**MAPS tool cost and effectiveness module documentation**

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**Guidelines for defining an intervention**

*Intervention type*

The MAPS tool cost and effectiveness module allows users to estimate the cost, effectiveness, and cost-effectiveness of large-scale food fortification (LSFF), biofortification (via crop breeding), and agronomic biofortification interventions.

Food fortification is the addition of vitamins and/or minerals to foods during processing to increase their nutrient content (Olson, Gavin-Smith, Ferraboschi et al., 2021). Large-scale food fortification (LSFF) is food fortification that occurs during processing at formal, centralized industries (USAID Advancing Nutrition, 2023b). In the MAPS cost and effectiveness module, LSFF food vehicle choices currently include wheat flour, maize flour, refined oil, rice, salt, and sugar. Food vehicle choices may be expanded in the future to include bouillon, margarine, and other condiments.

Biofortification via crop breeding is the process of increasing the vitamin or mineral content of a crop by crossing parent lines with high vitamin or mineral levels over several generations to produce plants with enhanced nutrient content and desired agronomic traits (Saltzman, Birol, Bouis et al., 2013). In the MAPS cost and effectiveness module, modeling of the cost, effectiveness, and cost-effectiveness of biofortification is limited to crops for which one or more biofortified variety has been released (or is near release) (see [this table](https://www.harvestplus.org/harvestplus-biofortified-crops-map-and-table-updated-with-2020-data/) from HarvestPlus 2020 data on biofortified crops released or in testing by country). Before a biofortified seed variety is released, a 6 to 8 year process of discovery and development research is typically required (Bouis, Hotz, McClafferty et al., 2011). Because costs and effectiveness are modeled over a 10-year time horizon in MAPS (see methods below), biofortified crop varieties that are still in the discovery and developmental research phases would require a longer modeling time horizon to adequately capture costs and/or impacts after the variety is released. Therefore, when estimating the cost of biofortification via crop breeding, research costs incurred prior to in-country final testing and release of the variety are assumed sunk and are not accounted for.

Agronomic biofortification is the process of increasing the micronutrient content of the edible portion of a crop through applying micronutrient-enriched fertilizers to the soil (granular) and/or sprayed on the plant leaves (foliar) (de Valença, Bake, Brouwer et al., 2017). The effectiveness of agronomic biofortification has been most widely studied for zinc, selenium, and iron, though agronomic biofortification with other nutrients is also possible. In the MAPS cost and effectiveness module, default application rates and grain concentrations/expected uptake are provided for some crop and mineral combinations. These defaults can be modified by tools users, and users can use the MAPS cost and/or effectiveness modelling framework to model crop and mineral combinations without default values (users will be required to specify application rates, expected grain concentrations, etc.).

*Intervention status*

The intervention status can be set to either existing intervention program or hypothetical intervention program. This choice will impact some of the default cost and effectiveness modeling assumptions. Based on the descriptions in **Table 1** below, the user should choose the intervention status that best reflects the current status of the intervention in the specific country context.

Table 1. Intervention status options

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| --- | --- | --- | --- |
| **Intervention type** | **Intervention status** | **Description** | **Default modeling assumptions** |
| LSFF | Existing intervention program | Mandatory fortification standards exist for the food vehicle, including the focus micronutrient. | Both costs and effects accrue in all 10 years of the modeling time horizon. |
| Hypothetical intervention program | Either fortification standards for the food vehicle do not exist or the fortification standards do not include the focus micronutrient. | Costs accrue in all 10 years of the modeling time horizon (start-up costs incurred in years 1-2), while effects accrue in years 3-10. |
| Biofortification (via crop breeding) | Existing intervention program | At least one biofortified variety of the crop has been released in the country. | Both costs and effects accrue in all 10 years of the modeling time horizon. |
| Hypothetical intervention program | No biofortified variety of the crop has been released in the country, but a biofortified variety is expected to be released soon. | Costs accrue in all 10 years of the modeling time horizon (start-up costs incurred in years 1-3), while effects accrue in years 4-10. |
| Agronomic biofortification | Existing intervention program | Granular and/or foliar biofortification of the crop is being promoted and adopted at a scale larger than pilot programs in the country. | Both costs and effects accrue in all 10 years of the modeling time horizon. |
| Hypothetical intervention program | Granular and/or foliar biofortification of the crop is not being promoted and adopted at a scale larger than pilot programs in the country. | Costs accrue in all 10 years of the modeling time horizon (start-up costs incurred in years 1-2), while effects accrue in years 3-10. |

*Nature of intervention*

The user choice regarding the nature of the intervention will determine how the intervention is modeled over. The choices for the nature of the intervention depend on the type of intervention and whether the intervention is existing or hypothetical (see **Table 2**).

Selecting the nature of the intervention at this stage will impact several of the default cost and effectiveness model parameter values, but all of these values can be changed by the user within the cost and effectiveness module. As such, users need not worry about selecting the “right” nature of intervention option. For example, if the user wants to model an existing LSFF intervention with both improved compliance and a revision of the current standard, the user can choose either “Improved compliance” of “Revision of existing standard” and then carefully review and edit the default parameter values to ensure the model parameters reflect the intervention characteristics they are hoping to model.

