.

**A recent study of the cost of 24-hour recall surveys in nine countries estimated that it would cost US$2.3 million to develop (from scratch) a clean, ready-to-use nutrient intake analytic file for 8,500 households [22]. In sharp contrast, to develop a nutrient intake analytic file from an extant, already processed HCES would cost about US$40,000, roughly 2% of the 24-hour recall survey costs. For a discussion of the precision–cost tradeoffs employing different criteria, see Coates et al. [28].

household, not individual, data. To our knowledge, however, no other surveys or databases provide the opportunity to simulate all three of these types of the largest micronutrient programs and to do so at the household and individual levels. In the absence of alternative datasets with which to address the complex issues inherent in managing the micronutrient program portfolio, we adopt HCES to begin portfolio analysis, which is so long overdue.

Why study the micronutrient program portfolio mix?

The growing number and coverage of supplementation and fortification programs have been impressive but have also contributed to growing speculation about whether all of them are necessary. The proliferation of programs has also raised concern about the possibility that some programs in some countries may be putting some individuals at risk for excessive intakes. Such concerns were first expressed about the iodine content of salt in Tanzania [29], and more recently in Zimbabwe and the Democratic Republic of the Congo [30]. There has been steady growth in calls for more evidence about the need for, and the effectiveness and safety of, micronutrient programs in general [31, 32], in vitamin A programs in particular (Philippines [34, 34], Uganda,* India [35], and Bangladesh**), and regarding the appropriateness of folic acid fortification levels [36, 37]. If governments are to comply with the public health maxim of "do no harm," it is essential that governments know how they impact individuals' nutrient intake levels and how they affect individuals' risk of excess intake.

At first glance, it might seem that the different characteristics of these three interventions would mean that they would be overwhelmingly complementary. That would seem to largely dispel concerns about excess intakes, since it would seem that few people would be reached by multiple programs. The distinctive target populations and locational characteristics of micronutrient programs, however, are rapidly becoming blurred. Urbanization, the penetration of commercial and industrial food markets into the rural areas of even the poorest countries, and the westernization of global diets—including the rapid adoption of nontraditional foods, in particular wheat and wheat flour—have all served to blur the lines. By implication, the possibility of putting individuals at risk for excess intake is increasing, and as it does, it becomes increasingly important that government be aware of, track, and attempt to control this exposure. This blurring of lines, however, also means that it becomes increasingly difficult to do so. Using HCES to conduct vitamin A portfolio analysis provides a means to move forward into this new terrain and understand the frequency, mix, and ramifications of individuals being covered by multiple micronutrient programs. Although the use of HCES may not be able to solve the risk of excess intake, it may be able to draw attention to where it might be problematic. Particularly in countries in which there are multiple fortification vehicles, it has a potentially important role to play.

There are also motivations beyond the public health concerns of excess intake for adopting a more integrated and comprehensive approach to analyzing and managing micronutrient programs, namely, economic and financial considerations. The opportunity cost of inefficient programs is that more and/or better nutrition programs are not being implemented with the same amount of resources, resulting in malnutrition rates that are likely to be higher than they would otherwise be. Although growth in the number and coverage of nutrition programs results at some point in overlap, overlap does not necessarily mean that programs are duplicative or obsolete. Overlap may be desirable to address issues of the seasonality of nutrient availability, or, where vitamin A deficiency is severe and programs do not, individually, provide enough additional micronutrient intake, overlap may be essential for adequately narrowing Estimated Average Requirement (EAR) gaps. Portfolio analysis can be particularly useful in this context, because it analyzes program coverage as well as (albeit imperfectly) nutrient intake levels and quantifies additional nutrient intake delivered by programs and program impacts. For the vast majority of countries that have little or no food consumption data, HCES-based portfolio analysis can be a useful tool for understanding the coverage and impact of existing programs, for prioritizing potential food vehicles, and for designing new initiatives.

This study represents a modest beginning in addressing these issues. It focuses on just vitamin A and only a subset of vitamin A program interventions. It is intended to start addressing a number of unanswered questions about which, to date, there has been much speculation, but little empirical evidence. Will biofortification be complementary to supplementation and/or fortification, or is it more likely to supplant them? Is it less expensive? Is it more cost-effective? Is it the preferred strategy for reaching isolated rural areas or, more generally, subsistence farmers?

*Personal communication, Robert Orr, President of the Uganda Sugar Technologists Association, April 7, 2009.

**As reported by Dr. Zeba Mahmud, Country Director of the Micronutrient Initiative, Dhaka, Bangladesh, personal communication, July 1, 2010.

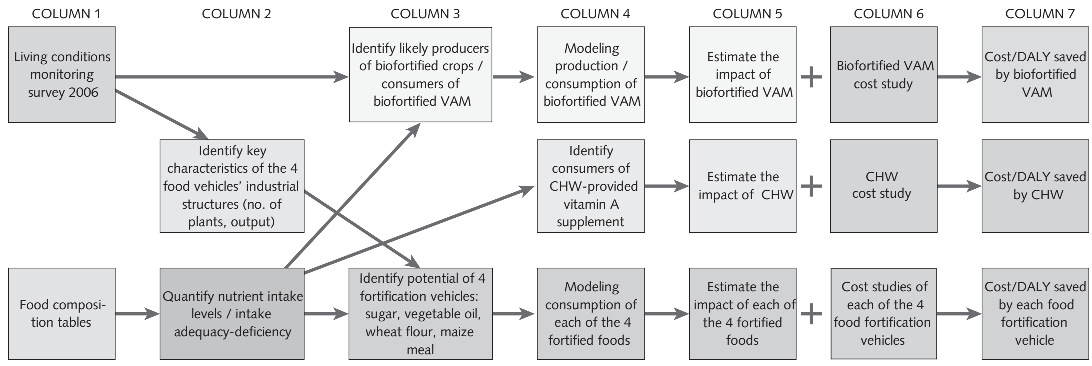

FIG. 3. Estimating the cost, coverage, impact, and cost-effectiveness of each of Zambia's six vitamin A program interventions. CHW, Child Health Week; DALY, disability-adjusted life-year; VAM, vitamin A maize

Methods

We analyzed six vitamin A interventions in Zambia, comprising two existing programs and four hypothetical programs. Our primary data source, the Zambia 2006 LCMS, provides reliable estimates at the provincial and national levels. **Figure 3** presents the analytic approach to Zambia's vitamin A program portfolio. The LCMS data (row 1, column 1) were used in combination with food composition tables (row 2, column 1) to estimate each household's "apparent consumption" at baseline.

The LCMS data were used to estimate the nutrition status of each household member. To do so, the specific types and quantities of foods in the LCMS questionnaire's food list that the household reported it acquired during the recall period were examined. Three specific acquisition modes are identified: purchases, consumption from home or own production, and received without payment or "gifted" (from friends, relatives, or a program). It was assumed that all of the food that was acquired during the reference period was consumed during that period, and this quantity was used to proxy a household's "usual intake."* Adjustments were made for the edible portion of foods, but no adjustments were made for waste or loss of food, or for food purchased or eaten outside the recall period. Also, it was assumed that the food was not given away or used for other than human consumption. To remind the reader of these important assumptions, we refer to this quantity as food that was "apparently consumed" during the recall period.

We combined the data on the types and quantities of food purchased or consumed with information from food composition tables to estimate the household's total caloric intake and its total nutrient intakes of vitamin A, iron, and zinc, assuming that all of the food was distributed within the household in direct proportion to each member's share of the household's total Adult Male Consumption Equivalent (AME) [38]. Next, we quantified each individual's "usual daily intake" from the household's total nutrient intake over the recall period, and, for vitamin A and zinc, compared the individual's micronutrient intake levels with his or her age- and sex-specific EAR levels to characterize the individual's micronutrient intake as "adequate" for a level equal to or greater than the EAR, or "inadequate" when the level was less than the EAR [39].

