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Prioritizing Countries for Biofortification Interventions: Biofortification Priority Index Second Edition (BPI 2.0)

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HarvestPlus
Better Crops • Better Nutrition

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Contents

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Abstract

Approximately two billion people suffer from micronutrient malnutrition, also known as hidden hunger. Biofortification, a nutrition-sensitive agricultural intervention is one proven solution that can work alongside other complementary interventions including fortification, supplementation, and other dietary diversification strategies. Biofortification uses conventional plant breeding methods to increase the densities of vitamin A, iron and zinc in staple food crops. To determine where and in which crop-micronutrient combinations to invest, HarvestPlus developed the Biofortification Priority Index (BPI) in 2013. This paper is the second edition of the BPI using updated data for 128 countries in Africa, Asia, and Latin America and the Caribbean; improves upon the methodology; and includes an additional eleven crop-micronutrient combinations. The BPI ranks countries according to their suitability for investment in biofortification inventions to be used by stakeholders with differing objectives. The BPI is calculated based on three subindices: production, consumption, and micronutrient deficiency using country-level data. Data for the production and consumption subindices is primarily sourced from the Food and Agriculture Organization of the United Nations, while the micronutrient subindex's data comes from the World Health Organization. Results show that Africa and South Asia remain the highest priority regions for the introduction of biofortified crops, globally. Among the primary crops, vitamin A crops — vitamin A maize, vitamin A cassava, and vitamin A orange sweet potato — are predominately most suitable in Africa south of the Sahara. Irons beans are suitable in Latin America and the Caribbean region, as well as South Asia and Africa south of the Sahara while iron pearl millet is most suitable in countries of the Sahel region of Africa and South Asia. Zinc wheat is predominantly suitable in North Africa and Asia while zinc rice is most suitable in South and Southeast Asia. Finally, zinc maize is generally most suitable in Africa south of the Sahara and Central America.

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1. INTRODUCTION

The Scourge of Hidden Hunger

From 1990 to 2016, the total burden of nutritional deficiencies measured in Disability-Adjusted Life Years (DALYs) fell by 12.7 percent (Hay et al., 2017), while from 2006 to 2016, the number of years of life lost (YLL) to these deficiencies fell by 24.1 percent (Naghavi et al., 2017). Despite this significant progress, the global burden of nutritional deficiencies — commonly referred to as "hidden hunger" — was estimated at nearly 61 million DALYs in 2016 (Hay et al., 2017). It is estimated that more than two billion people — over 30 percent of the world's population — still suffer from micronutrient deficiencies alone, illustrating the continued threat of hidden hunger on global public health (FAO, 2013; Kennedy et al., 2003). Micronutrient deficiencies leading to the greatest burden of disease include iodine, iron, vitamin A, and zinc (FAO, IFAD, and WFP, 2015; Black et al., 2013).

Hidden hunger impairs proper physical and cognitive growth and development in children, limits normal physical and mental function in adults, and increases the vulnerability or exacerbation of infectious disease (WHO, 2019a). In addition to potentially life-long, negative health impacts or even death, micronutrient malnutrition can also lead to a lifetime of income losses as individuals are unable to capitalize on economic opportunities (Bryce et al. 2003; Alderman et al., 2006). On a global scale, hidden hunger is estimated to cost the world $3.5 trillion a year (WHO, 2016a).

Cognizant of the impact of hidden hunger on the development of people and countries for generations to come, the global community has set targets for alleviating this and all forms of malnutrition, including through Sustainable Development Goal (SDG) 2 which has targets related to ending hunger *and all forms of malnutrition* by 2030 (UNDP, 2018). In addition, the World Health Assembly (WHA) defined six targets for improving maternal, infant and young child nutrition by 2025 for stunting, anemia, low birth weight, childhood overweight, breastfeeding and wasting (WHO, 2019b). Furthermore, the Rome Declaration on Nutrition defined ten commitments — designed to ensure progress toward achieving the six WHA targets — that can be implemented through a Framework for Action related to ending hunger and all forms of malnutrition and were adopted at the Second International Conference on Nutrition in 2014 (WHO, 2019c). Given these targets and commitments, the United Nations (UN) General Assembly declared 2016–2025 as the UN Decade of Action on Nutrition in April 2016 (WHO, 2019c).

Despite these recent commitments and targets, nutritional deficiencies rank among the leading causes of the burden of disease, specifically in lower-income countries where access to a diverse diet is limited (Hay et al., 2017). The burden of hidden hunger is shouldered disproportionately by the most highly vulnerable group in the most vulnerable countries in the world: children under five years of age, adolescent girls and women of child bearing age, especially those in sub-Saharan Africa and South Asia (Ruel-Bergeron et al., 2015). These groups not only have higher biological needs for micronutrients (Black et al., 2013; Branca et al., 2015; Ruel-Bergeron et al., 2015; De-Regil et al., 2016), they also have limited access to micronutrient-rich foods, such as animal source foods. Even when available, these foods are often allocated to men or adolescent boys in the households (Gittelsohn and Vastine, 2003; Herrador et al., 2015). A disheartening prospect is that unless significant investments are made to meet the aforementioned targets, the underlying micronutrient shortfalls are projected to persist — if not grow — in developing countries for decades to come. A recent study by Nelson et al. (2018) showed that even under the most optimistic scenarios for widely shared economic growth, significant gaps in micronutrient availability — including for vitamin A, iron and zinc — are likely to remain in developing countries (Nelson et al. 2018). The negative effects of climate change on crop production and micronutrient content of commonly consumed staples, as well as on food prices are expected to exacerbate the problem, especially in Africa south of the Sahara (Nelson et al., 2018; Smith and Myers, 2018).

Biofortification: A Promising Solution

Over the past quarter century, there has been a steady and significant increase in the number and coverage of programs to alleviate micronutrient malnutrition. The key interventions have been mass fortification — the addition of vitamins and minerals to staple foods post-harvest — and supplementation programs, while other approaches include dietary diversity promotion and exclusive breastfeeding. More recently, biofortification has emerged as a promising complementary intervention to these other approaches (Bouis and Saltzman, 2017).

Biofortification uses conventional plant breeding methods to increase the density of vitamins and minerals in staple crops consumed as part of daily diets in Africa, Asia, and Latin America and the Caribbean (LAC). Biofortification's comparative advantage lies with its ability to reach the rural population, which often lacks access — in terms of geography and finances — to an all year around diverse diet as well as to other solutions to micronutrient malnutrition like supplements and commercially fortified foods (Bouis and Saltzman, 2017). Because the incremental costs of breeding for higher micronutrient density are expected to decline considerably over time, the long-term cost-effectiveness of biofortification is another advantage (Bouis and Saltzman, 2017; Lividini et al., 2018). Biofortification delivers micronutrients to rural areas, where the majority of lower-income, small-holder farmers that tend to grow and consume a staple-food based diet reside, and where rates of micronutrient deficiency are generally higher (Bouis and Saltzman, 2017).

Plant breeding for biofortification is conducted within the agricultural research partnership known as the CGIAR, while HarvestPlus, a program within the CGIAR, sets the micronutrient targets for breeding, coordinates the breeding efforts, and leads the generation and communication of evidence on the acceptability, efficacy, and effectiveness of biofortified crops (HarvestPlus, 2018). New staple crop varieties— bred to be more nutritious as well as high-yielding and climate-smart—are developed and made available for testing and release by national agricultural research systems (NARS), which ensure varieties are well-suited for specific agro-ecological zones and have the traits local farmers and consumers prefer (HarvestPlus, 2018).

Given that table salt is fortified with iodine and achieves high coverage globally, and that it most naturally occurs in marine sources, (i.e., not in staple crops), CGIAR breeders focus on vitamin A, iron, or zinc for biofortification in staple crops. Globally it is estimated that there are roughly 200 million, one billion, and 1.3 billion people at risk of vitamin A, iron, and zinc deficiencies, respectively (Saltzman et al., 2017). Target levels of vitamin A, iron, and zinc in biofortified crops are based on achieving delivery of 25-50 percent of the estimated average requirement (EAR) for daily intake of these micronutrients based on normal consumption patterns of young children and women of reproductive age (HarvestPlus, 2018). To set the targets, nutritionists conduct extensive research to understand the losses and retention of nutrients in biofortified crops given typical storage, processing and cooking practices (Boy and Miloff, 2009; Carvalho et al., 2012; De Moura et al., 2014; De Moura et al., 2015; Mugode et al., 2014; Taleon et al., 2017) and have quantified the absorption and bioavailability of these nutrients when consumed in biofortified crops (La Frano et al., 2014).

Biofortification has been shown to be effective for addressing both the underlying causes and outcomes of hidden hunger. For example, vitamin A orange sweet potato (OSP), cassava and maize have all been shown to have positive effects on vitamin A status, by increasing provitamin A (Palmer et al., 2016a; Palmer et al., 2018), serum retinol (Hotz et al., 2012; Talsma et al., 2016) and/or total body vitamin A stores (Haskell et al., 2004; van Jaarsveld et al., 2005; Low et al., 2007; Gannon et al., 2014) of women and children. Among young children, OSP has been shown to decrease the prevalence of diarrhea, which is the second leading cause of death among children under five (Jones and de Brauw, 2015), and vitamin A maize has been shown to improve eyesight among vitamin A-deficient children (Palmer et al., 2016b). Iron beans and pearl millet have been shown to improve iron status (Haas et al., 2016; Finkelstein et al., 2015) and cognitive performance (Murray-Kolb et al., 2017; Scott et al., 2018) among young women and adolescents. Finally, biofortified zinc rice has been shown to be as effective as post-harvest zinc fortification (Brnić et al., 2016) while absorption of zinc from biofortified zinc wheat has been shown to be significantly greater than non-biofortified wheat (Rosado et al., 2009; Signorell et al., 2019). In addition, regular consumption of zinc-biofortified wheat was found to reduce morbidity outcomes such as the number of days with pneumonia and vomiting in children, and with fever among their mothers (Sazawal et al., 2018).

Evidence from field day evaluations, monitoring surveys, and adoption studies to date shows farmers are willing to grow biofortified crops and that they like many of the production and consumption attributes of biofortified crops (Saltzman et al., 2017; Bouis et al., 2019). Likewise, consumer acceptability and willingness to pay studies have shown that consumers like the taste and attributes of biofortified foods and place a value on them (Birol et al., 2015; Oparinde and Birol, 2019). By the end of 2018, it is estimated that about 7.6 million farm households (38 million people) across 16 countries in Africa, Asia, and LAC were growing and benefiting from biofortified crops (HarvestPlus, 2019). Increasing the scale of delivery is essential not only for maximizing the benefits of biofortification but also for realizing its long-term cost-effectiveness. A recent review of ex-ante analyses by Lividini et al. (2018) showed that under most of the scenarios pertaining to coverage and cost, biofortification is highly cost-effective according to World Bank criteria for evaluating health interventions (World Bank, 1993). Exceptions typically involved scenarios where biofortification did not reach sufficient scale (Lividini et al., 2018). While ex-post evaluation cost-effectiveness data are still limited, results from Uganda have shown biofortification with OSP to be highly cost-effective (Arimond et al., 2010).