Table 2. Nature of intervention

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| --- | --- | --- | --- | --- |
| **Intervention type** | **Intervention status** | **Nature of intervention** | **Description** | **When to use** |
| LSFF | Existing intervention program | Status quo | Modeled fortification standards and compliance with standards held constant over the 10-year time horizon. | Relevant when you want to model the cost and/or effectiveness of an existing program operating at current levels of compliance. |
| Improved compliance | Investment made during years 1-2 enhanced monitoring and evaluation. Modeled industry compliance levels scaled up over 10-year time horizon. | Relevant when you want to model the cost and/or effectiveness of an existing program if compliance with the standard improves to a specified level or a relatively newly established program is scaling up. |
| Revision of existing standard | Investment made during years 1-2 to plan for and revise the national standard. Modeling in years 1-2 reflects the current standard, while years 3-10 reflect the revised standard. | Relevant when you want to model the cost and or effectiveness of modifying an existing national standard, such as a change to the fortification level, a change to the required micronutrient compound, or the addition of a new micronutrient to the standard. |
| Hypothetical intervention program | New food vehicle | Investments made during years 1-2 to plan for, implement, and launch the fortification of a new food vehicle. | Relevant when you want to model the cost and/or effectiveness of introducing national standards for the fortification of a new food vehicle at assumed/potential levels of compliance. |
| Biofortification (via crop breeding) | Existing intervention program | Status quo | Modeled farmer adoption rates held constant over 10-year time horizon. | Relevant when you want to model the cost and/or effectiveness of an existing program operating at current farmer adoption rates. |
| Scale up | Investments made during years 1-3 to promote farmer adopt of the biofortified crop. Modeled farmer adoption rates scaled up over 10-year time horizon. | Relevant when you want to model the cost and/or effectiveness of an existing program if farmer adoption rates increase. |
| Hypothetical intervention program | New biofortified crop | Investments made during years 1-3 to plan for and launch the release and promotion of the biofortified crop variety. | Relevant when a biofortified crop variety is nearly ready for release and you want to model the cost and/or effectiveness of the new biofortified crop variety at assumed/potential farmer adoption rates. |
| Agronomic biofortification | Existing intervention program | Status quo | Modeled farmer adoption rates held constant over 10-year time horizon. | Relevant when you want to model the cost and/or effectiveness of an existing program operating at current farmer adoption rates. |
| Scale up | Investments made during years 1-2 to promote farmer adoption of agronomic biofortification. Modeled farmer adoption rates scaled up over 10-year time horizon. | Relevant when you want to model the cost and/or effectiveness of an existing program if farmer adoption rates increase. |
| Hypothetical intervention program | New biofortified crop | Investments made during years 1-2 to plan for and promote agronomic biofortification. | Relevant when you want to model the cost and/or effectiveness of a new agronomic biofortification program at assumed/potential farmer adoption rates. |

**Summary of methods used in the cost and effectiveness module of the MAPS tool**

*Modeling costs in the MAPS tool*

1. Type of costing and data sources

For each type of micronutrient intervention, we have developed an activity- and ingredients-based cost model to estimate the cost of the intervention over a 10-year time horizon. That is, for each type of intervention, we have defined a series of activities required to undertake the intervention, from start-up to scale-up through annual operating activities. Then, for each activity, we have identified the types and quantities of inputs, or ingredients, that are required to execute each activity, including equipment and supplies, personnel, etc. The models are then populated with data relevant to the specific country context. It is important to note that the cost models were designed to estimate the *additional* or *incremental* cost of the interventions and exclude costs involved in the production and distribution of the food vehicle or crop in the absence of fortification or biofortification. LSFF intervention costs, for example, do not include the cost of raw materials or ingredients used to produce the food vehicle itself (e.g., wheat, oil, salt, etc.) or the labor and management costs associated with producing the food vehicle. Similarly, biofortification costs do not include farmer labor or inputs that are typically employed in the cultivation of the non-biofortified variety of the crop.

The additional or incremental activities and ingredients required to execute each type of micronutrient intervention were identified through a combination of literature reviews and interviews with international and local experts in LSFF and biofortification. Then, for Malawi and Ethiopia, country-specific data to populate each parameter of the cost models (including intervention characteristics, quantities of inputs, unit costs or the value of each input, etc.), were based on local primary data collection (interviews with government, industry, local experts, and other stakeholders), review of existing budgets, online sources (e.g., GFDx, the UNICEF supply catalogue, etc.), and the literature. The source of each parameter is documented in each cost model. The sources do not identify specific individuals or organizations. More information about specific sources is available upon request. Where no data source could be identified, the source is listed as “assumed” or “estimate”, meaning that we were unable to identify a good source of data for that parameter and had to make an informed guess about its value. Note that for hypothetical interventions, default cost model parameters are based on both data collection relevant to the specific food vehicle or crop as well as imputed based on data collected on existing, related intervention program costs (e.g., if a country has an existing wheat flour fortification program but does not have a maize flour fortification program, some of the maize flour fortification cost modeling parameters may be borrowed from the wheat flour cost data).

2. Costing perspective

By default, intervention costs are estimated from a societal perspective, meaning that the economic value of all resources used in providing and accessing an intervention are accounted for, regardless of who incurs them (Sanders, Neumann, Basu et al., 2016). As such, the cost estimates include costs potentially paid by industry, the government, civil society (aid and donor organizations, NGOs, etc.), farmers, consumers, etc. Note that because the stakeholder groups that ultimately pays each cost is not necessarily know (e.g., what proportion of LSFF premix costs will be passed on to consumers, what proportion of industry equipment costs might directly paid by industry vs subsidized by the government or an NGO, etc., whether the incremental cost of a biofortified seed variety will be paid for by farmers or subsidized by the government, etc.), in the cost models we intentionally avoid assigning costs to specific stakeholder groups and instead refer to “industry-related” costs, “government-related” costs, etc.