For iron, because the distribution of requirements is not assumed to be normal, the "full probability method" is used to estimate the prevalence of inadequate intake [3].

Our estimated rates of inadequate intake are somewhat higher than might be found using biological or clinical measures of deficiency. Inconsistencies between these sets of measures might stem from several factors, including an individual's infection status (e.g., malaria, diarrhea, respiratory tract infections, HIV/AIDs) and differences in individual metabolic rates, physical activity levels, or supplement-taking behavior. Supplements taken by individuals might include iron supplements or iron–folic acid tablets that many Zambian women take when they are pregnant, vitamin A capsules that women receive as part of routine postpartum care in Ministry of Health facilities, or vitamin A capsules that children 6 to 59 months of age may receive during Child Health Weeks (CHWs) [40–42]. We assumed bioavailability to be low: 5% for iron and 25% for zinc. Recognizing these sources of variation in these rates, we are careful to refer to our estimates as "adequate/inadequate apparent intake," as distinct from "non-deficient/deficient," to help the reader remember our specific dietary assessment measure [39].

Based on analysis of LCMS and Food and Agriculture Organization data [43], files of the National Fortification Alliance [44, 45], and interviews with food industrialists, we assumed that 100% of the sugar, 100%

*This assumes that there were no food stocks purchased prior to the recall period that were consumed during the recall period and that no purchases were made during the recall period that were carried over for consumption in subsequent periods.

of the wheat flour, 100% of the breakfast and roller maize meal, and 100% of the vegetable oil produced in Zambia were fortifiable (row 2, column 2). We used the LCMS to estimate households' and individual household members' coverage and the quantity consumed of each fortifiable food vehicle, assuming only purchases of these food items (and not food consumed from home production or food received in-kind or gifted) were fortifiable (row 3, column 2). We estimated the additional vitamin A intakes from each fortifiable food as the product of the quantity of the food consumed and the level of fortification, assuming that each vehicle was fortified at the level specified in Zambian government fortification regulations, and adjusted for estimated vitamin A degradation due to postproduction transport, storage, and cooking losses (column 4).* Fortification program impacts were modeled as the change in nutrient intake status (i.e., baseline nutrient intake level minus endline intake level, column 5).

We developed models to simulate the adoption, production, disposition, consumption, and dissemination of biofortified vitamin A maize based on analysis of the LCMS and the 2008 Food Security Research Project Supplementary Survey (columns 4 and 5). We assumed that all forms of vitamin A maize except that received as a gift were biofortifiable and that the additional vitamin A content of biofortified vitamin A maize was 7.5 ppm from 2013 to 2018, and thereafter doubled to 15.0 ppm. For CHW coverage, we used the LCMS, which reports the receipt of a vitamin A capsule in the past 6 months by children 6 to 59 months of age.

Economic analysis of the incremental costs of each of the interventions was conducted (column 6) based on primary data collected specifically for this study. The estimated costs of each intervention were divided by the number of disability-adjusted life-years (DALYs) it was estimated to have saved to provide an estimate of its cost-effectiveness (column 7).

The annual costs, coverage, and cost-effectiveness of each of the six individual interventions were analyzed cross-sectionally (for the year 2013) at the country and provincial levels. Then, drawing on output from the International Food Policy Research Institute's IMPACT model [47, 48], we developed a longitudinal analysis of the period from 2013 to 2042. The IMPACT model estimates annual levels of food production, productivity, cultivated area, food consumption patterns, per capita income levels, food prices, demand for oil and biofuels, and climate change. We mapped IMPACT's 31 food categories to the LCMS's 43-item food list and used IMPACT's predicted 2013–2042 growth rates to develop estimates for each LCMS food item. This enabled us to use the LCMS to simulate individual farming households' adoption, production, consumption, and sale of vitamin A maize; simulate Zambian consumers' changing consumption of four food fortification vehicles; simulate overall changing dietary patterns and nutrient intakes over time; and thereby estimate the changing impact of these vitamin A interventions on Zambians' vitamin A intake annually from 2013 through 2042.

*Losses from the three identified sources were estimated to be 32%, 28%, 21%, 21%, and 62.5% for oil, sugar, maize meal, wheat flour, and vitamin A maize, respectively [46].

The determinants of vitamin A program intervention impacts in Zambia

The impact of a vitamin A intervention on a population's vitamin A intake is a function of the prevalence of inadequate vitamin A intake; the severity of vitamin A intake inadequacy; the coverage of the intervention; for food-based interventions (five of the six interventions analyzed here), the average amount of the food consumed by those consuming some of it (i.e., the "conditional average consumption level"); and the amount of vitamin A delivered by the intervention (e.g., per 100 g of edible food for the food-based interventions or per vitamin A capsule in the case of CHWs).

Results

Inadequate vitamin A intake: Prevalence and severity

Table 3 presents the estimated vitamin A intake levels and the prevalence of inadequate intakes. Intake inadequacies are both widespread and severe throughout the country.

Vitamin A program coverage

Figure 4 shows the coverage of the six individual interventions at baseline (2013) and the growth in coverage over 2013 to 2042, nationally and by rural vs. urban location. At baseline, sugar and vegetable oil provide the highest fortification coverage, 62% and 61%, respectively. Both also have strikingly high rural coverage rates—57% in both cases. The coverage of wheat flour products is also surprisingly high, 46% nationwide—nearly double the level of roller maize and breakfast maize meals, combined—and it too has higher than expected rural penetration, 32%. At baseline, biofortified vitamin A maize is still just beginning to be rolled out in Zambia and covers only 6%, the lowest level among the six interventions. Over 2013–2042, however, the coverage of vitamin A maize increases to 58%, an increase that is more than four times greater than that of wheat, the intervention with the next greatest growth in coverage. The large increase in the coverage of vitamin A maize is due to two factors: adoption of vitamin A maize by

TABLE 3. Daily intake of vitamin A and prevalence of inadequate vitamin A intake, Zambia 2013

Province/domain	Percent population		Mean vitamin A intake (all ages) (µg RAE)	% with inadequate vitamin A intake	Preschool children (12–59 mo)			Women (15–49 yr)		
	Urban	Rural			Mean vitamin A intake (µg RAE)	% of EAR	Estimated DALYs lost (all U5)	Mean vitamin A intake (µg RAE)	% of EAR	Estimated DALYs lost
Central	22%	78%	110	95.5	58	26%	11,126	121	24%	295
Copperbelt	79%	21%	148	97.3	66	30%	15,970	144	29%	423
Eastern	8%	92%	68	99.0	35	16%	14,744	73	15%	390
Luapula	12%	88%	848	41.2	441	199%	8,359	890	179%	221
Lusaka	85%	15%	167	96.7	78	36%	14,584	172	35%	386
Northern	16%	84%	454	67.7	221	100%	13,545	479	96%	359
Northwestern	15%	85%	389	78.6	188	84%	6,369	419	84%	169
Southern	21%	79%	65	99.6	29	13%	13,235	74	15%	350
Western	14%	86%	336	83.1	140	63%	7,825	304	61%	207
National	35%	65%	248	87.2	128	58%	105,757	250	50%	2,800
Urban	100	—	158	96.0	82	37%	36,861	168	34%	976
Rural	—	100	268	82.5	146	66%	68,896	302	61%	1,824

DALY, disability-adjusted life-year; EAR, Estimated Average Requirement; U5, children under 5 years of age; RAE: Retinol Activity Equivalent

farmers who produce it and retain at least some for home consumption, and access to vitamin A maize by those who purchase maize in the market.