A Need for Targeted Interventions

The first wave of biofortified staple crops released were major staples including vitamin A maize, cassava, and sweet potatoes; iron beans and pearl millet; and zinc rice and wheat. Breeding for the biofortification of other staples (hereafter referred to as "secondary biofortified crops"), such as vitamin A bananas, plantains; and iron-zinc sorghum, Irish potatoes, lentils, and cowpeas, is ongoing, along with breeding for even-more nutritious and higher-yielding varieties of the major staples. By the end of 2018, over 300 varieties of 11 staple crops have been released for delivery to farmers in over 30 countries, while testing is ongoing in approximately 30 more (HarvestPlus, 2018).

HarvestPlus has been partnering with public, private and civil society organizations to deliver the planting material of biofortified crops to farming households in Africa, Asia and LAC. However, with roughly two billion people suffering from hidden hunger, biofortification must be scaled significantly to make a meaningful contribution to alleviating this burden. HarvestPlus' goal is to reach 20 million farming households with biofortified planting materials by 2020, and to catalyze the scaling up of biofortification to benefit one billion consumers globally by the end of 2030. Investment in biofortification is required by many partners, including country governments, donor institutions, CGIAR centers, private sector, civil society organizations and international financial institutions for biofortification to be sustainably scaled up, and for biofortified crops to become the new normal. Since resources are scarce, optimal investment decisions that will maximize the alleviation of hidden hunger as cost-effectively as possible can only be made if costs, benefits, and suitability (across time, geographies, and target groups) of all options including industrial fortification, supplementation, and dietary diversification approaches, are taken into consideration.

Methods and tools must be developed to guide decision-making so that finite resources can be employed effectively and efficiently. For biofortification, the effective and efficient use of resources involves targeting the development and delivery of biofortified seeds to areas where the biofortified crops will be produced and consumed by populations at greatest risk for micronutrient deficiencies. This paper describes the data and the analyses behind one such tool to guide decision-making: the Biofortification Priority Index (BPI 2.0 tool, https://bpi.harvestplus.org/). This paper builds upon the foundational methods, data and research utilized in the first BPI paper (hereon referred to as BPI 1.0, see Asare-Marfo et al., 2013). This second paper advances the original methodology, includes an additional eleven crop-micronutrient combinations available through six additional crops, and updates the analysis by using the most current data. The BPI can be used by governments, donors, researchers, program-implementers, and others interested in furthering the nutrition-sensitive agriculture intervention of biofortification to assess developing countries' benefit from micronutrient-enriched crops.

2. CONCEPTUAL FRAMEWORK AND METHODOLOGY

The BPI is a composite, crop and micronutrient-specific index which accounts for the intensity and level of supply and demand of a specific crop, in a country, as well as the micronutrient deficiency prevalence related to the micronutrient with which the specific crop can be enriched through conventional plant breeding.

This paper follows the same general methodology established in BPI 1.0 analysis (Asare-Marfo et al., 2013) with a few notable exceptions. First, a three-year average was used to construct production and consumption indices. Adjustments were also made regarding how imputations were handled in the case of missing observations and lack of secondary data sources. Finally, a change was also made to how quintiles are generated for prioritization categories. The details of these methodological changes will be outlined in the following sections. Using imputation, secondary sources, or triangulation, missing data was minimized with nine out of the 12 crops having ten or fewer missing values. BPI results for the primary biofortified crops are presented in section four of the paper, along with abbreviated results for the secondary biofortified crops.

Necessary Conditions for Biofortification Interventions

For the introduction of a biofortified staple crop to be considered a potentially impactful intervention in a country three conditions should be met:

1. The country must produce the biofortifiable crop and retain (i.e., not export) a significant proportion of production for domestic consumption, i.e., what is retained should not be primarily utilized for feed, seed, and industrial use.
2. The country's population must consume a significant portion of the biofortifiable crop from their own domestic production, i.e., a significant portion of consumption should not be sourced from imports.
3. The country's population suffers from significant prevalence of deficiency of the micronutrient (i.e., vitamin A, iron, or zinc) which can be addressed through biofortification of the crop.

Methodology

Description of the BPI Calculation

Each of the previously mentioned conditions contributes to a subindex in the overall BPI calculation. Condition number one contributes to the production subindex (PSI); condition number two contributes to the consumption subindex (CSI); and the third condition contributes to the micronutrient deficiency subindex (MDSI). Similar to the Human Development Index (HDI) (UNDP, 2013) and in keeping with the original BPI, a geometric mean is used as opposed to an arithmetic mean. This accounts for the complementary nature of the subindices as opposed to their substitutability since all three conditions (indices) are necessary for biofortification interventions to be successful. Due to the high and significant correlation between production and consumption of a crop, a geometric mean of the production and consumption subindices is calculated before calculating the overall BPI's geometric mean. Doing so ensures equal weight is given to the micronutrient deficiency subindex and the geometric mean of the production and consumption subindices. The final BPI is calculated as:

$$Biofortification\ Priority\ Index\ (BPI) = \sqrt{\sqrt{(Production\ Subindex * Consumption\ Subindex)} * Micronutrient\ Deficiency\ Subindex}$$

The calculation yields a BPI value between zero and one. For ease of use, the BPI is multiplied by 100 to obtain a final BPI score between zero and 100. Following this, each crop-micronutrient-specific BPI value is rescaled, using the formula outlined in Section 2.2.2, to obtain a range of zero to 100. A country which receives a BPI score of 100 for a specific biofortified crop is most suitable among the 128 countries included in the analysis for the introduction of that biofortified crop intervention. All non-zero BPI values[1] are then split into quintiles with the fifth quintile being "top priority". The remaining quintiles are labeled as follows: "high priority" (fourth quintile), "medium priority" (third quintile), "low priority" (second quintile), and "little priority" (first quintile). In BPI 2.0 the category called "no priority" is given to countries with a BPI score of zero, which results from scoring zero in either the production or consumption index.

[1] This represents a change from the methodology used in BPI 1.0 where countries with zero values were factored into the generation of quintiles.

Linear Transformation of the Subindices

The variables used to construct the three subindices are bound by different units of measurement. Therefore, for mathematical addition and aggregation of the variables into subindices and later into one index, they are converted into new variables without units of measurement (e.g., kilograms or hectares). Similar to the method employed in the HDI, all variables are converted to a common unitless measurement and rescaled to range from zero to one by employing the formula below.

$$Rescaled\ value\ (r) = \frac{actual\ value - minimum\ value}{maximum\ value - minimum\ value}$$

A heuristic approach is used to employ an arbitrary set of weights for the variables within the three subindices. Equations with the superscript, r, indicate that the variable has been rescaled using the aforementioned equation. The minimum and maximum values for each variable were either the minimum and maximum values among the observations for all countries in the dataset, or zero and 100, for variables expressing percentage values.

Definitions and Construction of the Subindices

Each index is specific to the crop-micronutrient combination in question at the national level for the 128 countries included in this analysis.

Production Subindex

The production subindex measures the intensity of production, or supply, of crop *j* within a specific country. Three variables are used to construct the production index:

1. The share of land area harvested for crop *j* in country *i*, out of total land area harvested for all crops in country *i*,
2. Per-capita area harvested of crop *j*, estimated through the land area allocated to crop *j* in country *i*, divided by the total population in country *i*, and
3. Export share, estimated through the percentage of total production of crop *j* in country *i* which is exported.

The formula used to calculate the production subindex is detailed below.

$$Production\ Subindex\ (PSI) = \left[\left(\frac{1}{2} * per\ capita\ area\ harvested\right)^r + \left(\frac{1}{2} * share\ of\ area\ allocated\ to\ crop\right)^r\right] * (1 - export\ share)^r$$

The first two variables measure the relative importance of crop *j* in country *i*'s agricultural sector. For crop development and delivery costs associated with the introduction of biofortified crops, utilizing economies of scale, the higher the quantity of land area allocated to crop *j*, the lower per hectare unit costs of seed multiplication and delivery efforts of crop *j* would be. The per capita area harvested variable measures factor intensity, i.e., the intensity of land allocated to crop *j* in relation to labor available, proxied by total population, in country *i*. Since agricultural land is a non-renewable asset that in most countries is scarce, and in the BPI, we evaluate only food crops, a country which devotes a large portion of its land to a particular crop in relation to its population size (i.e., a high land-to-labor ratio), signals that the crop is likely seen as important for the food supply/security of the country. Therefore, the crop will likely be given greater political support in the agri-food sector and enabling environment, for example through agricultural research, extension, and food companies. Thus, through this measure, the enabling (political) environment for improvement of a specific crop, (e.g., through biofortification) in a specific country can be indirectly assessed. If country *i* does not cultivate crop *j*, both the area share, and the land area allocated to crop *j* is zero, and the country is not suitable for biofortification of that crop.

Though a country may have high values for the area share and land-to-labor ratio variables for a specific crop, it does not necessarily mean that it is the best suited for biofortification of that crop, as some countries export a large portion of their production, leaving little for domestic consumption. To account for exports, the first two variables are corrected by the export share of national production. The variable export share for crop *j* is calculated as Export Share = exports / (production + imports).

Consumption Subindex

The consumption subindex measures the intensity of consumption of the specific crop within each country through per capita consumption of crop *j*.

Two variables are included in the consumption subindex:

1. Consumption per capita per year, and
2. Import dependency ratio (IDR) or Import share, (i.e. own production of crop *j)* must account for a significant portion of crop *j* consumed in country *i*.

The formula used to calculate the consumption subindex is detailed below.

$$Consumption\ Subindex\ (CSI) = (Consumption\ per\ capita\ per\ year)^{r} *\ (1 - IDR)^{r}$$

The higher the per capita consumption of crop *j*, the easier it is to increase an individual's micronutrient intake through biofortified crop *j*. The second variable, the Import Dependency Ratio, is used as a correction factor for the first variable to account for the proportion of a country's consumption of crop *j* supplied by imports. The import share is calculated as Import Dependency Ratio (IDR) = Imports / (Production + Imports – Exports). The import share is one if the production of crop *j* in country *i* is zero and the per-capita consumption of crop *j* in country *i* is positive. Given that biofortification targets rural farming families, holding all else constant, countries with a high import dependency ratio are lower priorities for introduction of biofortification interventions for that crop, compared to countries that produce most, if not all, of the domestic consumption of crop *j* themselves.

Micronutrient Deficiency Subindices

Three separate micronutrient deficiency subindices were created, one each for vitamin A, iron, and zinc. Each index measures the extent to which the population in country *i*, is deficient in the micronutrient of interest. Biofortified maize, cassava, sweet potato, and banana and plantain are enriched with vitamin A. Iron-biofortified crops include beans, pearl millet, cowpea, Irish potato, sorghum, and lentils. Rice, wheat, maize, cowpea, Irish potato, sorghum, and lentils are conventionally bred to have higher levels of zinc content.