For users who wish to estimate costs from a narrower perspective (e.g., government perspective), this is possible by zeroing out costs in the cost model that are expected to be paid by other stakeholder groups.

3. Economic costs

Intervention costs also reflect the economic (vs financial) cost of inputs, meaning that the value represents the opportunity cost of the input, or the value of the input in its next best alternative use (Turner, Sandmann, Downey et al., 2023; World Health Organization, 2003). For inputs that have a market value, such as paid labor, the economic cost may be the same as the financial cost. However, for inputs that are not paid for (e.g., volunteer labor or household time to participate in an intervention) the economic cost of the input is the input’s value in its next best alternative use. Similarly, for capital costs such as equipment, the annualized economic cost accounts not only for the expected useful life of the capital good but also the assumed discount rate (3% by default) to account for the opportunity cost of using the equipment for the intervention. In the tool, capital costs are annualized using the following equation (World Health Organization, 2003):

where

Here, P is the purchase value of the capital item, including shipping and taxes (note that this assumes the salvage value, or the value of the capital item at the end of its useful life, is zero), n is the assumed useful life of the capital item, and r is the discount rate.

4. Costing base year

In the current version of the MAPS tool, costs are reported in 2021 US dollars (USD). For costs reported in USD, the value was adjusted to 2021 USD using the Bureau of Economic Analysis implicit price deflators for gross domestic product (Bureau of Economic Analysis, 2020). For costs reported in other currencies (e.g., Malawi Kwacha or Ethiopian Birr), costs were first adjusted to the 2019 value (where necessary) using the local GDP price deflator, then converted to USD using the average 2021 exchange rate. To maintain consistency, user-defined costs (i.e., costs modified by the user from the default value) should also be entered in 2021 USD.

*Modeling effectiveness in the MAPS tool*

1. Effectiveness (and related) indicators

In the MAPS tool, the effectiveness of micronutrient interventions is based on the concept of effective coverage, or the number or percent of households with inadequate apparent intake of the focus micronutrient without any interventions (that is, based on diets alone) who achieve dietary micronutrient adequacy as the result of the intervention. In the tool, the prevalence of micronutrient inadequacy and effective coverage can be calculated based on either apparent micronutrient intake per adult female equivalent (AFE) or based on the nutrient density of the household diet. Each of these approaches are described in detail below.

In addition to effective coverage, several other indicators are automatically calculated in the MAPS tool effectiveness modeling framework, as defined in **Table 3**.

Table 3. Effective coverage and related indicators

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| **Indicator** | **Definition** |
| Effective coverage | The proportion of household with an inadequate apparent intake of the focus micronutrient at baseline (i.e., without interventions) that achieve dietary micronutrient adequacy with the specified intervention. In other words, this is the change in the prevalence of inadequacy from the baseline scenario to the modeled micronutrient intervention scenario. |
| Micronutrient inadequacy | Estimate of the percent of households with an inadequate apparent intake of the focus micronutrient. This percentage is estimated both for the baseline scenario (i.e., without any interventions) as well as with the modeled micronutrient intervention scenario. Note that the difference in these two percentages is equivalent to effective coverage. |
| Risk of high intakes | The percent of households with apparent intake of the focus micronutrient above the tolerable upper intake level (UL). |
| Reach | The proportion of household that reported consuming the food vehicle or crop, in any quantity, during the recall period. |
| Apparent consumption among consumers | The quantity of a food vehicle or crop apparently consumed among consumers (i.e., excluding household who did not consume the food vehicle or crop) per day per adult female equivalent (AFE). |

2. Data sources and methods for modeling effectiveness and other indicators

Effective coverage and related indicators are modeled in the MAPS tool using food consumption data from household consumption and expenditure surveys (HCESs). HCESs, also known as household income and expenditure surveys, household budget surveys, integrated household surveys, and Living Standards Measurement Study surveys, are designed to collect data on various dimensions of household socioeconomic conditions, but most surveys also include a module to collect data on household consumption of and/or expenditures on a pre-defined list of food items (Fiedler, 2013; Coates, Colaiezzi, Fiedler et al., 2012). Variation in the design of the food consumption/expenditure modules of HCESs means that there is also variation in how well-suited the resulting data are to assess the micronutrient adequacy of diets and model the impacts of micronutrient interventions (Food and Agriculture Organization of the United Nations & The World Bank, 2018). There are also a number of limitations inherent in using these data for nutrition analyses. Both of these issues are discussed in detail below. We qualify many of our estimates with the term “apparent” (e.g., apparent food consumption, apparent micronutrient intake, etc.) to emphasize the assumptions and limitations associated with using household-level food consumption data.

The methods used in the MAPS tool to assess the adequacy of the household diet without and with micronutrient interventions generally follow the steps laid out in the USAID Methods Guide for using HCES data conduct a needs assessment and design/redesign an LSFF program (USAID Advancing Nutrition, 2023a). As noted above, the MAPS tool allows for calculating effectiveness (and related) indicators based on two approached: (1) apparent intake per AFE, and (2) the nutrient density of the household diet. Based on each approach, the steps listed below describe the methods used assess the baseline apparent adequacy of the household diet for meeting the requirements of household members, to model the impact of a micronutrient intervention on the micronutrient adequacy of the household diet, and to assess the risk of high micronutrient intakes in the MAPS tool cost and effectiveness module.