The quantity of food consumed

Estimating the average impact of food-based interventions requires two consumption parameters: the percentage of persons consuming some of the food vehicle and what is referred to as the "conditional average" amount of the food consumed. The conditional average is equal to total consumption divided by the number of persons who consume some of the food in question. In contrast, the "unconditional average" is equal to total consumption divided by the total population, i.e., consumers and nonconsumers, alike. In the case of food staples, and particularly in monocultures where coverage is high, conditional and unconditional averages may track one another quite closely. As the percentage of the total population not consuming the food vehicle increases, the difference in the conditional and unconditional average consumption level increases. The greater the difference in the conditional and unconditional average consumption levels, the greater will be the difference in the estimated impacts calculated on the bases of those average consumption levels. By implication, the greater the difference in the conditional and unconditional average consumption levels, the more the impact of the intervention on consumers of the vehicle will be underestimated if the unconditional as opposed to the conditional average is used in the impact calculations.*

Table 4 shows the coverage, i.e., the percentage of persons consuming, each of the five food vehicles in Zambia and their conditional and unconditional average consumption levels. The two average consumption measures differ markedly. Although sugar and oil have very similar levels of coverage, the conditional mean consumption level of sugar is 50% higher than that of oil, making it—other things being equal—a relatively more attractive fortification vehicle. The conditional mean consumption levels of sugar, oil, and wheat are two to three times higher in urban areas than in rural areas. In contrast, the two maize-based interventions—biofortified vitamin A maize and maize meal fortification—both have conditional mean consumption levels that are higher in rural areas, and their rural and urban levels are much more similar. Other things being equal, the maize-based interventions would provide a much larger rural area

*At the same time, however, one must be careful not to use the conditional average consumption level to estimate the impact of the intervention on the entire population, since it will overestimate impact.

impact vis-à-vis their respective urban area impacts than sugar, oil, and wheat, and thus are more likely to provide a larger and more rural-targeted impact. Given that vitamin A maize has a coverage rate that is nationally twice as high as that of maize meal (and in rural areas seven times as high), despite the fact that vitamin A maize has a conditional mean consumption level that is only one-third that of maize meal, it is likely to generate substantially more impact. The coverage rate and conditional mean consumption level of vitamin A

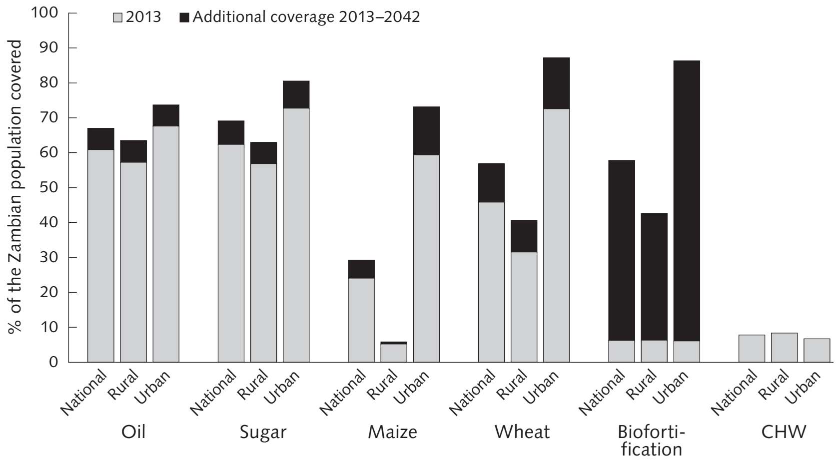

FIG. 4. Coverage of the six individual micronutrient interventions in 2013 and in 2042. CHW, Child Health Week

TABLE 4. Consumption levels of fortification and biofortification vehicles in 2042.

Vehicle	Coverage	Per adult equivalent consumption (g/ACE/day)			
		Conditional		Unconditional	
		Mean	Median	Mean	Median
National					
1. Oil	67%	24.5	17.6	16.0	8.8
2. Sugar	69%	37.6	28.1	25.1	15.7
3. Maize meal (B&R)	29%	427.2	362.5	119.8	0.0
4. Wheat	57%	129.4	89.1	72.0	18.0
5. VAM	58%	159.5	111.1	87.9	33.5
Rural					
1. Oil	63%	13.5	18.7	11.5	5.5
2. Sugar	63%	29.6	22.3	17.8	8.6
3. Maize meal (B&R)	6%	453.1	389.7	25.9	0.0
4. Wheat	41%	77.1	49.8	30.0	0.0
5. VAM	43%	176.6	134.5	71.5	0.0
Urban					
1. Oil	74%	33.6	26.0	24.4	17.7
2. Sugar	81%	49.1	37.9	38.8	30.0
3. Maize meal (B&R)	73%	423.2	359.7	296.4	264.5
4. Wheat	87%	173.5	129.6	150.8	109.3
5. VAM	86%	143.8	93.3	118.8	75.0

a. “Conditional” averages include only consumers of the food vehicle. “Unconditional” averages include consumers and nonconsumers.

ACE, Adult Consumption Equivalent; B&R, breakfast and roller meal; VAM, vitamin A maize

maize are both higher than that of wheat nationwide and in rural areas. Other things being equal, vitamin A maize is also likely to outperform wheat, especially in rural areas.

Program differences in the amount of vitamin A delivered

The amount of vitamin A delivered by these six interventions is another source of variation in their impacts. **Table 5** provides a rough comparison for the case of children under five.* The amount of vitamin A contained in CHW-delivered supplements is predetermined: children 6 to 11 months old receive one vitamin A capsule with 100,000 IU, and children 12 to 59 months old receive one capsule with 200,000 IU. The other five interventions, however, are food-based: the amount of vitamin A delivered by each is a function of the amount of the specific food consumed and its level of vitamin A fortification or biofortification. **Table 5** shows the amount of additional vitamin A that would be provided by fortification or biofortified vitamin A maize over a 3.5-month period—which is the duration of vitamin A “protection” delivered by a single vitamin A capsule—calculated at the conditional mean consumption level of children 6 to 11 and 12 to 59 months of age, and presents this amount as a percentage of that provided by CHWs [36, 49]. Vitamin A maize provides the least additional vitamin A among the five other interventions, and oil provides the most.

Cost-effectiveness of the six individual vitamin A interventions

Figure 5 shows the estimated cost per DALY saved of the six individual interventions in the year 2013 and over the entire 30-year accounting period (with both DALYs and costs discounted at an annual rate of 3%). Vegetable oil is the most cost-effective in both of the time periods analyzed. The relative cost-effectiveness of the five interventions for which we have observations for both time periods (all but vitamin A maize) does not change. Surprisingly, CHW is the second most cost-effective intervention. CHW does well for several reasons. First, it does well because it is targeted to 6- to 59-month olds, who comprise the overwhelming share of the population for which DALYs can be estimated, because adequately rigorous, internationally

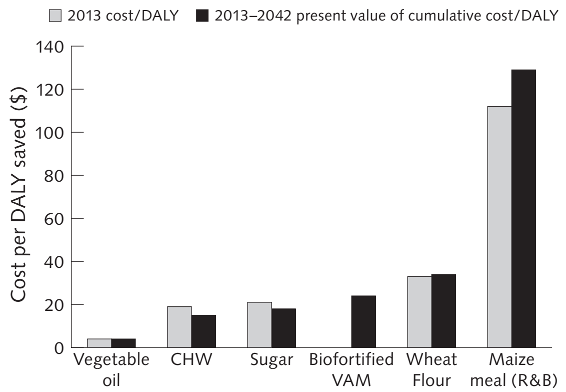

FIG. 5. Cost per DALY saved for the six individual micronutrient interventions: 2013 annual and present value of 2013–2042 cumulative totals. CHW, Child Health Week; DALY, disability-adjusted life-year; B&R, breakfast and roller meal; VAM, vitamin A maize

accepted estimates of vitamin A–attributable DALYs exist only for under-five children and pregnant or lactating women. As a result, CHW does not “waste” resources on persons who do not (and cannot) “count” in the sense that they do not have the possibility of generating DALYs saved. This is clearly a limitation of our methods, which results in a bias in favor of CHW. A second reason CHW does well is that it delivers by far the largest quantity of vitamin A of any of the interventions: CHW has a bigger, longer-term impact on vitamin A status and thus generates relatively more DALYs. In sum, fewer “wasted costs” and a larger vitamin A dose both contribute to CHW’s relative low cost per DALY saved.