The vitamin A micronutrient deficiency subindex is calculated using two variables. The first variable is the gold-standard estimated measurement of vitamin A deficiency — the national prevalence of children under five years of age with serum retinol levels less than 0.70 µmol per liter (WHO, 2009; WHO, 2017; Wirth et al., 2017). The second variable included in the subindex is the Disability-Adjusted Life Years (DALYs)[2] per 100,000 inhabitants in country *i* due to vitamin A deficiency (WHO, 2016b).

$$Vitamin\ A\ Deficiency\ Subindex\ (VADSI) = \left(\tfrac{1}{2} * Proportion\ of\ children\ with\ serum\ retinol < 0.7\mu mol/l\right)^r + \left(\tfrac{1}{2} * DALYs\ per\ 100{,}000\ inhabitants\ by\ VAD\right)^r$$

Two variables are also used to construct the zinc deficiency subindex. The gold standard data for zinc deficiency, serum zinc, is not available in most countries and therefore, the most often-used proxy variable is used in this analysis: the proportion of the population in country *i* at risk of inadequate zinc intake. Inadequate zinc intake was determined by comparing the estimated absorbable zinc content available in the national food supply using national food balance sheet data from FAO to the per capita physiological requirements using estimated physiological requirements for absorbed zinc and demographic data from UN estimates (Wessells et al., 2012). The second variable included is the national estimate of the prevalence of stunting in children under five years of age (UNICEF, WHO, World Bank, 2017).

$$Zinc\ Deficiency\ Subindex\ (ZDSI) = \left(\tfrac{1}{2} * Proportion\ of\ population\ at\ risk\ of\ inadequate\ zinc\ intake\right)^r + \left(\tfrac{1}{2} * prevalence\ of\ stunting\right)^r$$

Direct biochemical measures of iron deficiency, serum ferritin or transferrin receptor, are not available in most low- and middle-income countries. Therefore, in this BPI analysis and consistent with the BPI 1.0, the prevalence of anemia in preschool-aged children — widely available and commonly used proxy for iron deficiency — is used. Specifically, the variable for prevalence of anemia is defined as a hemoglobin level below 110 grams per liter (WHO, 2015). The second variable used is the number of Disability-Adjusted Life Years per 100,00 inhabitants in country *i* by iron-deficiency anemia (WHO, 2016b).

$$Iron\ Deficiency\ Subindex\ (IDSI) = \left(\tfrac{1}{2} * Proportion\ of\ children\ with\ Hb < 110g/l\right)^r + \left(\tfrac{1}{2} * DALYs\ per\ 100{,}000\ inhabitants\ by\ IDA\right)^r$$

In each micronutrient subindex, the two variables used are correlated with one another. For example, the estimated prevalence of inadequate zinc intake is correlated with the prevalence of stunting in children under five years of age (Wessells et al., 2012). However, since the two variables included in each subindex provide different pieces of information, calculation of the indices based on both variables is preferred.

Land Area and Population Weighted BPI Calculations

The subindex calculations in the BPI intentionally avoid including variables that measure a country's size in absolute terms, such as through quantity produced, land area harvested, the size of the population, or

[2] Disability-Adjusted Life Years (DALYs) estimated by the World Health Organization, is the estimated disease burden on a population. Specifically, DALYs are the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability (http://www.who.int/mental_health/management/depression/daly/en/) .

the total amount of food consumed. This is done to measure a country's suitability for biofortification irrespective of its land size or population.

However, including weighting variables may prove useful for different stakeholders, depending on their goals and definition of "impact". Impact to one stakeholder may be defined by the absolute number of vulnerable people reached or the number of DALYs saved through biofortification while to another, impact may be based on the largest land area sown to a biofortified crop or the largest quantity of a biofortified crop produced. Therefore, two alternative indices are calculated, as shown below, that account for absolute land area and size of biofortification's target population. In the equation below, *A* is a weight measuring the size of a country in relation to all countries included in this analysis and is scaled between zero and one.

$$BPI\ weighted = (BPI * A)^r * 100$$

The first weighted BPI calculation incorporates biofortification's target population and is therefore referred to as the "population-weighted BPI". The target population for biofortification is women of child-bearing age (15–49 years), and children under five years of age living in rural areas. The second weighted BPI, the "land area-weighted BPI", considers the relative importance of a country's production of a crop among the 128 countries used in this analysis, measured through the land area harvested for the specific crop. After rescaling, the resulting figures that are between zero and one are then multiplied by a factor of 100. These weighted BPI results for each crop-micronutrient combination are then comparable to the unweighted BPI results for the same crop-micronutrient combination.

3. DATA

The primary source of data for the analysis was FAOSTAT. As in BPI 1.0, the "dry beans" and "millet" categories were used as proxies for the bean varieties targeted for biofortification and pearl millet, due to data limitations. However, the bean types targeted for biofortification comprise the majority of the "dry bean" data for most countries and the pearl millet targeted for biofortification comprises the majority of the "millet" data (Asare-Marfo et al., 2013). In this analysis, to accommodate 11 additional crop-micronutrient combinations, data for area harvested, production, and per capita consumption were added for an additional six crops relative to BPI 1.0: banana, plantain[3], cowpea, Irish potato, sorghum, and lentil. Deviating slightly from the approach used in BPI 1.0 (in which data from the most recent single year were used), three-year averaged data were used for all variables included in the production and consumption subindices in BPI 2.0. A three-year average was used to account for and smooth any seasonality or shocks that a country may have experienced in their agricultural sector. Also, all variables included in this analysis were updated to the most recent years available in FAOSTAT. We used a yearly commodity balance sheet model to evaluate and balance all measurable supply and demand factors within a country and used the most recent data that were available across all variables of interest at the time of analysis — 2011, 2012, and 2013.

[3] Banana and plantain both belong to the *Musa* genus though vary at the species level. Since plant breeding efforts are similar among banana and plantain, CGIAR breeders often consider them as one crop. However, in this analysis, they are treated as two separate crops as FAOSTAT collects and provides data for them separately.

Included in this analysis are 128 countries: 52 countries from Africa, 44 from Asia, and 32 from Latin America and the Caribbean. In keeping with BPI 1.0 analysis, Japan, South Korea, and Israel, along with all high-income Organization for Economic Cooperation and Development (OECD) member countries, were excluded. Three OECD member countries (Mexico, Chile, and Turkey) were included in the analysis because they are not categorized as high-income countries according to the World Bank. Additionally, due to missing data for most variables, Western Sahara and the Bahamas were excluded from the analysis. The full list of 128 countries included in the analysis are included in the Appendix; South Sudan was added to the country list from BPI 1.0 following its formation in 2011. An overview of data sources is shown in Table 1.

Table 1: Variables used in calculating the unweighted and weighted BPIs

Subindex	Variable Name	Variable Explanation	Main Data Source and Year
Production Subindex	Share of area harvested (%)	Total area harvested of a specific crop (ha)/total agricultural land of a country (ha)	FAO 2011, 2012, 2013 average
	Per-capita area harvested (ha)	Total area harvested of a specific crop (ha)/total population in the country	FAO 2011, 2012, 2013 average
	Export share (%)	If Production greater than 0: Export share = Exports/(Production + Imports); otherwise export share is 0%	FAO 2011, 2012, 2013 average
Consumption Subindex	Per-capita food consumption	Per-capita food supply (kg/year)	FAO 2011, 2012, 2013 average
	Import Share (%)	If Production greater than 0: Import share = Imports/(Production+ Imports-Exports); otherwise import share is 100%	FAO 2011, 2012, 2013 average
Micronutrient Deficiency Subindices	**For vitamin A**		
	Serum Retinol < 0.7umol/l	Proportion of preschool-age children with retinol < 0.7umol/l	WHO 2009/2017; Wirth et al. 2017
	DALYs VAD	DALYs lost per 100,000 inhabitants to VAD	WHO 2016
	For iron		
	DALYs IDA	DALYs lost per 100,000 inhabitants to IDA	WHO 2016
	Hb<110g/l	Proportion of preschool-age children with Hb<110 g/l	WHO 2015
	For zinc		
	Inadequate Zinc	Percentage of population at risk of inadequate zinc intake	Wessels et al. 2012
	Stunting Zinc	Prevalence of stunting among children age 6-59 months	UNICEF, WHO, World Bank 2017
Population Weighted	Share of rural target population	Rural target population (women age 15–49 and children under five years) in country/ target population "globally"	UNDESA 2017 (for 2011, 2012, 2013 data)
Land Area Weighted	Share of crop area	Total area harvested of a specific crop in a given country (ha)/total area harvested of a specific crop "globally" (ha)	FAO 2011, 2012, 2013 Average

Production Data

The three variables used in the production subindex are built from six different indicators. The six indicators are, for the crop of interest: area harvested, production, total imports, total exports, total land area cultivated and total population for each country of interest. All variables except population were sourced from FAOSTAT for 2011, 2012, and 2013.

The United States Department of Agriculture Foreign Agricultural Service Division's Production, Supply, and Distribution Database (USDA, 2013), or USDA FAS PSD, was used to address missing data from FAOSTAT. This database was used to fill in missing data for the variables area harvested, production, import, and exports for maize, millet, rice, sorghum, and wheat[4], taking care to ensure that different crop categories were not mixed, (i.e., "crop" versus "crop and products").

Other sources utilized to address missing production data included the Food Fortification Initiative (FFI, 2013) database for rice, maize, and wheat; individual country's national agricultural statistics reports; and in some cases, United States Agency for International Development (USAID) reports, when measurements and reporting were the same as FAO's method.

Consumption Data

The two variables included in the consumption subindex are calculated from four indicators, all of which are sourced from FAOSTAT for 2011, 2012, and 2013. The first variable is food supply quantity measured as kg/capita/year, a proxy for per capita consumption. The following three variables are used to calculate the import share for a country: production, imports, and exports of the crop of interest.

Similar to the production section, USDA FAS PSD and FFI data were used to fill missing gaps in FAOSTAT's consumption data. Only data with a value of zero were utilized from USDA FAS PSD. This is because the data reported does not disaggregate that which is used as "Food" from that used for "Seed", and/or "Industrial Use."

Micronutrient Deficiency Data

Since figures are not reported annually, the data utilized for the micronutrient deficiencies subindices do not follow the same three-year average. Instead, the data used are the most recently available estimates for each variable of interest. Data for serum retinol in preschool-aged children were mostly sourced from the World Health Organization (WHO) (WHO, 2009; WHO, 2017), Wirth et al. (2017), and Galacia et al. (2016). In some instances, Ministry of Health data from specific countries were sourced (Brazil MOH, 2009; Zhao, 2008; República Dominicana, 2014; Freire, 2013; Pérez, 2012; Cediel, 2015; and Jordan MOH, 2010).

Data on DALYs for vitamin A deficiency and iron-deficiency anemia were obtained from WHO (2016b) (reporting on 2015 data). Data on the prevalence of anemia in preschool aged children came from the WHO's 2015 report of the global prevalence of anemia in 2011 (WHO, 2015). Inadequate zinc intake data were sourced from Wessells et al. (2012) while the prevalence of stunting data came from a joint UNICEF, WHO, World Bank 2017 report.

[4] Data for other crops are not included in this database.

Population Data

For the population-weighted BPI analysis that scales the BPI by biofortification's target population (women of child-bearing age and children under five years of age living in rural areas), several population variables were used. These variables include total country population, rural population within the country, the number of children under five years of age (both sexes), and the summation of females aged 15 to 49. All population data were sourced from the United Nations Department of Economic and Social Affairs Population Division's *World Population Prospects: The 2017 Revision* (UNDESA, 2017). In line with production and consumption data, a three-year average of 2011, 2012, and 2013 for each variable of interest was used.

Land Area Data

Data for the land area-weighted BPI calculation does not require additional variables except for the creation of a "global" land area harvested of a specific crop of interest. The "global" land area used in the analysis is the summation of the land area dedicated to the crop of interest for the 128 countries included in the analysis. Therefore, this new variable relies upon the variable included in the production data section, land area harvested for a specific crop in a country.