* *Steps in estimating baseline prevalence of micronutrient inadequacy*

**Apparent intake per AFE approach**

1. For each food in the food list, we convert the reported quantity of food consumed by the household during the recall period (typically the past seven days) to grams and, where relevant, adjusted for the edible portion. Estimates of the edible portion of foods are taken from a locally-relevant food composition table (FCT), where possible, and otherwise based on input from local experts.
2. We match each food in the food list with a locally-relevant FCT entry to estimate nutrient composition of each food (link to description of matching process). Note that, unless the food in the HCES food list specifies a cooking method (e.g., sweet potato, boiled), foods are matched with the raw version of the food in the FCT, meaning that potential micronutrient losses during cooking are not accounted for.
3. We sum the apparent intake of the focus micronutrient from each food to calculate total daily average apparent micronutrient intake (total household intake divided by the number of days of recall).
4. Using information from the household roster, we calculate the number of AFEs in each household. Note that the number of AFEs in the household is calculated based on the sum of each household member’s age- and sex-specific energy requirements relative to the energy requirements of the reference household member, a non-pregnant, non-lactating adult female 18–30 years of age. Energy requirement estimates are based on the FAO/WHO Human Energy Requirements report (Food and Agricultural Organization of the United Nations & World Health Organization, 2001), assuming a physical activity level of 1.6 for adults and average bodyweight based on country-specific estimates where available (e.g., Demographic and Health Survey).

Table 4 summarizes the adjustment factors incorporated to account for energy requirements during lactation and the energy provided via breastmilk when infants are breastfeeding. Specifically, to account for additional energy requirements during lactation, we assume that all households with a child under 2 years of age also have a lactating mother (note that this is expected to be an overestimation of the total number of lactating women since there is likely to be variation in the degree of adherence to international breastfeeding guidelines). We add an additional 500 kcal per day to the base energy requirements of women assumed to be breastfeeding a child (Centers for Disease Control and Prevention, 2024). For infants under 2 years of age, we estimate total energy requirements from complementary foods (i.e., energy provided from the household diet) by subtracting the energy contributions from breastmilk from their daily energy requirements. The assumed contribution of breastmilk is age-specific (WHO Programme of Nutrition, 1998). We assume that children 0-2 months are exclusively breastfed and hence do not consume any portion of the household diet. For documentation on how these requirements are coded, see (link to GitHub). Because pregnancy status is not adequately collected (or not collected at all) in HCESs, we do not account for additional energy requirements during pregnancy.

Note that adult female serves as the reference household member because her food consumption is expected to be approximately the average in the household. Moreover, her micronutrient requirements are generally high relative to other household members, so if the household’s micronutrient intake is adequate to meet her requirements (assuming that food is distributed within the household in proportion to age- and sex-specific energy requirements), it is likely adequate to meet the needs of other household members

Table 4. Energy adjustment parameters for lactating women and breastfeeding infants

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| Parameter | Value |
| Additional energy requirement for lactation (kcal) | 500 |
| Energy intake from breastmilk, age 3-5 months (kcal) | 434 |
| Energy intake from breastmilk, age 6-8 months (kcal) | 413 |
| Energy intake from breastmilk, age 9-11 months (kcal) | 379 |
| Energy intake from breastmilk, age 12-23 months (kcal) | 346 |

1. We divide average daily total apparent micronutrient intake by the number of AFEs in the household to calculate baseline daily apparent micronutrient intake per AFE.
2. We compare daily apparent micronutrient intake per AFE to the estimated average requirement (EAR) of an adult female to classify the household diet as adequate or inadequate to meeting the focus micronutrient requirements of an adult female. These estimates are then summarized, accounting for survey weights, at national and subnational levels to generate estimates of the baseline prevalence of inadequacy of the focus micronutrient. Note that the default EARs in the tool are based the harmonized average requirements presented in Allen, Carriquiry & Murphy (2019), but these values can be modified by the user within the cost and effectiveness module framework of the tool.

**Nutrient density of the household diet approach**

1. For each food in the food list, we convert the reported quantity of food consumed by the household during the recall period (typically the past seven days) to grams and, where relevant, adjusted for the edible portion. Estimates of the edible portion of foods taken from a locally-relevant food composition table (FCT), where possible, and otherwise based on input from local experts.
2. We match each food in the food list with a locally-relevant FCT entry to estimate energy and nutrient composition of each food (link to description of matching process). Note that, unless the food in the HCES food list specifies a cooking method (e.g., sweet potato, boiled), foods are matched with the raw version of the food in the FCT, meaning that potential micronutrient losses during cooking are not accounted for.
3. We sum the apparent intake of the focus micronutrient from each food to calculate total daily average apparent micronutrient intake (total household intake divided by the number of days of recall).
4. We sum the apparent intake of energy from each food to calculate total daily average apparent energy intake (total household energy intake divided by the number of days of recall).
5. For the focus micronutrient, we calculate the baseline nutrient density of the household diet by dividing total daily average apparent micronutrient intake by total daily average apparent energy intake, multiplied by 1000 to express the nutrient density per 1,000 kcal.
6. We compare the household nutrient density to the critical nutrient density of an adult female to classify the household diet as adequate or inadequate to meeting micronutrient requirements of an adult female, assuming energy requirements are met. These estimates are then summarized, accounting for survey weights, at national and subnational levels to generate estimates of the baseline prevalence of inadequacy of the focus micronutrient.
   1. Note that the critical nutrient density is calculated as the EAR of a non-pregnant, non-lactating adult female 18-30 year of age divided by the energy requirements of a non-pregnant, non-lactating adult female 18-30 years of age, multiplied by 1,000.