Figure 6 shows the variations in the cost per DALY saved by place of residence. With only relatively minor rural–urban differences in both the cost per person covered by each intervention and in prevalence rates of vitamin A inadequacy, the rural–urban differences in cost per DALY saved are not large for each intervention and are driven primarily by differences in intake adequacy gaps and consumption. Vitamin A maize is the fourth most cost-effective of the six individual interventions and has unique temporal characteristics in terms both of its costs and of the health benefits it produces (**fig. 7**). Most of the costs of vitamin A maize are incurred during the period from 2013 to 2019, whereas the DALYs it saves are generated over a much longer period, reflecting the slow, accretionary growth in its adoption and production. Looking at just the period from 2013 to 2022 reveals that vitamin A maize saves very few DALYs in its first 5 years. Starting in 2018, however, it initiates a surge of annually increasing numbers of DALYs saved. Valuing 1 DALY at US$1,000, we find that vitamin A maize, as an investment, does not generate annual benefits as large as its annual costs until mid-2019. That year is particularly monumental for vitamin A maize, as it is also the year

*We acknowledge that there is evidence that the delivery of a therapeutic megadose once every 6 months cannot be considered directly comparable to the much more constant low dose that would be consumed daily in a staple food [31, 32]. Although we recognize that variations in the quantity of vitamin A delivered are an important source of differential impacts and give rise to differences in cost-effectiveness, in the absence of consensus among nutritionists about these differences and how to make these measures more directly comparable, we present them as is.

TABLE 5. Comparing the amount of vitamin A delivered by micronutrient intervention to children 6–59 months old, conditional mean consumption of food vehicles, fortification levels, CHW Vitamin A capsule content and additional vitamin A provided over the course of a 3.5 month period at 2042 consumption levels

			Children 6–11 months old				Children 12–59 months old			
	Fortification level	Conditional per adult equivalent consumption	Children ages 6–11 mo	Additional VA per day	Additional VA over 3.5 mo		Children ages 12–59 mo	Additional VA	Additional VA over 3.5 mo	
Vehicle	μg/g RAE	Mean g/ACE/ day	Mean g/p/day	(μg)	(μg)	As a % of CHW	Mean g/p/day	(μg)	(μg)	As a % of CHW
National										
1. Oil	30	24	5	108	11,539	38%	9	184	19,568	33%
2. Sugar	10	38	8	59	6,264	21%	14	100	10,623	18%
3. Maize meal (B&R)	1	427	93	73	7,799	26%	157	124	13,226	22%
4. Wheat	5.9	129	28	79	8,366	28%	48	133	14,188	24%
5. VAM	15	160	35	30	3,190	11%	59	51	5,410	9%
6. CHW	—	—	—	—	30,030	100%	—	—	60,060	100%
Rural										
1. Oil	30	14	3	60	6,383	21%	5	102	10,825	18%
2. Sugar	10	30	6	46	4,932	16%	11	79	8,363	14%
3. Maize meal (B&R)	1	453	98	78	8,273	28%	167	132	14,030	23%
4. Wheat	5.9	77	17	47	4,983	17%	28	79	8,451	14%
5. VAM	15	177	38	33	3,531	12%	65	56	5,989	10%
6. CHW	—	—	—	—	30,030	100%	—	—	60,060	100%
Urban										
1. Oil	30	34	7	149	15,830	53%	12	252	26,845	45%
2. Sugar	10	49	11	77	8,171	27%	18	130	13,857	23%
3. Maize meal (B&R)	1	423	92	73	7,727	26%	156	123	13,103	22%
4. Wheat	5.9	174	38	105	11,213	37%	64	179	19,016	32%
5. VAM	15	144	31	27	2,876	10%	53	46	4,877	8%
6. CHW	—	—	—	—	30,030	100%	—	—	60,060	100%

Fortification vehicles are based on quantities from purchases only
1 IU retinol = 0.3003 ug retinol
ACE children 6–11 mo = 0.217; AME children 12–59 mo = 0.368, the average across ages 12–59 mo
A value of 106.5 days was used to convert 1 day to 3.5 months to enable direct comparison of food based vehicles' measures of grams per day with a vitamin A capsule dose with an assumed level of active vitamin A protection period of 3.5 months.
Bread estimated to be 60% wheat flour.
ACE, Adult Consumption Equivalent; B&R, breakfast and roller meal; CHW, Child Health Week; RAE, Retinol Activity Equivalent; VA, vitamin A; VAM, vitamin A maize

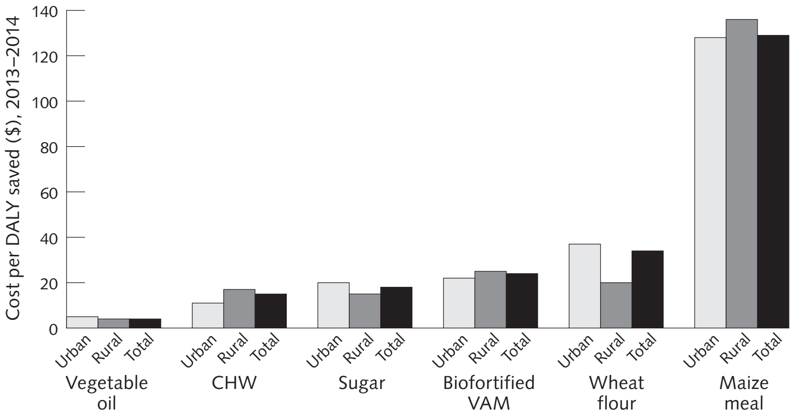

FIG. 6. Variations in rural-urban-total cost per DALY saved for the six independent vitamin A interventions. CHW, Child Health Week; DALY, disability-adjusted life-year; VAM, vitamin A maize

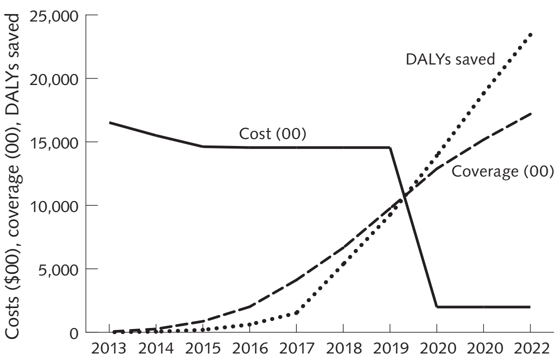

FIG. 7. Biofortified VAM present value of costs and DALYs saved, Zambia 2013–2022. DALY, disability-adjusted life-year; VAM, vitamin A maize

when the cumulative benefits of vitamin A maize come to exceed its cumulative total costs.

The distinct temporal characteristics of vitamin A maize prompt us to conduct a sensitivity analysis of the length of the accounting period. Shortening the analytic period from 2013–2042 to 2013–2032 results in the total costs of vitamin A maize falling by just 6%, while total DALYs saved fall by 49%, and the cost per DALY saved increases by 85% from US$24 to US$44. The changes that occur in the other individual interventions are markedly less: both their total costs and their total DALYs saved are reduced by roughly one-third, i.e., in proportion to the reduction in the number of years in the analytic period, with the impact on cost per DALY saved being far smaller, ranging from a 1% to a 5% reduction for the other five independent interventions. Further reducing the accounting period to just 10 years dramatically increases the cost per DALY saved with vitamin A maize, with relatively minor changes in the cost per DALY saved by the other interventions (**fig. 8**).