Dealing with Missing Observations

As mentioned above, data for this analysis came primarily from FAOSTAT for 2011, 2012, and 2013, the three most recent and consecutive years for which food balance data were completed and reported in FAOSTAT at the time this analysis was conducted in 2018. In total approximately 31,000 observations were utilized. For this analysis we sought to address as many missing observations as possible, to confirm the instances in which they were in fact values of zero, or to find additional sources or impute plausible values where they were not. Using additional data sources (discussed above), triangulation of data, and imputation, most values initially flagged as missing were addressed; as a result, nine crops had ten or fewer missing country observations, meaning that all necessary variables for analysis were accounted for at the country level. Detailed documentation regarding how missing data were addressed for each observation, including the use of substitute data sources, methods, and assumptions made to replace missing data, beyond what is discussed below, can be obtained from the authors upon request.

To address missing data, data triangulation was first used to confirm whether apparent missing values were in fact zero. For example, the FAOSTAT production and trade databases have many missing observations for particular crops, countries, and/or years. In most cases, these apparent missing values represent true zeros. To confirm true zeros, FAOSTAT's food balance sheet (FBS) database — which translates production and trade information into domestic supply and its various food and non-food uses — was consulted. Missing values were confirmed as true zeros when the variable was not included in the food balance equation or the value listed was a zero.

After addressing all possible missing values through triangulation, the next step involved consulting additional data sources. To address unresolved missing data for production-related variables, the USDA FAS PSD or FFI databases were consulted. To address consumption-related variables, the FFI and the USDA FAS PSD databases were also used. However, USDA FAS PSD data were only used for consumption-related variables when the value was zero due to the database not disaggregating “Food”, “Seed”, and “Industrial Use”.

Finally, after all triangulation approaches were exhausted and in cases where data sources for the exact variable in question could not be found, if possible, imputation was used to address the remaining missing values. While imputations were made for per capita consumption, yield, and land area, most imputations were made in this analysis for per capita consumption. To impute missing consumption values (in which no country-specific FBS information was available), the FBS equation from the region in which the country belonged was used. The regional FBS was used to calculate the stock variation as a percent of total domestic supply and food consumption as a percent of total domestic supply. These percentages were then combined with the country-specific production and trade data to “build” a country-specific FBS equation. The country-specific consumption was then determined from the equation. Dividing the country-specific consumption by the total country population produced a per capita consumption figure for the country.

For the production subindex, area harvested was imputed by dividing the production by the average yield for the crop of interest, or the regional level’s yield for the crop if the country level was not available.

Imputation of missing data for the micronutrient deficiency indicators was conducted in the same way as in BPI 1.0. The mean value of the respective income tercile of the sub-region was used if the region included at least nine countries with valid data (World Bank, 2016). The gross national income (GNI) per capita in purchasing power parity, as of 2015, was used as the income variable to determine terciles per region. If a region had fewer than nine countries with valid data, two groups were used opposed to three. If no GNI per capita data existed, then the mean value of the whole region was used to replace the missing observation.

4. RESULTS

This section presents results for the unweighted BPIs for each of the primary crop-micronutrient combinations for the top-ranking ten countries globally and within each region and is organized by vitamin A, iron, and zinc crops. Unweighted BPI results for secondary biofortified crops are also presented by vitamin A crops, iron crops, and zinc crops with the top five ranking countries globally reported. A top five-ranking regional list for secondary crops is available in the appendix. Maps for each crop-micronutrient combination are also included in the appendix. Following the unweighted BPI results, population- and land area-weighted BPIs for the primary biofortified crops are presented. Tables showing the top-ten ranking population- and area-weighted BPI results for secondary crops are included in the appendix.

BPI Results: Primary Crops Unweighted

Vitamin A Crops

Maize

Table 2 below shows the top ten countries, in absolute ranking, as well as by region, in terms of suitability for vitamin A maize interventions. Consistent with BPI 1.0 results, Africa has the most potential for tackling vitamin A deficiency through the introduction of vitamin A-biofortified maize. Consistent with the common Malawian saying, "Maize is life" (Smale, 1995), it is not surprising that Malawi remained the top-ranking country for VAM intervention when compared to results from the BPI 1.0 analysis in 2013. This is likely due to the high importance of maize in its agricultural system and the high consumption of this crop through foods such as *nshima* (a starchy porridge often made from maize) and *mgaiwa phala* (maize meal) (Enzama, 2016). Furthermore, vitamin A deficiency in Malawi is quite high with 59 percent of preschool-aged children deficient in this micronutrient (WHO, 2009).

Compared to BPI 1.0 rankings, Malawi remains the same at number one in Africa; however, the region's remaining top five ranking countries rotated amongst themselves. In Asia, Nepal overtook Timor-Leste as the top-ranked country for the region for vitamin A maize (VAM) interventions and Pakistan has now entered the top ten. Mexico remains the highest priority country for VAM in the LAC region. Guatemala, previously ranked as number two within the region, dropped in global rank from 32 to 36, while two others in the region's top ten, Bolivia and Nicaragua moved up in global rank by 13 and 21 spots, respectively.

Table 2: BPI Rankings for Top 10 Countries: Vitamin A Maize in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Malawi	100.0	Malawi	100.0	Nepal	48.5	Mexico	43.4
2	Zambia	77.4	Zambia	77.4	Timor-Leste	41.6	Paraguay	40.0
3	Angola	76.2	Angola	76.2	Bhutan	38.6	Haiti	39.4
4	Kenya	75.3	Kenya	75.3	North Korea	36.6	Bolivia	37.9
5	Benin	75.0	Benin	75.0	Laos	33.4	Honduras	36.0
6	Mozambique	68.0	Mozambique	68.0	Pakistan	31.0	Guatemala	34.4
7	Lesotho	67.1	Lesotho	67.1	Philippines	30.5	El Salvador	31.9
8	Togo	66.0	Togo	66.0	India	29.1	Brazil	31.8
9	Burkina Faso	64.6	Burkina Faso	64.6	Georgia	26.9	Nicaragua	30.6
10	Zimbabwe	62.0	Zimbabwe	62.0	Kyrgyzstan	26.0	Belize	26.5

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Cassava

As a main grower of cassava, Africa remains the priority region for having the best suitability for vitamin A cassava (VAC) as seen in Table 3 below. Compared to BPI 1.0 results, Angola is now ranked as most suitable for VAC. While Angola is not ranked number one for either the production subindex or the consumption subindex (though it is in the top five for both), it has the highest ranking on the vitamin A deficiency subindex. Mozambique, ranked as the number one country for VAC interventions in BPI 1.0, fell to rank number five in BPI 2.0.

Cambodia is the top ranked country in Asia and Laos is the second-ranking country, though globally they are ranked as 26 and 28, respectively. Compared to BPI 1.0, the top three countries rearranged with Timor-Leste previously ranked first. In the LAC region, Paraguay is most suitable country for VAC introduction, ranking 23rd globally.

Table 3: BPI Rankings for Top 10 Countries: Vitamin A Cassava in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Angola	100.0	Angola	100.0	Cambodia	26.6	Paraguay	37.3
2	Central African Republic	93.3	Central African Republic	93.3	Laos	24.0	Haiti	24.5
3	Ghana	79.8	Ghana	79.8	Timor-Leste	16.8	Brazil	20.0
4	Congo	77.1	Congo	77.1	Philippines	14.3	Colombia	18.7
5	Mozambique	77.0	Mozambique	77.0	Indonesia	13.9	Peru	16.9
6	Sierra Leone	76.1	Sierra Leone	76.1	Thailand	12.9	Bolivia	14.8
7	DRC	69.4	DRC	69.4	Myanmar	11.0	Dominican Republic	12.7
8	Benin	60.2	Benin	60.2	Viet Nam	10.8	Saint Lucia	10.8
9	Gabon	56.4	Gabon	56.4	Sri Lanka	10.8	Nicaragua	9.7
10	Madagascar	51.3	Madagascar	51.3	India	10.0	Dominica	7.7

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Sweet Potatoes

Among the top ten-ranking countries for the suitability of OSP (Table 4), nine are in Africa while one (Haiti, which ranks eighth) is in the LAC region. Malawi replaced Angola as the most suitable country for the introduction of OSP from BPI 1.0. Due to data constraints at the time, Malawi and Equatorial Guinea were not included in the BPI 1.0 analysis. Beyond the change in the number one and two spots, there is also slight movement among the top ten countries as Tanzania moved up two spots, Mozambique fell six spots from number four in BPI 1.0, and Burundi moved from spot number two in BPI 1.0 to seven in BPI 2.0 analysis.

As noted earlier, Haiti is the top-ranking country for OSP in LAC, rated as a "top priority" country. In Asia, North Korea ranks number one. Haiti was the number one ranked country in the LAC region in BPI 1.0 while Laos was ranked first in Asia in BPI 1.0.

Table 4: BPI Rankings for Top 10 Countries: Vitamin A Sweet Potatoes in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Malawi	100.0	Malawi	100.0	North Korea	11.9	Haiti	28.4
2	Equatorial Guinea	51.5	Equatorial Guinea	51.5	Laos	11.6	St Vincent & the Grenadines	13.2
3	Angola	42.2	Angola	42.2	Timor-Leste	11.5	Jamaica	11.6
4	Tanzania	33.6	Tanzania	33.6	China	11.1	Dominica	10.6
5	Sierra Leone	32.5	Sierra Leone	32.5	Philippines	8.5	Peru	8.0
6	Uganda	31.1	Uganda	31.1	Viet Nam	7.3	Paraguay	7.3
7	Burundi	30.1	Burundi	30.1	Cambodia	6.7	Uruguay	7.3

8	Haiti	28.4	Madagascar	25.7	Indonesia	5.8	Dominican Republic	5.9
9	Madagascar	25.7	Mozambique	25.0	India	5.4	Saint Lucia	5.7
10	Mozambique	25.0	Rwanda	23.8	Bangladesh	5.2	Antigua & Barbuda	5.2

Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data

Iron Crops

Beans

Africa and LAC account for the top ten globally ranked priority countries for iron-biofortified beans (Table 5). Burundi and Rwanda reversed spots from BPI 1.0 with Burundi now the "top priority" country for iron beans out of the 128 countries included in the analysis. New countries to the top five global list in BPI 2.0 analysis are Togo (previously ranked sixth) and Uganda (previously eighth), replacing Benin and Myanmar.

Myanmar, North Korea, and Timor-Leste are the top three-ranking countries in Asia for iron biofortification of beans, all considered "high priority" investment opportunities. LAC is also well suited for investments in iron beans, as shown in Table 4 below with four of the top ten countries in the region considered "top priority". Nicaragua is the top-ranking country in the region, followed by Haiti, ranked eighth and tenth globally, respectively.