* *Steps in modeling the impact of micronutrient interventions and risk of high intakes*

**Apparent intake per AFE approach**

1. We calculate total average daily apparent household consumption of the relevant food vehicle (for modeling LSFF) or crop (for modeling biofortification). This includes fortifiable/biofortifiable food equivalents from processed foods containing the food vehicle or crop (e.g., wheat flour in bread). Fortifiable/biofortifiable food equivalents are drawn from a MAPS database of country-specific equivalents populated based on local recipes and input from in-country experts.
2. We divide total average daily apparent household consumption of the food vehicle or crop by the number of AFEs in the household to generate estimate of daily average apparent consumption per AFE.
3. For modeling LSFF, for each year of the 10-year modeling time horizon we calculate the additional daily apparent micronutrient intake per AFE provided by LSFF by multiplying daily average apparent consumption of the food vehicle per AFE (assumed constant over the 10-year horizon) by the year-specific average fortification level. Note that the average fortification level in each year is calculated as the target fortification level multiplied by the percent of the food vehicle that is fortifiable, the proportion of the food vehicle that is fortified to any extent, the average fortification level among the fortified food vehicle as a percent of the standard (at point of fortification), and the expected micronutrient retention from point of fortification to households. Each of these parameters is modifiable by the user in the tool.
   1. Note that to account for higher bioavailability of folic acid compared to dietary folate, we convert average folic acid fortification levels to dietary folate equivalents (DFEs) by multiplying the average fortification level by 1.7 (Bailey, 2000).
4. For modeling biofortification (via crop breeding or agronomic biofortification), for each year of the 10-year modeling time horizon we calculate the additional daily apparent micronutrient intake per AFE provided by biofortification by multiplying daily average apparent consumption of the crop per AFE (assumed constant over the 10-year horizon) by the year-specific average additional micronutrient content in the biofortified crop. Note that the average additional micronutrient content in the biofortified crop (via crop breeding) in each year is calculated as the difference in the micronutrient concentration in the non-biofortified variety and the biofortified variety, where the micronutrient concentration is calculated as the average of country-specific released varieties according to the HarvestPlus database of biofortified crops released (https://bcr.harvestplus.org/)) multiplied by the modeled annual farmer adoption rate. See Table 5 for biofortification effectiveness parameters for Malawi and Ethiopia. Each of these parameters is modifiable by the user in the tool.
   1. Note that we convert vitamin A in the form of pro-vitamin A (PVA) to retinol activity equivalents (RAE) assuming a 12:1 conversion factor of PVA to RAE (Institute of Medicine, 2001).

For agronomic biofortification, the average additional micronutrient content is based on published studies (either based on the absolute increase in the micronutrient contents if reported int the study or calculated based on the percent increase reported in the study. See Tables 6 and 7 for agronomic biofortification effectiveness parameters for granular and foliar applications, respectively. Each of these parameters is modifiable by the user in the tool.

1. We add additional daily apparent micronutrient intake per AFE provided by LSFF or biofortification to baseline daily apparent micronutrient intake per AFE to generate an estimate of total daily apparent micronutrient intake per AFE with LSFF or biofortification.
2. We compare daily apparent micronutrient intake per AFE with LSFF or biofortification to the EAR of an adult female to classify the household diet as adequate or inadequate to meeting the focus micronutrient requirements of an adult female with the micronutrient intervention. These estimates are then summarized, accounting for survey weights, at national and subnational levels to generate estimates of the prevalence of inadequacy of the focus micronutrient with LSFF or biofortification.
3. For each year of the 10-year modeling time horizon, we subtract the prevalence of inadequacy with LSFF or biofortification from the baseline prevalence of inadequacy to estimate effective coverage of the micronutrient intervention.
4. For micronutrients with a tolerable upper intake level (UL), we compare daily apparent micronutrient intake per AFE with LSFF or biofortification to UL of an adult female to classify the household diet as providing less than or above the UL threshold for and adult female. These estimates are then summarized, accounting for survey weights, at national and subnational levels to generate estimates of the prevalence of high intakes per AFE with LSFF or biofortification.
   1. Note that the UL for vitamin A applies only to preformed retinol, and the UL for folate applies only to synthetic folic acid.