Biofortified vitamin A maize is by far the most time-sensitive of the six interventions analyzed in this study. Shortening the accounting period has a relatively modest impact on the costs of vitamin A maize, but it has a substantial effect on its health benefit stream and significantly reduces its cost-effectiveness, both in absolute terms and relative to the other interventions. As judged by the criterion of cost-effectiveness, in Zambia biofortified vitamin A maize must be regarded as a long-term strategy.

Analysis of multiple vitamin A program portfolios

We defined 56 other combinations of the six basic interventions and used the LCMS-IMPACT database to model the additional intake, costs, impacts, and cost-effectiveness of all 62 portfolios. As shown in **figure 9**, half of these portfolios were found to have a cost per DALY saved of less than US$50, an arbitrary benchmark but one that is well below the equivalent of the per capita gross domestic product, which the World Health Organization (WHO) and the World Bank regard as a reference point for highly cost-effective health interventions.

Going beyond average cost-effectiveness analysis: Other criteria for selecting a vitamin A program portfolio

Cost-effectiveness may not be the only criterion that Zambia (or other countries) may consider important to take into account in crafting micronutrient program policies. Zambians might also want to take into account the total costs of an intervention, or they might want a larger public health impact than what the single most cost-effective portfolio would afford. Another possibility is that Zambians may feel that DALYs—which are overwhelmingly focused on a subset of the entire population—are an inadequate program impact measure and may choose an alternative measure, such as the coverage of a portfolio, despite the fact that it only captures the "reach" of the program (without any indication of the significance of the program's effect on those it reaches).

Figure 10 shows the coverage, total costs, and total DALYs saved by the seven most cost-effective portfolios over the entire period from 2013 to 2042,

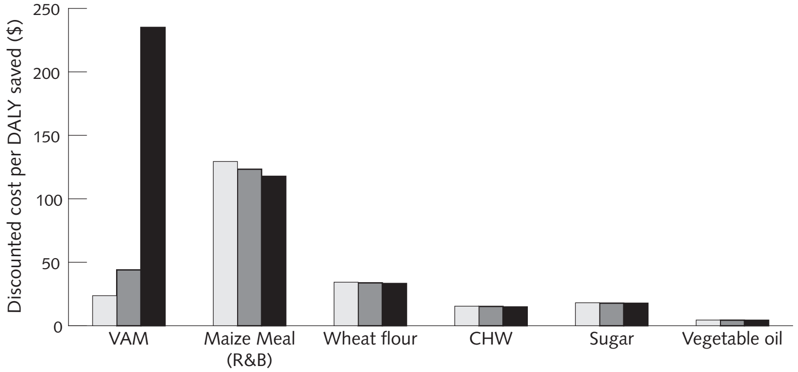

FIGURE 8. Cost-effectiveness of the 6 individual micronutrient interventions using 3 alternative accounting periods. CHW, Child Health Week; R&B, roller meal and breakfast meal; VAM, vitamin A maize

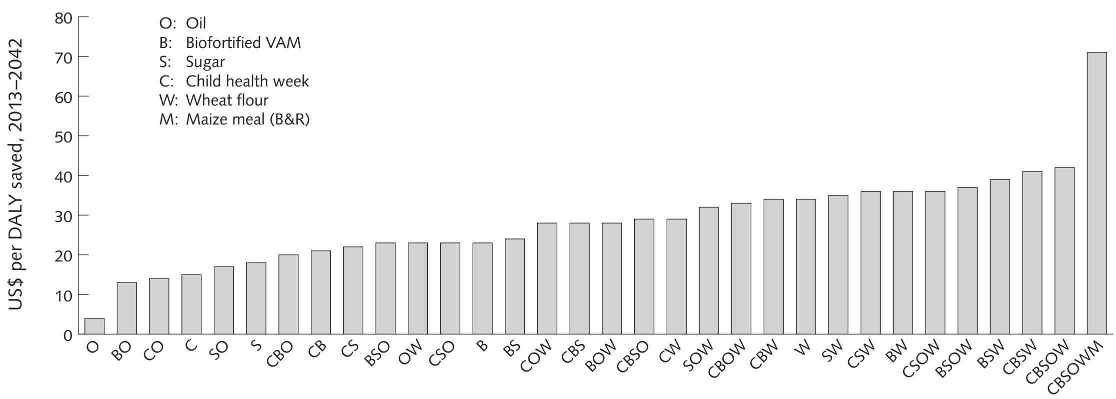

FIGURE 9. The 31 vitamin A program portfolios and discounted cumulative costs per DALY saved of less then $50 plus CBSOWM, 2013–2042

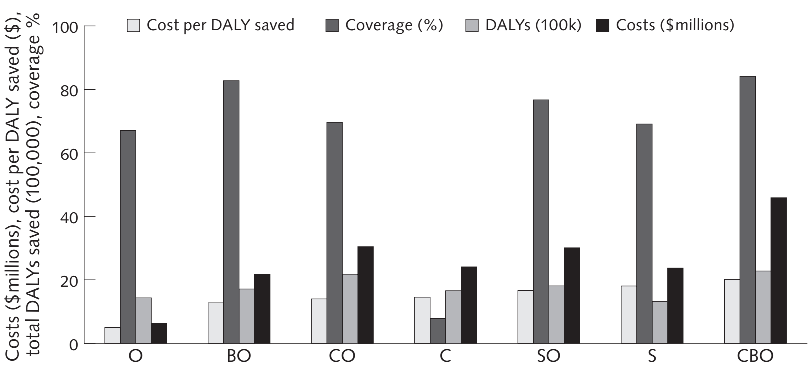

FIGURE 10. Comparing the total costs, cost per DALY saved, total DALYs saved and coverage of the 7 most cost-effective portolios. O: Oil; VAM: Vitamin A maize; BO: Biofortified VAM & Oil; CO: Child Health Week & Oil; C: Child Health Week; SO: Sugar & Oil; S: Sugar; CBO: Child Health Week & Biofortified VAM & Oil.

providing a menu of options, and reveals the tradeoffs involved with each of the three additional criteria discussed. If cost-effectiveness is the only criterion, the portfolio will consist of the single intervention portfolio of oil fortification. If, however, coverage is regarded as the most important criterion, then the portfolio of choice will be CHW, biofortified VAM and vegetable oil (CBO). If both coverage and cost-effectiveness are considered to be important, then the portfolio is likely to be biofortified VAM and oil (BO), which has only 4% less coverage than CBO but has 35% greater efficiency, with a cost per DALY saved of just US$13, compared with US$20 for CBO. Although CHW is among the four most cost-effective interventions, it covers only 2 million Zambians, less than 10% of the coverage of the portfolio with the next lowest coverage among the seven most cost-effective. It is noteworthy, however, that CHW is focused on the most vulnerable and the only target population for which the global burden of disease estimates a significant impact from reducing vitamin A deficiency.