Table 5: BPI Rankings for Top 10 Countries: Iron Beans in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Burundi	100.0	Burundi	100.0	Myanmar	51.6	Nicaragua	68.8
2	Rwanda	98.7	Rwanda	98.7	North Korea	50.2	Haiti	64.5
3	Togo	90.3	Togo	90.3	Timor-Leste	49.6	El Salvador	57.9
4	Tanzania	79.0	Tanzania	79.0	India	42.2	Guatemala	57.6
5	Uganda	77.6	Uganda	77.6	Cambodia	37.2	Belize	46.1
6	Angola	72.2	Angola	72.2	Bhutan	31.0	Brazil	46.0
7	Kenya	71.6	Kenya	71.6	Kyrgyzstan	23.6	Honduras	44.5
8	Nicaragua	68.8	Mozambique	67.7	Viet Nam	16.6	Cuba	41.2
9	Mozambique	67.7	Chad	63.3	Turkey	15.9	Mexico	33.5
10	Haiti	64.5	Cameroon	62.2	Pakistan	15.9	Paraguay	32.8

Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data

Pearl Millet

Africa remains the priority region for the introduction of iron pearl millet as nine of the ten top-ranking countries globally are from the region (Table 6). Niger is the number one country for investment in iron-biofortified varieties of this crop, as in BPI 1.0. Mali moved up four spots from the BPI 1.0, while the rest of the top five countries remain the same. A new addition to the top ten list is Sudan, which was not included in the BPI 1.0 analysis due to missing data, and India, which moved up two spots.

India is the only country in Asia ranked as a "top priority" for pearl millet, ranking tenth globally. The crop is typically cultivated in arid areas, which is indicative of the climate of the remaining countries in the region. As no countries in the LAC region grow and/or consume pearl millet, all countries received a score of zero for production and/or consumption, resulting in "no" priority.

Table 6: BPI Rankings for Top 10 Countries: Iron Pearl Millet in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Niger	100.0	Niger	100.0	India	23.0	**None*	
2	Mali	65.9	Mali	65.9	Nepal	19.0		
3	Burkina Faso	59.6	Burkina Faso	59.6	Yemen	12.4		
4	Gambia	56.1	Gambia	56.1	North Korea	8.9		
5	Chad	54.1	Chad	54.1	Pakistan	8.9		
6	Senegal	44.8	Senegal	44.8	Myanmar	7.2		
7	Namibia	30.6	Namibia	30.6	Kazakhstan	4.5		
8	Nigeria	29.9	Nigeria	29.9	Afghanistan	2.9		
9	Sudan	26.1	Sudan	26.1	China	2.8		
10	India	23.0	Guinea-Bissau	18.0	Sri Lanka	2.8		

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Zinc Crops

Wheat

Asia is the priority region for investment in zinc wheat interventions, followed by North Africa (Table 7). Pakistan is the number one ranking country for zinc wheat, moving up from number five in BPI 1.0. Closely following Pakistan is Afghanistan, and then India and Azerbaijan. Tajikistan, ranked number one for zinc wheat in BPI 1.0, is now12th following a decrease in wheat production and increased wheat imports.

In Africa, Egypt and Morocco are the top two most suitable countries for zinc wheat. While countries do produce and consume wheat in the LAC region, compared to global rankings, the top-ranking countries in the region are a mixture of lower priority level categories.

Table 7: BPI Rankings for Top 10 Countries: Zinc Wheat in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Pakistan	100.0	Egypt	66.1	Pakistan	100.0	Uruguay	27.6
2	Afghanistan	90.2	Morocco	65.3	Afghanistan	90.2	Bolivia	25.4
3	India	78.6	Tunisia	49.4	India	78.6	Paraguay	24.7
4	Azerbaijan	75.2	Algeria	41.6	Azerbaijan	75.2	Argentina	21.0
5	Turkey	73.6	Ethiopia	38.4	Turkey	73.6	Mexico	16.7
6	Nepal	73.1	Libya	30.6	Nepal	73.1	Peru	14.8
7	Syrian Arab Republic	72.6	South Africa	29.2	Syrian Arab Republic	72.6	Brazil	12.7
8	Egypt	66.1	Rwanda	28.5	Iran	62.9	Chile	12.4
9	Morocco	65.3	Lesotho	25.5	Iraq	61.2	Ecuador	4.7
10	Iran	62.9	Zambia	23.5	Tajikistan	58.5	Honduras	4.1

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Rice

Moving up one spot from BPI 1.0, Bangladesh is now the top-ranked country for the introduction of zinc rice (Table 8). In Bangladesh, rice can be grown throughout the entire country and for much of the country, in all three cropping seasons. The top four countries remained the same, but traded places. Viet Nam, previously ranked number five is now tenth.

Sierra Leone and Guinea are the top-ranking countries for zinc rice interventions in Africa while much of the region's top ten list remains a "top" or "high" priority. While no country in LAC is ranked as "top priority", the majority of countries in the top ten for the region ranked as "high priority".

Table 8: BPI Rankings for Top 10 Countries: Zinc Rice in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Bangladesh	100.0	Sierra Leone	67.0	Bangladesh	100.0	Suriname	42.7
2	Laos	82.5	Guinea	59.9	Laos	82.5	Guyana	39.7
3	Cambodia	81.4	Madagascar	54.3	Cambodia	81.4	Nicaragua	29.5
4	Myanmar	73.5	Guinea-Bissau	49.9	Myanmar	73.5	Panama	29.1
5	Indonesia	71.0	Liberia	48.8	Indonesia	71.0	Ecuador	27.3
6	Sri Lanka	69.3	Mali	41.5	Sri Lanka	69.3	Dominican Republic	24.2
7	Sierra Leone	67.0	Comoros	38.3	Nepal	62.7	Peru	22.1
8	Nepal	62.7	Gambia	35.7	Viet Nam	58.5	Cuba	21.0
9	Guinea	59.9	Côte d'Ivoire	35.3	Thailand	57.8	Haiti	19.5
10	Viet Nam	58.5	Tanzania	30.5	India	57.5	Bolivia	18.9

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Maize

Similar to the VAM ranking, Malawi is also the top-ranking country for suitability for zinc maize due to its high production and consumption of the crop (Table 9). In Asia, four countries are ranked as being "top" priority with the rest falling into "high" and "medium" priority status. Therefore, much potential exists for zinc maize in addressing zinc deficiency in all regions for which biofortification is suited.

Table 9: BPI Rankings for Top 10 Countries: Zinc Maize in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Malawi	100.0	Malawi	100.0	Timor-Leste	40.4	Guatemala	47.2
2	Zambia	80.9	Zambia	80.9	Nepal	34.8	Nicaragua	35.1
3	Zimbabwe	76.0	Zimbabwe	76.0	North Korea	32.6	El Salvador	30.7
4	Guatemala	69.9	Tanzania	65.8	Bhutan	32.0	Honduras	30.3
5	Tanzania	65.8	Togo	64.5	Indonesia	27.4	Haiti	29.2
6	Togo	64.5	Mozambique	62.2	Laos	23.1	Mexico	27.7
7	Mozambique	62.2	Burkina Faso	60.1	Philippines	22.0	Belize	21.6
8	Burkina Faso	60.1	Lesotho	57.8	Georgia	19.5	Bolivia	19.9
9	Timor-Leste	59.9	Benin	56.7	Pakistan	17.5	Paraguay	19.3
10	Lesotho	57.8	Kenya	54.0	Cambodia	16.7	Venezuela	16.8

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Secondary Crops

With conventional breeding, most biofortified crops are bred for an increase in one specific micronutrient. However, for several crop-micronutrient combinations, the density of a second micronutrient is indirectly increased because of shared biochemical pathways. These include cowpeas, sorghum, lentil, and Irish potatoes. Iron is prioritized when breeding biofortified cowpeas, Irish potatoes, and lentils, however zinc concentration is also indirectly increased. In sorghum, zinc is the micronutrient which breeders prioritize, however the concentration of iron also indirectly increases. The BPI is not designed to compare multiple micronutrients within one crop across countries. Therefore, for cowpeas, sorghum, lentil and Irish potatoes, while these crops contain increases in both iron and zinc within the same varieties, comparisons are shown for each nutrient independently. Finally, these cases are distinguished from that of zinc maize vs. vitamin A maize in which zinc maize varieties are entirely distinguished from vitamin A maize varieties; maize is biofortified with *either* zinc *or* vitamin A.

Crops Biofortified with One Micronutrient

Banana and Plantains

Although banana and plantain are closely related crops, they are different species and were therefore treated separately in this analysis. Many more countries were found to produce bananas (87) compared to the production of plantains (43) of the 128 countries included in this analysis. The top five countries for each of the crops are all African countries as shown in Table 10 below, emphasizing the potential benefit to the region of investments in biofortification of these crops. Following the potential in African countries for vitamin A banana, is LAC with Dominica, Saint Vincent and the Grenadines, Haiti, and Grenada all ranking as "top priority" for the crop. In Asia, Laos was identified as most suitable for the introduction of vitamin A banana.

For vitamin A plantains, six LAC countries are considered "top" priority countries with Colombia and Peru ranking the highest within the region. Only three Asian countries produce plantains, with two of them — Sri Lanka and the Philippines — ranking as "top" priority countries for the introduction of the biofortified crop.

Table 10: Secondary Vitamin A Crops BPI Global Top 5 Country Rankings

Global Rank	Vitamin A Banana		Vitamin A Plantain	
1	Burundi	100.0	Gabon	100.0
2	Rwanda	97.7	Ghana	87.7
3	Angola	94.9	Côte d'Ivoire	73.6
4	Comoros	79.5	Uganda	70.1
5	Central African Republic	76.6	Cameroon	51.2

**Priority levels:* (dark blue) *= Top,* (blue) *= High,* (teal) *= Medium,* (light green) *= Low,* (light cyan) *= Little,* (beige) *= None,* (grey) *= No data*

Crops Biofortified with Two Micronutrients

Iron-Prioritized Multiple Micronutrient Crops

As cowpeas, also known as black-eyed peas, are predominately produced in Africa, it is not surprising that the top five-ranking countries, which can benefit from both the iron and zinc-biofortified micronutrient content, are in Africa. As shown in the table below (Table 11), the prioritization of cowpeas as they relate to iron yields the same top five countries as when they are prioritized based on their zinc content. In both cases, Niger is the number one ranked country. The top fifteen countries also remain the same, although some rearrange themselves. Outside of Africa, LAC shows promise with Haiti ranking eighth globally when prioritized based on iron deficiency and seventh for zinc deficiency. Myanmar shows the greatest potential suitability in Asia, ranking 15th globally for iron and 13th for zinc.

Table 11: Iron and Zinc Cowpea BPI Global Top 5 Country Rankings

Global Rank	Cowpea			
	Prioritized based on iron		Prioritized based on zinc	
1	Niger	100.0	Niger	100.0
2	Burkina Faso	60.4	Burkina Faso	61.9
3	Nigeria	47.3	Nigeria	44.3
4	Mali	39.4	Mali	35.7
5	Cameroon	25.8	Cameroon	31.8

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

BPI results for iron- and zinc-biofortified Irish potatoes show that there is potential throughout all regions with Africa, LAC, and Asia being represented in the top-five ranking countries globally (Table 12). Malawi ranks as the number one country for the introduction of biofortified Irish potatoes. While the top two countries remain the same for Irish potatoes when comparing its potential for iron and zinc, the remaining top-five countries differ. Bolivia ranks third globally when analyzing the iron potential followed by Kyrgyzstan and Kazakhstan. When comparing the potential suitability with the focus on zinc, Nepal, North Korea, and Lesotho round out the top five.