**Nutrient density of the household diet approach**

1. We calculate total average daily apparent household consumption of the relevant food vehicle (for modeling LSFF) or crop (for modeling biofortification). This includes fortifiable/biofortifiable food equivalents from processed foods containing the food vehicle or crop (e.g., wheat flour in bread). Fortifiable/biofortifiable food equivalents are drawn from a MAPS database of country-specific equivalents populated based on local recipes and input from in-country experts.
2. For modeling LSFF, for each year of the 10-year modeling time horizon we calculate the additional daily apparent micronutrient intake provided by LSFF by multiplying daily average apparent consumption of the food vehicle (assumed constant over the 10-year horizon) by the year-specific average fortification level. Note that the average fortification level in each year is calculated as the target fortification level multiplied by the percent of the food vehicle that is fortifiable, the proportion of the food vehicle that is fortified to any extent, the average fortification level among the fortified food vehicle as a percent of the standard (at point of fortification), and the expected micronutrient retention from point of fortification to households. Each of these parameters is modifiable by the user in the tool.
   1. Note that to account for higher bioavailability of folic acid compared to dietary folate, we convert average folic acid fortification levels to dietary folate equivalents (DFEs) by multiplying the average fortification level by 1.7 (Bailey, 2000).
3. For modeling biofortification (via crop breeding or agronomic biofortification), for each year of the 10-year modeling time horizon we calculate the additional daily apparent micronutrient intake provided by biofortification by multiplying daily average apparent consumption of the crop (assumed constant over the 10-year horizon) by the year-specific average additional micronutrient content in the biofortified crop. Note that the average additional micronutrient content in the biofortified crop in each year is calculated as the difference in the micronutrient concentration in the non-biofortified variety and the biofortified variety, where the micronutrient concentration is calculated as the average of country-specific released varieties according to the HarvestPlus database of biofortified crops released (https://bcr.harvestplus.org/)) multiplied by the modeled annual farmer adoption rate. See Table 5 for biofortification effectiveness parameters for Malawi and Ethiopia. Each of these parameters is modifiable by the user in the tool.
   1. Note that we convert vitamin A in the form of pro-vitamin A (PVA) to retinol activity equivalents (RAE) assuming a 12:1 conversion factor of PVA to RAE (Institute of Medicine, 2001).

For agronomic biofortification, the average additional micronutrient content is based on published studies (either based on the absolute increase in the micronutrient contents if reported int the study or calculated based on the percent increase reported in the study. See Tables 6 and for agronomic biofortification effectiveness parameters for granular and foliar applications, respectively. Each of these parameters is modifiable by the user in the tool.

1. We add additional daily apparent micronutrient intake provided by LSFF or biofortification to baseline daily apparent micronutrient intake and recalculated the nutrient density of the household diet with LSFF or biofortification (that is, we divide total daily average apparent micronutrient intake with LSFF or biofortification by total daily average apparent energy intake, multiplied by 1000 to express the nutrient density per 1,000 kcal).
2. We compare the household nutrient density with LSFF or biofortification to the critical nutrient density of an adult female to classify the household diet as adequate or inadequate to meeting micronutrient requirements of an adult female with the micronutrient intervention, assuming energy requirements are met. These estimates are then summarized, accounting for survey weights, at national and subnational levels to generate estimates of the prevalence of inadequacy of the focus micronutrient with LSFF or biofortification.
3. For each year of the 10-year modeling time horizon, we subtract the prevalence of inadequacy with LSFF or biofortification from the baseline prevalence of inadequacy to estimate effective coverage of the micronutrient intervention.
4. For micronutrients with a tolerable upper intake level (UL), we compare household nutrient density with LSFF or biofortification to the critical upper density of an adult female to classify the household diet as providing less than or above the UL threshold for an adult female. These estimates are then summarized, accounting for survey weights, at national and subnational levels to generate estimates of the prevalence of high intakes with LSFF or biofortification.
   1. Note that the UL for vitamin A applies only to preformed retinol, and the UL for folate applies only to synthetic folic acid.
   2. Also note that the critical upper density is calculated as the UL of a non-pregnant, non-lactating adult female 18-30 year of age divided by the energy requirements of a non-pregnant, non-lactating adult female 18-30 years of age, multiplied by 1,000.

Table 5. Biofortification (via crop breeding) effectiveness parameter calculations

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | **Micronutrient content in non-biofortified variety** | | **Average micronutrient content in biofortified variety** | | **Additional micronutrient content in biofortified variety** | |
| **Country** | **Crop** | **Micronutrient** | **Micronutrient contents units** | **Value** | **Source** | **Value** | **Source** | **Value** | **Source** |
| Ethiopia | Maize | Vitamin A | mcg RAE per g | 0 | West African FCT, item 01\_004 | 3.1 | (1) | 3.1 | Calculation |
| Ethiopia | Sweet potato | Vitamin A | mcg RAE per g | 0.05 | West African FCT, item 02\_022 | 12.0 | (2) | 11.9 | Calculation |
| Malawi | Maize | Vitamin A | mcg RAE per g | 0 | Malawi FCT, item MW01\_0038 | 0.55 | (3) | 0.6 | Calculation |
| Malawi | Sweet potato | Vitamin A | mcg RAE per g | 0.02 | Malawi FCT, item MW01\_0065 | 5.83 | (4) | 5.8 | Calculation |
| Malawi | Beans | Iron | mg per g | 0.07 | Malawi FCT, average of items MW02\_0004, MW02\_0007, and MW02\_0017 | 0.09 | (5) | 0.02 | Calculation |

Sources:

(1) Average content of released varieties according to HarvestPlus (https://bcr.harvestplus.org/varieties\_released/country?id\_country=71&country\_name=Ethiopia) and assuming 12:1 conversion ratio of pro-vitamin A (PVA) to retinol activity equivalents (RAE).

(2) Average content of released varieties according to HarvestPlus (https://bcr.harvestplus.org/varieties\_released/country?id\_country=71&country\_name=Ethiopia) and assuming 12:1 conversion ratio of pro-vitamin A (PVA) to retinol activity equivalents (RAE).