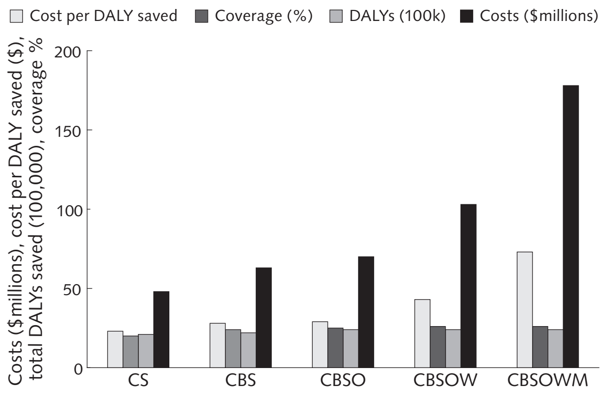

FIGURE 11. Total costs, cost per DALY saved, total DALYs saved and coverage of Zambia's current portfolio mix and how it might evolve with the introduction of new interventions over time

Long-term planning considerations: Phasing in and portfolio sequencing

Given Zambia's current low income level and the long accounting period, we believe that over time Zambians are likely to become more willing and able to spend more on nutrition than what the single most cost-effective portfolio would cost; i.e., that Zambians are likely to opt to expand the country's vitamin A program portfolio over time. In doing so, decision makers are likely to be guided in choosing which specific interventions they will add to their current portfolio by reviewing the relative average cost-effectiveness levels of the interventions. Starting with the current CHW and sugar (CS) portfolio, this would result in Zambia first adding biofortified vitamin A maize—resulting in a portfolio of CHW, biofortified VAM and sugar (CBS)—followed by the addition of vegetable oil resulting in CHW, biofortified VAM, sugar and vegetable oil (CBSO), then CHW, biofortified VAM, sugar, vegetable oil and wheat flour (CBSOW), and finally CHW, biofortified VAM, sugar, vegetable oil, wheat flour and maize meal (CBSOWM). **Figure 11** shows what such an evolution would mean in terms of the four criteria that have been identified.

Another criterion that might be considered in selecting a portfolio is equity. One way in which equity concerns have entered Zambian nutrition policy discourse has been to speculate about the likely impacts of policy on rural versus urban areas. **Figure 12** unpacks the same five portfolios just discussed to examine how the four indicators vary by rural vs. urban area and how such variation might influence the selection.

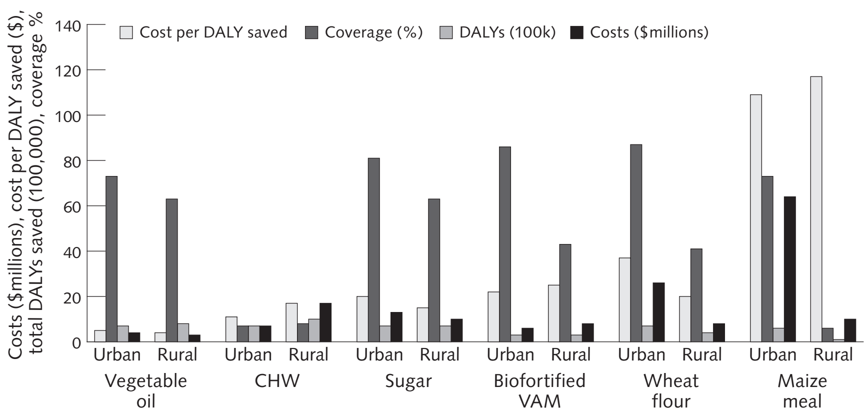

FIGURE 12. Rural–urban variations in total cost, cost per DALY saved, totaly DALYs saved and coverage of the 6 independent vitamin A interventions. CHW: Child Health Week; VAM: Vitamin A Maize

For CS, CBS, and CBSO, rural areas have higher costs and lower coverage but more DALYs saved, and thus have a lower cost per DALY saved. The addition of wheat flour fortification to CBSO increases total costs in rural areas from US$41 million to US$48 million (17%). In urban areas, the addition of wheat flour results in an increase in costs from the CBSO portfolio's US$32 million to US$59 million, an increase of 68% and one that is more than four times that of the increase in rural areas. In going from CBSO to CBSOW, the coverage in urban areas edges upward from 97% to 99%, while the coverage in rural areas climbs even less, from 84% to 85%. Going from CBSO to CBSOW results in increases in the number of DALYs saved of 34,202 in urban areas and 16,041 in rural areas, the equivalent of 3% and 1% increases, respectively. The much greater increase in costs relative to DALYs saved means that the addition of wheat to the portfolio results in the cost per DALY saved increasing in both areas, but especially in urban areas. The cost per DALY saved increases by 78%, from US$32 to US$57, in urban areas, compared with an increase of 13%, from US$28 to US$32, in rural areas.

The four graphs in **figure 13** show the significance and the annual changes in vitamin A intake due to diet and the changing impact of program interventions over the period from 2013 to 2042. The two graphs in the top portion of the figure provide easy-to-compare, side-by-side rural and urban depictions of the annual evolution in baseline vitamin A intake as a percentage of vitamin A EAR (i.e., that derived only from diet) and with the incremental additional intake attributable to each of the five individual interventions; sugar, biofortified VAM, vegetable oil, wheat flour and maize meal (S, B, O, W, M).* The boxed percentages on the right-hand edge of each graph identify the percentage of the EAR that each of the five individual interventions provides in 2042.

The two graphs in the bottom portion of **figure 13** are also constructed to enable easy comparison of rural and urban differences. In this case, the changes are in the prevalence of inadequate vitamin A intake from 2013 to 2042 that resulted from different portfolios. Starting with no intervention (only diet), then adding sugar, then biofortified VAM, followed by oil, wheat and finally maize, the graph shows the incremental reduction in the prevalence of inadequate intake attributable to each portfolio. This figure is a tool for considering the benefits and timing of phasing in additional vehicles to facilitate selecting Zambia's expansion path over the next 30 years. It is important to note that the additional change in the prevalence of vitamin A intake attributed to each portfolio in the bottom graphs is a function of their sequential ordering. The bottom graphs show the annual evolution in the prevalence of inadequate vitamin A intake in 2042 with no interventions (baseline) and with the alternative sequential incremental additions to sugar (S), biofortified VAM & sugar (BS), biofortified VAM & sugar & oil (BSO), biofortified VAM & sugar & oil & wheat flour (BSOW), biofortified VAM & sugar & oil & wheat flour & maize meal (BSOWM). The boxed percentages on the right-hand edge of each graph identify the endline (2042) values.

As may be seen in all four graphs, vitamin A intake from the diet changes relatively little over the 30-year period, underscoring the importance of introducing some combination of these interventions in order to improve the vitamin A intake of Zambians over the next three decades. As shown in the top graphs, in 2042 vitamin A intake derived exclusively from the diet will provide an average of 67% of EAR in rural areas and an average of just 41% in urban areas.** As shown in the lower graphs, in 2042 diet alone will enable 19% of the population to have adequate vitamin A intakes in rural areas, whereas in urban areas the corresponding percentage will be less than one-third that level, 6%. Vitamin A deficiencies will continue to be widespread and severe in Zambia, but the situation can be dramatically improved with the introduction of multiple vitamin A interventions. If all six interventions were implemented, the prevalence of inadequate vitamin A intake would fall by 36% (from 81% to 52%) in rural areas and by 84% (from 94% to 15%) in urban areas. The urban areas, which start with relatively low vitamin A intake levels and relatively high prevalences of inadequate intake, are the big winners, benefiting more than the rural areas. In the case of vitamin A maize, the urban–rural ratio differential is only 50%: relative to fortification, the benefits of vitamin A maize (as measured by the percentage of EAR delivered) impact rural areas more.

The top graphs in **figure 13** show that in 2042 vitamin A–fortified sugar would provide an estimated 19% of vitamin A EAR in rural areas and 40% in urban areas. The biggest reduction in the vitamin A intake

*CHW is not included in the graphs. Although it provides a therapeutic megadose of vitamin A intended to replenish liver stores and will ultimately save DALYs, it does not provide a regular daily dietary source of vitamin A. The prevalence of inadequate intake is based on group comparisons with the EAR for daily vitamin A intake.

**The reader is reminded that the EAR, by construction, is "the average daily nutrient intake level that is estimated to meet the requirements of half of the healthy individuals in a particular life stage and gender group." Although the term "average" is used, the EAR actually represents an estimated median requirement. As such, the EAR exceeds the needs of half of the group and falls short of the needs of the other half [36]. The objective of public nutrition policy, therefore, should be to attain a mean or median intake for the entire population that is greater than the EAR in order to reduce the percentage of the population with inadequate intakes. How much greater than the median EAR level public policy should strive to achieve, will depend on the distribution of intakes.