Table 12: Iron and Zinc Irish Potato BPI Global Top 5 Country Rankings

Global Rank	Irish Potato			
	Prioritized based on iron		Prioritized based on zinc	
1	Malawi	100.0	Malawi	100.0
2	Rwanda	82.1	Rwanda	89.3
3	Bolivia	77.5	Nepal	61.6
4	Kyrgyzstan	73.2	North Korea	52.6
5	Kazakhstan	70.1	Lesotho	50.4

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

The top-five ranking countries for iron and zinc-biofortified lentils are the same when iron is prioritized as they are with zinc prioritized (Table 13). In addition to Nepal, countries in Asia largely round-out the top five and top ten list except for Ethiopia (ranked fourth for both iron and zinc comparisons), Morocco (sixth for iron and seventh for zinc), and Ecuador (tenth for iron and eleventh for zinc). Beyond the top five countries, the remaining countries in the top fifteen are the same for the two prioritization perspectives, though some rearrange. This demonstrates that this crop is generally suitable for addressing multiple micronutrient deficiencies.

Table 13: Iron and Zinc Lentil BPI Global Top 5 Country Rankings

Global Rank	Lentil			
	Prioritized based on iron		Prioritized based on zinc	
1	Nepal	100.0	Nepal	100.0
2	Syrian Arab Republic	77.6	Syrian Arab Republic	68.2
3	India	50.4	India	41.4
4	Ethiopia	49.8	Ethiopia	39.7
5	Turkey	47.8	Turkey	39.5

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Zinc-Prioritized Multiple Micronutrient Crops

Driven by production and consumption of sorghum, the top-five ranking countries for the introduction of sorghum is the same when prioritized for either zinc or iron deficiency, although Sudan and Mali switch places (Table 14). While the top five-ranking countries do not change, there are some differences among the top fifteen ranking countries depending on which micronutrient is prioritized. Rwanda and Mozambique are included in the top fifteen when prioritization is based on zinc; Mauritania and Somalia replace them when iron is prioritized.

Outside of Africa, Yemen (ranked 11th based on zinc and 14th based on iron) and India (ranked 27th based on zinc and 15th based on iron) show the greatest potential in Asia. In LAC, El Salvador, and Haiti (ranked 17th and 25th, respectively, based on zinc and 21st and 24th, respectively, based on iron) show the greatest promise.

Table 14: Zinc and Iron Sorghum BPI Global Top 5 Country Rankings

Global Rank	Sorghum			
	Prioritized based on zinc		Prioritized based on iron	
1	Burkina Faso	100.0	Burkina Faso	100.0
2	Niger	97.0	Niger	99.4
3	Chad	92.3	Chad	92.1
4	Sudan	87.4	Mali	91.8
5	Mali	81.1	Sudan	91.5

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Weighted BPI Results

As discussed in the Methods section, the BPI has additionally been calculated with population and land area weights factored into the analysis. These two cases of weighting, by population and land area, can be utilized by stakeholders based on specific interests they have and how they define "impact". In the two tables below, the top ten countries, ranked globally for the primary biofortified crops, based on the population-weighted BPI and land area-weighted BPI, are presented. These results can be directly compared to the results presented in the above section to show how the inclusion of these weights may alter results. Population- and land area-weighted BPI results for the secondary 11 micronutrient-crop combinations are included in the appendix.

Population-weighted BPI Results

The population-weighted BPI considers the target population for biofortification of children under five and women of child-bearing age (15–49), living in rural areas. The weight given to each country for population is based on the country's share of the total "global" target population. (Global in this case is represented by the 128 countries included in this analysis.) As presented in the table below, the population-weighted BPI results look quite different than the unweighted BPI results for the primary eight biofortified crops. As expected, countries that have a greater population, like India and China, are prioritized in Asia; Nigeria and Tanzania are prioritized in Africa, while in LAC, countries like Mexico and Brazil rank higher.

The last row of the table highlights the percentage of countries included in the top-ten country ranking for the population-based BPI for the crop of interest that are among the top-ten ranking countries for the crop in the unweighted version of the BPI. Iron pearl millet and zinc wheat have the highest percentage of countries appearing in the two indices. Vitamin A and zinc maize have the least cross-over between the unweighted and population-weighted BPIs. The top-ranking country based on the unweighted BPI analysis for vitamin A maize, iron beans, and zinc maize do not maintain their top spots in the population-weighted version of the BPI. For example, Malawi, ranked as the number one country in the unweighted BPI for zinc maize falls to the 14th rank in the population-weighted BPI for the crop.

Table 15: Top 10 Ranking Countries for Population-weighted Primary Biofortified Crops

	Vitamin A			Iron		Zinc		
Global Rank	**Maize**	**Cassava**	**Sweet Potatoes**	**Beans**	**Pearl Millet**	**Wheat**	**Rice**	**Maize**
1	India	India	China	India	India	India	India	India
2	China	Nigeria	India	Tanzania	Nigeria	China	China	China
3	Nigeria	DRC	Nigeria	Uganda	China	Pakistan	Bangladesh	Indonesia
4	Ethiopia	China	Malawi	Kenya	Niger	Egypt	Indonesia	Nigeria
5	Pakistan	Indonesia	Tanzania	Ethiopia	Ethiopia	Bangladesh	Viet Nam	Pakistan
6	Kenya	Mozambique	Uganda	China	Pakistan	Ethiopia	Philippines	Ethiopia
7	Indonesia	Tanzania	Ethiopia	Myanmar	Burkina Faso	Afghanistan	Myanmar	Tanzania
8	Egypt	Uganda	Kenya	Pakistan	Sudan	Nepal	Pakistan	Kenya
9	Tanzania	Angola	Indonesia	DRC	Mali	Turkey	Nigeria	Philippines
10	DRC	Ghana	DRC	Indonesia	Chad	Iran	Thailand	DRC
% countries in unweighted BPI top 10	10%	30%	30%	30%	70%	70%	40%	10%

Land Area-weighted BPI Results

The second weighted BPI, the land area-weighted BPI, includes the relative importance of a country's land area allocated to a specific crop out of the total global (i.e., the 128 countries in this analysis) land area harvested for the crop. In Asia, India, China, Pakistan, and Bangladesh are prioritized. In LAC, Mexico and Brazil are ranked higher, while in Africa, Nigeria, and the Democratic Republic of the Congo (DRC) are prioritized.

The land area-weighted BPI results have more similarities to the unweighted BPI results than the population-weighted version. For example, vitamin A sweet potatoes land area weighted top ten ranking overlaps 70 percent of the time with the unweighted top ten ranking. For some crops such as zinc maize and vitamin A maize, the percentage of countries in the land area-weighted version of the BPI that are top-rated in the unweighted version are only 20 and 30 percent, respectively. Iron pearl millet has the most cross-over at 90 percent. The top-ranked countries in the unweighted BPI for all crop-micronutrient combinations except iron beans appear in the top-ten global country list for the land area-weighted BPI results.

Table 16: Top 10 Ranking Countries for Area-weighted Primary Biofortified Crops

Global Rank	Vitamin A			Iron		Zinc		
	Maize	**Cassava**	**Sweet Potatoes**	**Beans**	**Pearl Millet**	**Wheat**	**Rice**	**Maize**
1	China	Nigeria	Malawi	India	Niger	India	India	China
2	Brazil	DRC	China	Myanmar	India	Pakistan	Bangladesh	Mexico
3	Mexico	Angola	Nigeria	Brazil	Mali	China	Indonesia	Brazil
4	India	Mozambique	Tanzania	Tanzania	Burkina Faso	Kazakhstan	Thailand	Tanzania
5	Nigeria	Ghana	Uganda	Kenya	Chad	Turkey	China	Nigeria
6	Tanzania	Tanzania	Angola	Uganda	Nigeria	Iran	Myanmar	India
7	Malawi	Brazil	Madagascar	Angola	Sudan	Afghanistan	Viet Nam	Malawi
8	Kenya	Uganda	Burundi	Mozambique	Senegal	Morocco	Philippines	Indonesia
9	South Africa	Sierra Leone	Rwanda	Mexico	Gambia	Syria	Cambodia	South Africa
10	Mozambique	Madagascar	Haiti	Rwanda	Ethiopia	Iraq	Guinea	Kenya
% countries in unweighted BPI top 10	30%	60%	70%	60%	90%	70%	60%	20%

5. DISCUSSION AND CONCLUSIONS

In this paper, we presented the revised methodology and updated results for BPI 2.0. Data for this analysis came primarily from FAOSTAT for the years 2011, 2012, and 2013. Use of the FAOSTAT data to develop the BPI enables the BPI to be a powerful tool, given that the FAOSTAT production, trade and food balance databases provide a complete and consistent set of food system data that is inclusive of most countries in the world. In total approximately 31,000 observations were utilized for this analysis. The use of a three-year average of the most recent data for which food balance information was available for all countries for three consecutive years (i.e., 2011, 2012, 2013) should smooth any spurious results that may not represent a typical year, such as from bumper harvests, droughts or other shocks and conflicts. Additional future versions of the BPI should be calculated every five years to capture changing or emerging trends and allow for sufficient new data to be made available through FAOSTAT.

We sought to address as many missing observations as possible, to confirm the instances in which they were in fact values of zero, or to find additional sources or impute plausible values where they were not, so that the BPI was as complete, inclusive, and representative as possible. With the use of additional data sources, triangulation of data, and imputation, most values initially flagged as missing were addressed. As a result, nine crops had ten or fewer missing country observations, meaning that all necessary variables for analysis were accounted for at the country level.

As an example of how these additional steps benefited the resulting BPI 2.0, Malawi—not represented in the BPI 1.0 analysis due to data constraints—replaced Angola as the most suitable country for the introduction of OSP. In addition, we were able to better distinguish countries with true zero values from those with low values and have represented those as an additional category in the BPI 2.0 tool. This information is important for policymakers to know where biofortification has no application as opposed to low-priority application so as to not waste valuable resources. Detailed documentation regarding how missing data were addressed for each observation, including the use of substitute data sources, methods, and assumptions made to replace missing data (beyond what has been discussed) can be obtained from the authors upon request.

The results from BPI 2.0, as with BPI 1.0, provide a clear and concise guide for which countries to prioritize for biofortification interventions, development (breeding), and scaling. Not surprisingly, Africa and South Asia remain the highest priority regions. The highest ranked countries for each of the crop-micronutrient combinations come from Africa and South Asia: Malawi (vitamin A maize, OSP, iron and zinc Irish potato, and zinc maize), Angola (vitamin A cassava), Burundi (iron beans and vitamin A banana), Niger (iron pearl millet, iron and zinc cowpea), Pakistan (zinc wheat), Bangladesh (zinc rice), Gabon (vitamin A plantain), Burkina Faso (zinc and iron sorghum), and Nepal (iron and zinc lentil).

BPI 2.0 also provides a guide for which crops generally have comparative advantages in certain regions. Among the primary crops, vitamin A crops —maize, cassava, and OSP — are predominantly most suitable in Africa south of the Sahara (SSA) due to the high per capita production and consumption of these crops coupled with high vitamin A deficiency rates in this region (Figures 1-3, Appendix B). Iron beans are suitable in LAC (particularly Central America) as well as South Asia and SSA, especially in East Africa south of the Sahel region (Figure 4, Appendix B). Iron pearl millet is most suitable in countries of the Sahel region of Africa as well as South Asia (Figure 5, Appendix B). Zinc wheat is predominantly suitable in North Africa and West, Central, East, and South Asia (Figure 6, Appendix B) while zinc rice is generally most suitable in

South and Southeast Asia (Figure 7, Appendix B). Finally zinc maize shares a similar pattern with vitamin A maize and is generally most suitable in SSA and Central America (Figure 8, Appendix B). Among the secondary crops — which generally do not have the same coverage as primary crops — vitamin A banana and plantain are most suitable in Africa, though banana is suitable in parts of LAC and Asia as well (Figures 9 and 10, Appendix F). For iron-prioritized crops, iron and zinc-biofortified cowpeas are generally most suitable in Africa, while iron-zinc lentil is most suitable in Asia and iron-zinc Irish potato is suitable to address both iron and zinc deficiency in Africa and Asia. Iron-zinc Irish potato is also suitable in LAC, particularly Bolivia and Peru, for zinc deficiency (Figures 11-16, Appendix F). With zinc-prioritized crops, zinc and iron-biofortified sorghum is most suitable in Africa (Figures 17-18, Appendix F).