(3) Average content of released varieties according to HarvestPlus (https://bcr.harvestplus.org/varieties\_released/country?id\_country=134&country\_name=Malawi) and assuming 12:1 conversion ratio of pro-vitamin A (PVA) to retinol activity equivalents (RAE).

(4) Average content of released varieties according to HarvestPlus (https://bcr.harvestplus.org/varieties\_released/country?id\_country=134&country\_name=Malawi) and assuming 12:1 conversion ratio of pro-vitamin A (PVA) to retinol activity equivalents (RAE).

(5) Average content of released varieties in Rwanda according to HarvestPlus (https://bcr.harvestplus.org/varieties\_released/country?id\_country=184&country\_name=Rwandaa).

Table 6. Agronomic biofortification effectiveness parameters: granular application

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Micronutrient** | **Crop** | **Expected additional micronutrient content via agronomic biofortification** | **Units** | **Source** |
| zinc | millet | 0.004 | mg/g | Calculation based on Teklu, Gashu, Joy et al. (2023) |
| zinc | groundnut |  |  |  |
| zinc | maize | 0.002 | mg/g | Calculation based on Botoman, Chimungu, Bailey et al. (2022) |
| zinc | pigeon pea |  |  |  |
| zinc | rice | 0.002 | mg/g | Calculation based on Joy, Stein, Young et al. (2015) |
| zinc | teff | 0.007 | mg/g | Calculation based on Joy et al. (2015) |
| zinc | wheat | 0.004 | mg/g | Calculation based on Joy et al. (2015) |
| selenium | cowpea | 0.296 | mcg/g | Ligowe, Young, Ander et al. (2020) (average of 4C and T7) |
| selenium | groundnut | 0.711 | mcg/g | Ligowe et al. (2020) |
| selenium | maize | 0.209 | mcg/g | Ligowe et al. (2020) |
| selenium | pigeon pea | 0.017 | mcg/g | Ligowe et al. (2020) |
| iron | millet | 0.027 | mg/g | Calculation based on Teklu et al. (2023) |

Table 7. Agronomic biofortification effectiveness parameters: foliar application

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Micronutrient** | **Crop** | **Expected additional micronutrient content via agronomic biofortification** | **Units** | **Source** |
| zinc | maize | 0.004 | mg/g | Calculation based on Joy et al. (2015) |
| zinc | rice | 0.004 | mg/g | Calculation based on Joy et al. (2015) |
| zinc | wheat | 0.012 | mg/g | Zia, Ahmed, Bailey et al. (2020) |
| selenium | groundnut | 0.371 | mcg/g | Chilimba, Young. & Joy (2014) |
| selenium | maize | 0.100 | mcg/g | Chilimba et al. (2014) |
| selenium | soybeans | 0.768 | mcg/g | Chilimba et al. (2014) |

*Modeling cost-effectiveness in the MAPS tool*

When the user has estimated both the cost and effectiveness of a micronutrient intervention, they also able to generate estimates of the cost-effectiveness of the micronutrient intervention program over the 10-year time horizon. To estimate cost-effectiveness, the year-specific percent of households effectively covered (that is, the percent of households with inadequate intake of the focus micronutrient in the baseline (i.e., without intervention) scenario that achieve dietary micronutrient adequacy with the intervention) are converted to estimates of the annual number of households effectively covered. This requires introducing estimates of the projected number of households for each year of the 10-year time horizon.

We estimate the projected number of households by combining UN World Population Prospects population projections (United Nations, 2019) over the 10-year time horizon with estimates of average household size to project the number of households for each year of the 10-year time horizon. Specifically, we weight the national population projection in each year by the admin level 1 share of the national population (according to the most recent census data) to disaggregate the population projections to the sub-national level. Then, we estimate the number of households each year by dividing the sub-national projections by estimates of the average household size at each admin level 1 (typically according to the most recent Demographic and Health Survey or the most recent Household Consumption and Expenditure Survey). We then multiply the percent of households effectively covered in each year to the projected number of households in that year to estimate the number of households effectively covered in a specific year.

The cost-effectiveness of the intervention is then calculated as the 10-year sum of total annual costs divided by the 10-year total annual sum of households effectively covered, or:

**Interpreting and comparing cost-effectiveness estimates**

Section forthcoming.

**Limitations**

When using the modeled cost, effectiveness, or cost-effectiveness results generated using the MAPS tool cost-effectiveness module, it is important to keep the limitations of (and caveats associated with using) the underlying data sources in mind.

*HCES data*

Using household-level food consumption data to estimate the adequacy of the household diet without and with LSFF has several limitations (Adams, Vosti, Mbuya et al., 2022). Because the food consumption data are collected at the household level, it is not possible to generate estimates of individual-level food consumption and micronutrient intake without imposing assumptions about the intrahousehold distribution of food. In the MAPS tool, we assess apparent dietary micronutrient adequacy using the adult female equivalent method and assume that if the diet is adequate to meet the requirements of an adult female, it is likely adequate to meet the requirements of all household members. However, this does not mean that all household members are receiving an equitable share of the household’s total food consumption, so the micronutrient requirements of some household members may not be met even if the household diet is adequate to meet the requirements of a non-pregnant, non-lactating adult female.