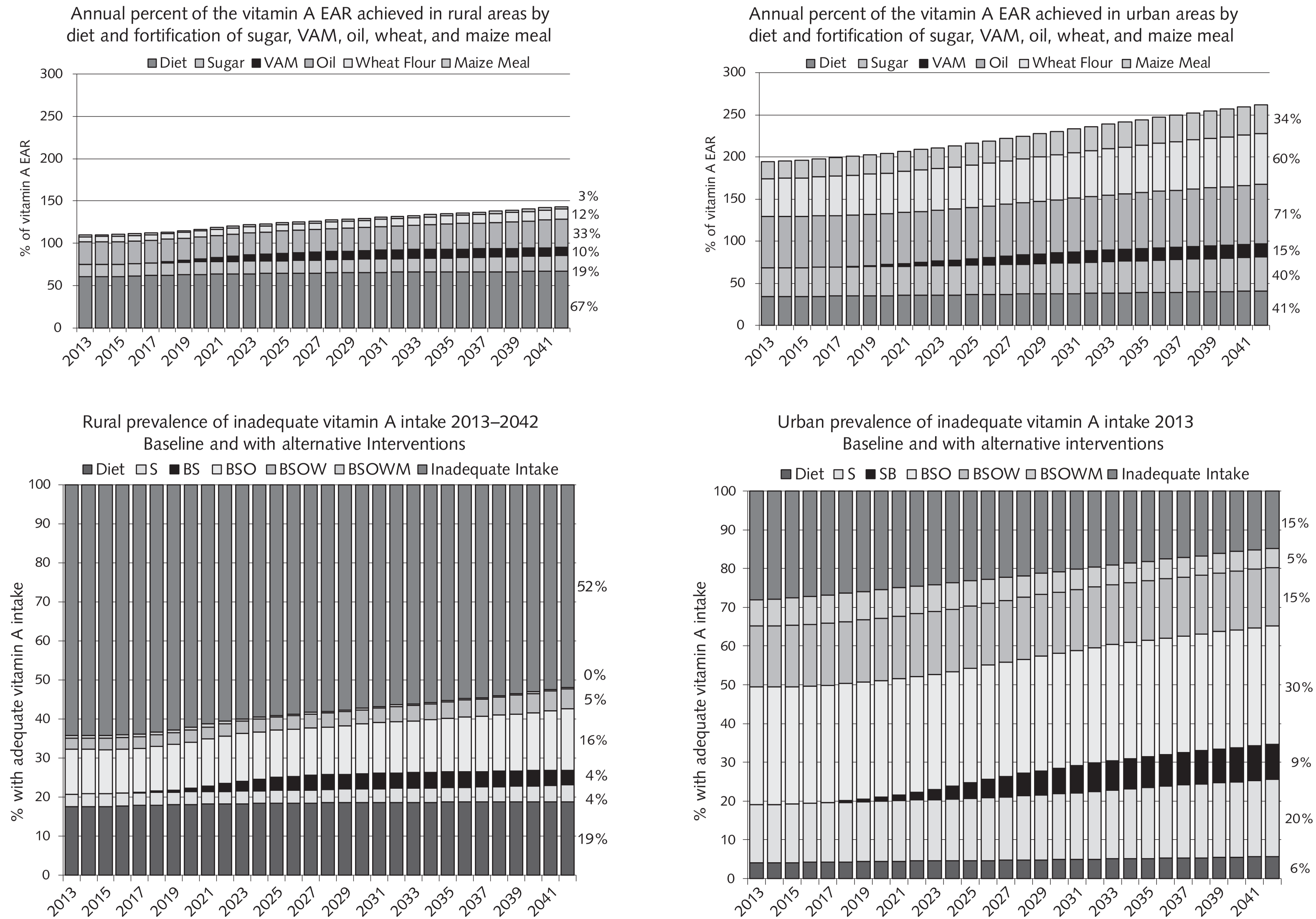

FIGURE 13. Rural–urban differences in percent of the vitamin A EAR achieved and in prevalence of inadequate vitamin A intake, 2012–2042. VAM: Vitamin A maize; B: Biofortified VAM; BS: Biofortified VAM & Sugar; BSO: Biofortified VAM & Sugar & Oil; BSOW: Biofortified VAM & Sugar & Oil & Wheat flour; BSOWM: Biofortified VAM & Sugar & Oil & Wheat flour & Maize meal

gap that these five individual vitamin A interventions could produce in both rural and urban areas by 2042 is that produced with oil: it could provide 33% of EAR in rural areas and 71% in urban areas. In urban areas, wheat would provide the next biggest percentage of vitamin A EAR, followed by sugar, maize meal, and vitamin A maize, in that order. In rural areas, the biggest increases in the percentage of vitamin A EAR, next to that provided by oil, would be provided by sugar, wheat, vitamin A maize, and maize meal, in that order.

Vitamin A maize would account for the smallest percentage of EAR produced by these five individual interventions in 2042 in urban areas, and the second smallest percentage in rural areas. These figures, however, belie the unique contribution of vitamin A maize in terms of its providing the greatest added coverage for persons who would otherwise be without any program coverage (13% by 2042), and the significance of vitamin A maize as a motor of change. All four of the graphs in **figure 14** reveal that the major sources of change over time are vitamin A maize, followed by wheat flour. Vitamin A maize, depicted as a black wedge that grows over time, is the source of the greatest dynamism among the five individual interventions (the top graphs) during the next three decades in Zambia: it starts at zero and by 2042 contributes 10% of vitamin A EAR in rural areas and 15% in urban areas. As part of the current sugar & biofortified VAM (SB) portfolio (bottom graphs), by 2042 it will reduce the prevalence of inadequate vitamin A intake by another 4% in rural areas and 9% in urban areas.

Vitamin A maize is also well targeted geographically. The four provinces with the lowest vitamin A intakes in 2013 are also the biggest vitamin A maize–producing provinces, the biggest vitamin A maize–consuming provinces, and the four provinces with the largest number of DALYs saved by vitamin A maize.

Other considerations: Policy predictability and the pace of phasing in larger portfolios

There are many ways in which increasingly costly programs might be added over time to the current portfolio. We will use the sequencing example just discussed, which was developed using average cost-effectiveness analysis, an unconstrained approach to choosing the most cost-effective portfolio over the entire 30-year period, and calculate the incremental cost-effectiveness of additions to the current portfolio to exemplify their differences by juxtaposing their different implications.

Figure 14 presents both the total and the incremental costs, DALYs saved, and costs per DALY saved for the four alternative portfolios. Initially, the portfolios are considered single, fixed portfolios that remain in effect throughout the period from 2013 to 2042. These are the average cost-effectiveness-based estimates shown in the first four bars in the figure, going from left to right. Then, using incremental cost-effectiveness analysis, we introduce three scenarios in which the portfolio mix changes. Evolving portfolio mix 1 goes from consisting of CHW & biofortified VAM & sugar (CBS) in 2013 and 2014 to adding oil and becoming CHW & biofortified VAM & sugar & vegetable oil (CBSO) starting in 2015 and remaining CHW & biofortified VAM & sugar & vegetable oil (CBSO) thereafter to the end of 2042. Evolving portfolio mix 2 is the same as evolving portfolio mix 1 from 2013 to 2015, but then, starting in 2016 it adds wheat flour fortification to the program mix to make it CHW & biofortified VAM & sugar & vegetable oil & wheat flour (CBSOW), which it remains thereafter to the end of 2042. Evolving portfolio mix 3 is the same as evolving portfolio mix 2 from 2013 to 2016, but then, starting in 2017 it adds maize meal fortification to the program mix to make it CHW & biofortified VAM & sugar & vegetable oil & wheat flour & maize meal (CBSOWM), which it remains thereafter to the end of 2042. The incremental costs per DALY saved of each of these three evolving portfolio mixes is shown as the three bars on the right of **figure 14**. This example involves relatively minor delays, and thus the reductions in total financing requirements are not large. Obviously, the longer the delays, the greater will be the impact on the total cost of the program.