Variations that provide results based on weighting by population or harvested land area enable the interpretation of the results from multiple viewpoints. For example, either India or China ranks as the most suitable country for each of the primary crops when weighted by population (Table 13). Among the top three of the primary crops are India, China, Nigeria, Tanzania, DRC, Uganda, Pakistan, Bangladesh, and Indonesia. Weighting by land area brings new top countries into consideration. Again, among the top three from any of the primary crops are Brazil, Mexico, Angola, Malawi, Myanmar, Niger, and Mali, in addition to Pakistan, China, Nigeria, DRC, India, Bangladesh and Indonesia (Table 14).

Finally, while not specifically designed for prioritizing countries based on a collective set of biofortifiable crops, BPI 2.0, allows for identifying a food basket of biofortifiable crops to address multiple micronutrient deficiencies. For example, Malawi ranks as the "top priority" country for vitamin A maize, vitamin A OSP, zinc maize and zinc/iron Irish potato making biofortification a potentially powerful food-based strategy for addressing three major micronutrient deficiencies. Burundi (with iron beans and vitamin A banana) and Niger (with iron pearl millet and iron/zinc cowpea) also rank as top priorities for multiple crops making them especially suitable for a biofortified food basket. And a food basket would also be of high potential suitability in countries such as Haiti (with vitamin A OSP, iron beans, and zinc maize) and India, which ranks as the highest priority country for seven of the eight primary crop-micronutrient combinations when weighted by population. A multiple-biofortified crop approach is also cost-effective, as several of the fixed costs of introduction of biofortification (e.g., gaining country buy-in, inclusion of biofortification in policies and programs, and raising awareness among public, private, civil society and consumer/producer stakeholders) would be lower — perhaps even non-existent — with each new biofortified crop introduced in a country.

There are of course areas in which the BPI can be further improved or expanded. For example, currently the BPI is suggestive of high potential cost-effectiveness in priority countries, but this is not a given. Future iterations of the BPI may incorporate a cost subindex either from directly quantified costs or from a set of related cost indicators as is done with the World Bank's Ease of Doing Business Index (World Bank, 2019). In addition, applying useful geospatial data such as for the existence of roads or other infrastructure, water sources, agricultural extension offices etc., or also whether countries can benefit from adapting already existing biofortified varieties, may help inform a cost-related subindex.

The BPI also does not currently utilize supply and demand trends for crops or projections moving forward under various scenarios pertaining to changes in climate, population, and other factors that affect supply and demand of staples. Future iterations of the BPI may take these into account potentially from a model such as IFPRI's IMPACT model in order to consider the longer-term applicability of the BPI results available at the time (IFPRI, 2019). Disaggregating the contributions from trade and projecting trends in micronutrient deficiency will be important challenges for such analyses.

Per capita nutrient availability may serve as a useful proxy in such exercises. Nelson et al. (2018) showed micronutrient availability is likely to remain inadequate for key micronutrients in Africa and South Asia for years to come under various socioeconomic and climate change scenarios. With respect to climate change, Smith and Myers (2018) examined the potential for increased iron and zinc deficiency in future scenarios where crops are grown under atmospheric CO_2 concentrations of 550 ppm and found that up to 175 million additional cases of zinc deficiency are possible and that dietary iron could be reduced by morethan 4 percent in some of the regions most vulnerable to anemia. Based on current projections by Sulser et al. (IFPRI, 2017), per capita cereal consumption is expected to increase in South Asia and SSA through 2030, making biofortification a long-term sustainable strategy for addressing hidden hunger. In addition, food prices are projected to increase for meats, fruits, and vegetables faster than for cereals and pulses through 2030, making access to these other nutritious foods relatively more difficult over time (Sulser et al., 2015). However, the uncertain effects from climate change could affect cereal prices relatively more than other commodities (Sulser et al., 2015).

With respect to the global agricultural system of trade, it is important to highlight that the BPI prioritizes countries based on their potential for addressing micronutrient deficiencies from *domestically sourced* production and consumption of staple crops. Imports and exports are removed from supply and demand calculations within the subindices. This ensures biofortification is prioritized for countries that can address micronutrient deficiencies through their own domestic production. However other perspectives are important. For example, countries that are large producers of staple crops and significant suppliers of a region and/or export to developing countries with a high prevalence of micronutrient deficiency could be potentially useful targets for biofortification. Van Ittersum et al. (2016) illustrated that for Africa to achieve self-sufficiency in cereals by 2050, yield gap closure, as well as significant increases in cropping intensity and irrigation will be required but difficult to achieve, and that an increased dependence on imports to meet demand is likely. Sulser et al. (2015) also show that increases in per capita consumption of cereals by 2030 and 2050 are likely to be accompanied by corresponding increases in cereal imports (IFPRI, 2017). Therefore, future versions of the BPI considering trade networks will be valuable.

In addition, countries that can benefit from multiple complementary crops can provide greater coverage for addressing one micronutrient deficiency and/or that can address multiple micronutrient deficiencies using a biofortified food basket approach may be high priorities. Adapting the BPI to enable a food-basket approach and/or multiple micronutrient analysis would therefore be desirable. Finally, the BPI enables comparisons across countries for specific crop-micronutrient combinations utilizing country-level means. However, considerable variation in supply and demand of biofortifiable crops as well as micronutrient deficiencies likely exist in most countries. While these variations are explored in country-specific subnational BPI (SBPI) analyses conducted by HarvestPlus, such SBPI analyses do not permit making cross-country comparisons. Considering measures of inequality in the supply and demand of staple crops as well as micronutrient deficiencies might help account for important variations in distribution in future BPI versions.

Additional considerations for the BPI include reviewing indicators as more complete data becomes available to ensure that the most optimal indicators are used, such as accounting for the percentage of anemia estimated to come from iron deficiency. Future versions of the weighted BPI will also continue to be explored so that the BPI can appropriately accommodate different important perspectives. Finally, overlaying the availability of other hidden hunger interventions such as fortification using data from the global fortification data exchange to better identify and target countries for the most suitable intervention can be considered for a hybrid BPI tool.

Overall, the BPI 2.0 is a valuable tool which can inform decisions about where and which types of investments in crop biofortification are most effective to help alleviate micronutrient deficiencies. These decisions and corresponding investments would move us closer to achieving the Sustainable Development Goals and World Health Assembly targets pertaining to micronutrient malnutrition. While the BPI should not be the *only* tool utilized in decision-making strategies aimed at reducing micronutrient malnutrition (through biofortification or other interventions), it can be a *key* tool in identifying which crop-micronutrient combinations and which geographical locations are most suitable for biofortification.

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APPENDIX A

LIST OF COUNTRIES

Afghanistan	Gabon	North Korea
Algeria	Gambia	Occupied Palestinian Territory
Angola	Georgia	Oman
Antigua and Barbuda	Ghana	Pakistan
Argentina	Grenada	Panama
Armenia	Guatemala	Paraguay
Azerbaijan	Guinea	Peru
Bahrain	Guinea-Bissau	Philippines
Bangladesh	Guyana	Qatar
Barbados	Haiti	Rwanda
Belize	Honduras	Saint Kitts and Nevis
Benin	India	Saint Lucia
Bhutan	Indonesia	Saint Vincent and the
Bolivia	Iran	Saudi Arabia
Botswana	Iraq	Senegal
Brazil	Jamaica	Sierra Leone
Brunei Darussalam	Jordan	Singapore
Burkina Faso	Kazakhstan	Somalia
Burundi	Kenya	South Africa
Cambodia	Kuwait	Sri Lanka
Cameroon	Kyrgyzstan	South Sudan
Cape Verde	Laos	Sudan
Central African Republic	Lebanon	Suriname
Chad	Lesotho	Swaziland
Chile	Liberia	Syria
China	Libya	Tajikistan
Colombia	Madagascar	Tanzania
Comoros	Malawi	Thailand
Congo	Malaysia	Timor-Leste
Costa Rica	Mali	Togo
Côte d'Ivoire	Mauritania	Trinidad and Tobago
Cuba	Mauritius	Tunisia
Cyprus	Mexico	Turkey
Democratic Republic of the Congo	Mongolia	Turkmenistan
Djibouti	Morocco	Uganda
Dominica	Mozambique	United Arab Emirates
Dominican Republic	Myanmar	Uruguay

Ecuador	Namibia	Uzbekistan
Egypt	Nepal	Venezuela
El Salvador	Nicaragua	Viet Nam
Equatorial Guinea	Niger	Yemen
Eritrea	Nigeria	Zambia
Ethiopia		Zimbabwe