Another limitation is that household food consumption data are typically collected using a closed food list that may include aggregate food items (e.g., fresh fish), which can error in the estimated micronutrient content of the food, and/or may be missing key foods needed to accurately characterize diets, capture all important sources of nutrients, and accurately estimate the potential for LSFF, biofortification, or agronomic biofortification to improve the micronutrient adequacy of diets. Related, foods consumed away from home are often inadequately captured in HCESs or are not captured at all. Estimates of household food consumption are typically based on the recall of one (or several) household members, so underreporting of foods consumed by individuals, particularly outside the home, is possible. Because foods consumed away from home are, in many low- and middle-income countries, an increasingly important source of nutrients, the inadequate accounting of foods consumed outside the home could lead to an underestimation of total nutrient intake and overestimation of the prevalence of inadequate apparent intake. If foods consumed away from home are fortifiable or biofortifiable foods, this will also lead to an underestimate of the impact of these interventions on the micronutrient adequacy of diets. Finally, because HCESs do no collect data on consumption of micronutrient supplements, our estimates of micronutrient adequacy do not account for supplement use.

*Cost data*

The default cost parameters used in the MAPS cost models are, to the extent possible, based on the best available data and information sources. However, there is undoubtedly some level of error in these parameters, as, for example, it was not possible to interview all wheat flour refineries to collect data on the costs associated with fortification at their facilities, so many of our estimates are based on interviews with one or two refineries and extrapolated to the entire industry. Likewise, information provided from a few government personnel about the activities and costs associated with, e.g., regulatory monitoring of LSFF programs were assumed to reflect the situation nationally. It is also possible that some of the activities included in our cost models may not be relevant, or some relevant activities may not be included (this may be especially true for ex-ante cost models that estimate the cost of hypothetical micronutrient intervention programs, making locally-specific data collection particularly challenging). As such, it is critical for users to carefully scrutinize each cost parameter for accuracy in their local context and to make changes where needed. Conducting sensitivity analyses around particularly uncertain parameters (described below) is also very important.

**Sensitivity analysis**

Assessing the influence of uncertainty is an important part of conducting a comprehensive cost-effectiveness analysis. When estimating the cost of a micronutrient interventions, there is typically some degree of uncertainty around most parameter values. However, some sources of uncertainty will typically be much more important than other sources. Key sources may include parameter values that have a large impact on the total cost estimate, for example uncertainty about the cost of micronutrient premix for LSFF or the incremental cost of a biofortified seed variety compared to a traditional variety. Or, if the cost estimates will be used to help allocate government resources, paying special attention to uncertainty in M&E costs would be important. There can also be uncertainly in estimated program impacts, and it is important to conduct sensitivity analyses around assumptions or uncertain parameter values that influence the impact, or effectiveness, of the intervention. In the context of estimating effective coverage in MAPS, this could include uncertainty around adherence with LSFF standards or framer adoption rates of biofortified crop production.

Ultimately, we hope to add functionality to the cost and effectiveness module of the tool to allow users to define and automatically conduct sensitivity analyses around the cost, effectiveness, and/or cost-effectiveness of each intervention they define. In the meantime, we urge all users to manually conduct sensitivity analyses after estimating the cost, effectiveness, or cost-effectiveness of an intervention by copying the primary intervention and adjusting key parameters up and/or down to reflect uncertainty, and re-estimating cost, effectiveness, and/or cost-effectiveness.

For cost estimates, this could begin by first identify key program cost drivers. Once these parameters are identified, data can be collected (e.g., time series data, if available) or assumptions made to establish ranges of uncertainty (e.g., plus or minus 25%) regarding the amounts of specific inputs (e.g., person-days), input prices/values (e.g., micronutrient fortificant prices, seed prices, wage rates, etc.), or other key sources of uncertainty. Then, in the copy of the primary cost model, these parameters can be ‘shocked’ by the estimated or assumed uncertainty, and the change in estimated costs noted and reported alongside the primary cost estimate.

For effectiveness estimates, it is important to identify key sources of uncertainty for a specific intervention scenario. For LSFF this could include the percent of a food vehicle that is fortifiable, the expected micronutrient loss from point of fortification to households, or expected adherence with fortification standards. For biofortification via crop breeding, key sources of uncertainty could include the expected micronutrient contents of the biofortified variety compared to the traditional variety. For agronomic biofortification, an important parameter to include in sensitivity analysis might be expected increase in the mineral contents of the edible portion of the crop as a result of mineral-enhanced fertilizer application. And for both types of biofortification, modeling uncertainty in farmer adoption rates may be important.

When there is more than one source of uncertainty or you are aiming to simultaneously assess the impact of uncertainty in both costs and impacts of an intervention, uncertainly can be group into best-case and worst-case scenarios to identify ranges of possible costs, effectiveness, and cost-effectiveness for a specific intervention.

Interpreting and using the results of sensitivity analyses can be challenging, but doing so can lend credibility to the results. For example, if the results of best-case/worst-case sensitivity analyses suggest that Program A will always be more cost-effective than Program B, this can lend confidence to choosing Program A. On the other hand, if a given program under- or out-performs another depending on sensitivity analyses, this may leave decision-makers with doubts regarding which program to choose. Ultimately, it is up to the users of the evidence generated in the MAPS tool cost and effectiveness module to decide how much uncertainty they are comfortable with, but it is important to be transparent about uncertainty and integrate it into your economic evaluations using sensitivity analysis.

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