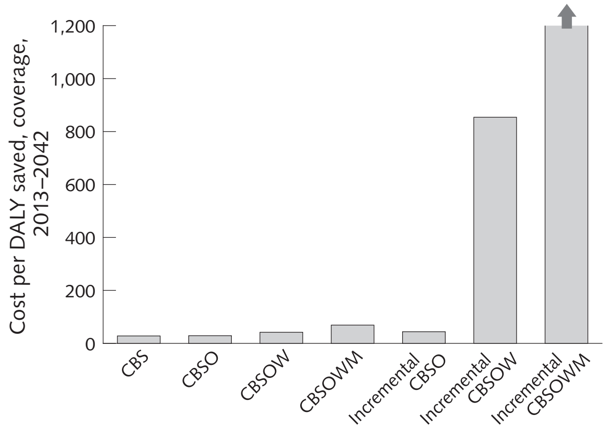

FIGURE 14. Total cost per DALYs saved by alternative portfolios and the incremental cost per DALYs saved of a potential sequencing of micronutrient portfolios, 2013–2042

Discussion and conclusions

In conducting the study, we became much more familiar with the interventions and learned of their various noncomparabilities (discussed earlier). We modified the study by adding additional criteria—including the magnitude of the public health impact (i.e., total

DALYs), affordability (total costs), and coverage. There nevertheless remain a host of noncomparabilities that introduce significant elements of uncertainty about the interventions and obfuscate which is the "best" intervention and which the "optimal" portfolio: that determination now depends on the relative importance that one might ascribe to each of these criteria.

Among the most salient of the noncomparabilities are those having to do with long-term feasibility and sustainability. Real-world experience, cross-country comparisons, and sensitivity analyses help to provide insights and data that may be triangulated and can help to provide a greater degree of confidence about the more familiar interventions—supplementation and fortification. The long-term viability of CHW would seem to be questionable. It appears vulnerable because of its annual program cycle, its financing mechanism, the nature of its delivery system, and the incidence of its costs. It has been dependent to date on the successful twice-annual mobilization of large groups of support throughout Zambian society, which, largely uncompensated, have provided enormous logistical and personnel support. It is vulnerable to the annual political battles that it must confront in securing requisite national funding, and to maintaining the political will of district-level authorities who are its key implementing agents. Donors, who provide periodic but critical injections of support, are already demonstrating fatigue [42]. Is it reasonable to expect the public's massive support not to wane over the next three decades? Each of these vulnerabilities individually is an important source of uncertainty. Considered together, they create skepticism about the long-term sustainability of CHW—at least, as it has been described and assessed here.

Turning to fortification, its Achilles' heel would appear to be the program's regulatory enforcement and business compliance. We need not address the issue of intent here, which may also play an important role, but simply acknowledge that for fortification to function as has been assumed in this analysis will require compliance with current government regulations [50]. Beyond this important consideration, the long-term viability and sustainability of fortification are perhaps the most secure of all three intervention types. Its costs are largely annual, recurrent, and relatively constant. Furthermore, they are shifted onto consumers and once they are in place are largely invisible. Fortification does not require annual approvals of its budget and it does not even need consumers who know about its importance for it to be effective. No social marketing campaigns or annual decision-making processes (such as allocating the CHW budget or assembling the CHW implementation team or selecting a particular maize seed) are required. This big battle for fortification would appear to be the initial one—whether or not it gets adopted (either voluntarily or by mandate). What insights and lessons might these observations hold for vitamin A maize?

Adoption by both farmers and consumers is the big determinant of the potential success of biofortification and is a long-term, recurrent issue. How sustainable is biofortification? Going out 5 to 10 years after the currently planned active project phase has shut down (slated for the end of 2019, but of course subject to change) and trying to make projections is virgin territory, replete with uncertainties. And yet, if the promise of biofortification is to be fulfilled, it must be able to sustain its popularity among both farmers and consumers for, at a minimum, another decade.

The dynamism of vitamin A maize in terms of its growth in coverage begins to ebb with the ending of the active vitamin A maize project cycle in 2019. This year will also be marked by a reduction in the attention brought to vitamin A maize by agents motivated more exclusively by the desire to improve nutrition and public well-being, and who are more willing and able to undertake social marketing to promote it as a nutrition and public health intervention. It will usher in an era when more narrow, and more purely pecuniary interests and more narrow private cost and private benefit calculations will be the predominant forces shaping the development of the market for vitamin A maize. That will bring with it the risk that vitamin A maize may become "just one more seed" that the private sector makes available to farmers. Or is it anticipated that the seed market by then will no longer undervalue the public health attributes of vitamin A maize? How will the vitamin A maize seed market remain dynamic after the vitamin A maize active project cycle ends? How will vitamin A maize continue year after year to be made more appealing to farmers than other newly developed seeds? Will the agronomic features and the vitamin A content of vitamin A maize continue to be "attractive enough" that Zambian farmers will continue to select it as their "best" option even while new seeds with new characteristics are being introduced?

Is it conceivable that the agronomic features of vitamin A maize could be developed in such a manner that vitamin A content could become a standard feature of most or even all maize varieties? Is it possible that government seed certification processes could come to include some minimum vitamin A content as a fundamental, universal requirement? There can be little doubt that vitamin A maize is a long-term strategy, and that it will be years before it has a sizeable impact on vitamin A deficiency in Zambia. The question now is how to best ensure that it can be made as sustainable as possible, so that it can be become "slow magic" [51].

Finally, it is important to acknowledge that this study looks only at Zambia's vitamin A portfolio, and not its micronutrient portfolio. Three of the interventions—CHW, wheat flour fortification, and maize meal fortification—provide multiple interventions that have not been taken into account here. Had these additional interventions been taken into account, the cost-effectiveness and impacts of these interventions would have been greater relative to the other studies analyzed—biofortified vitamin A maize and the fortification of vegetable oil and sugar.*

Zambia has had an established vitamin A portfolio—consisting of CHW and sugar fortification— since 1998, and as of November 2012 has embarked on transforming its current portfolio into CBS. Since January 2013, the country has discussed revisiting the issue of adding other fortification vehicles to this portfolio. Based on our analysis over the period from 2013 to 2042 and as assessed by the four criteria employed here, our recommendation would be to first introduce the fortification of vegetable oil, followed by wheat flour and then maize meal.

The incremental cost per DALY saved of the last of these interventions, maize meal fortification, is high relative to that of the other five interventions. It is important to bear in mind, however, that the portfolio composed of all six of these interventions—including maize meal—has a cost per DALY saved over the period from 2013 to 2042 of US$73, qualifying it for what WHO and the World Bank characterize as "very cost-effective" [52]. This suggests that if Zambia considers the cost-effectiveness of these interventions and compares them with that of other health interventions [53, 54], it is likely to find that all of these vitamin A portfolios—even the all-inclusive, six-intervention portfolio—will look to be among its best health investment options available. Additionally, there remains the still-unresolved affordability issue. How quickly might Zambia be willing and able to phase-in the six-intervention portfolio?

*The interventions not included are CHW's deworming medications and the inclusion of iron, zinc, and five B vitamins in fortified wheat flour and maize meal.

Authors' contributions

John L. Fieldler conceptualized the study, developed the costing methodologies, participated in data collection and data analysis, and prepared the manuscript. Keith Lividini developed the modeling tool to operationalize the study design, led the data analysis, finalized the nutrient intake analytic file, and reviewed and edited the manuscript.

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