APPENDIX B

BPI MAPS FOR PRIMARY CROP

Figure 1: BPI Map for Vitamin A Maize

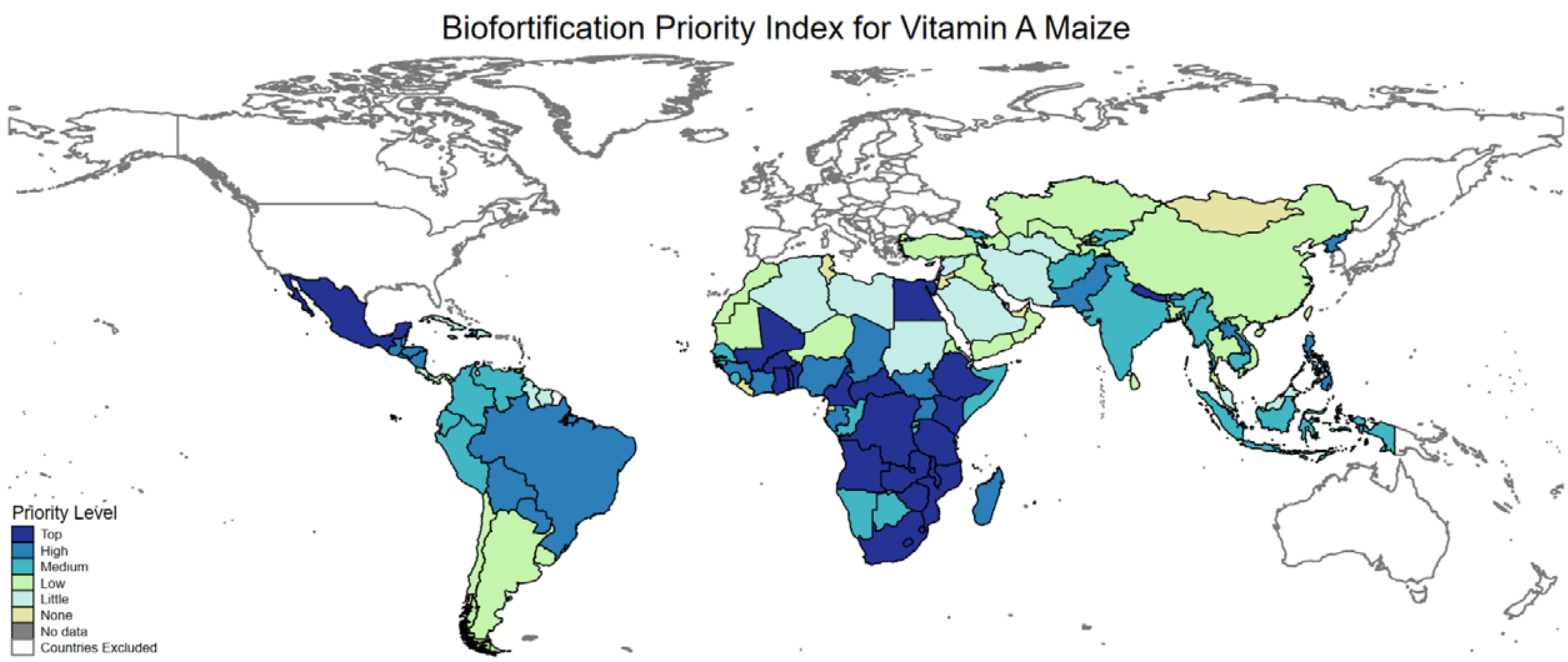


Figure 2: BPI Map for Vitamin A Cassava

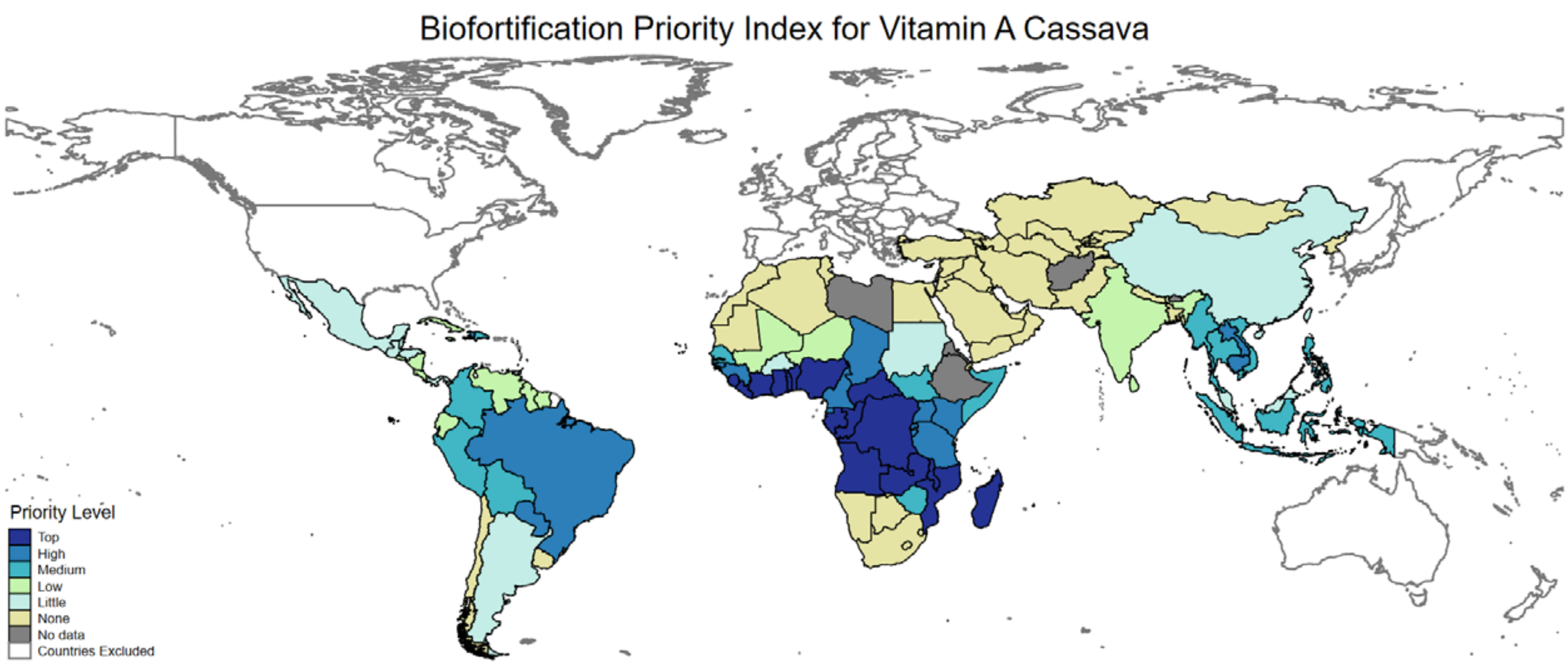


Figure 3: BPI Map for Vitamin A Sweet Potato

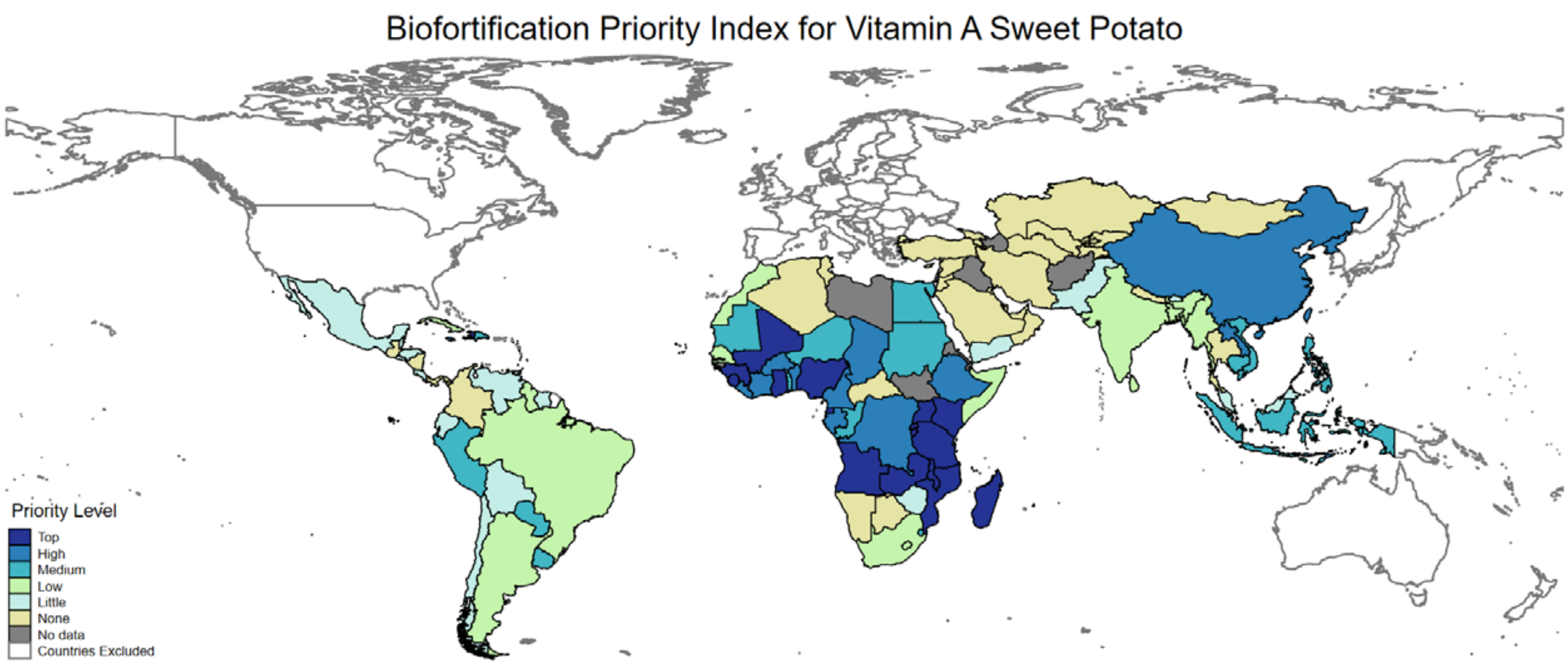


Figure 4: BPI Map for Iron Beans

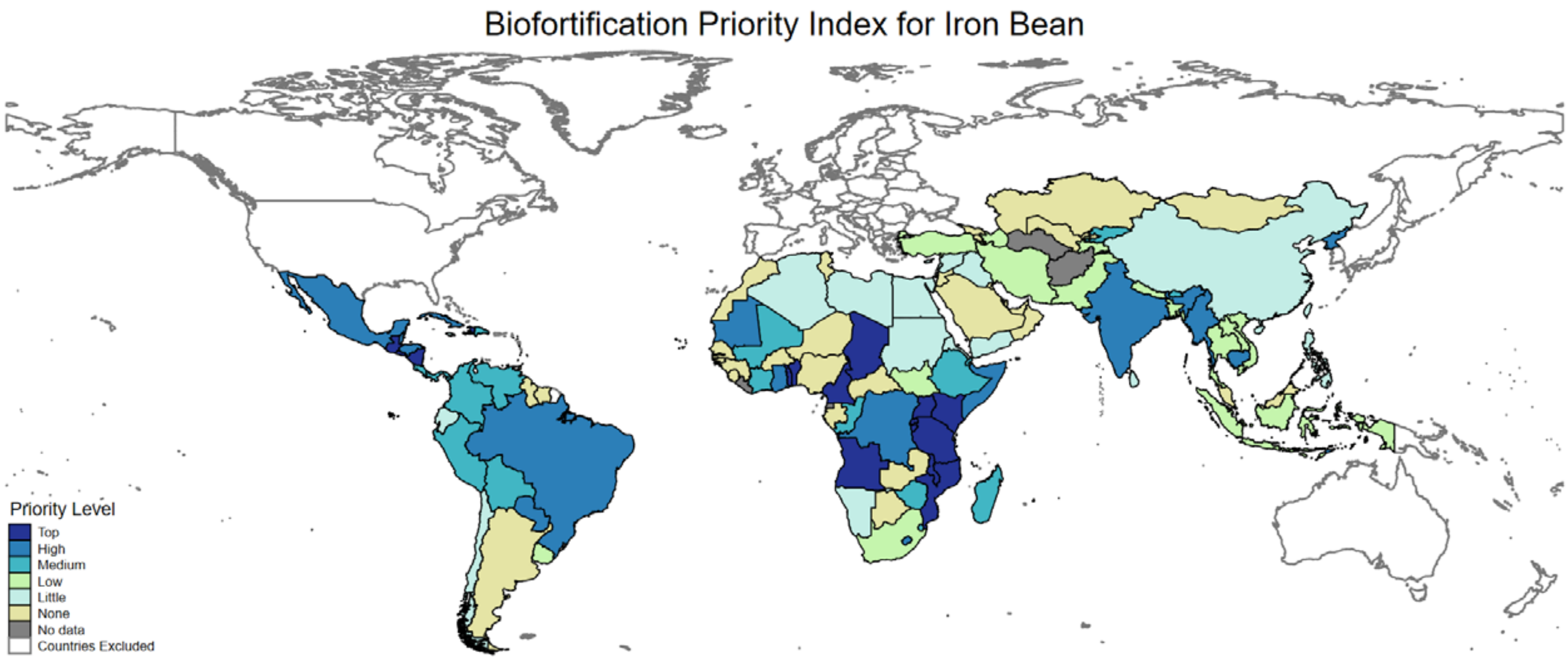


Figure 5: BPI Map for Iron Pearl Millet

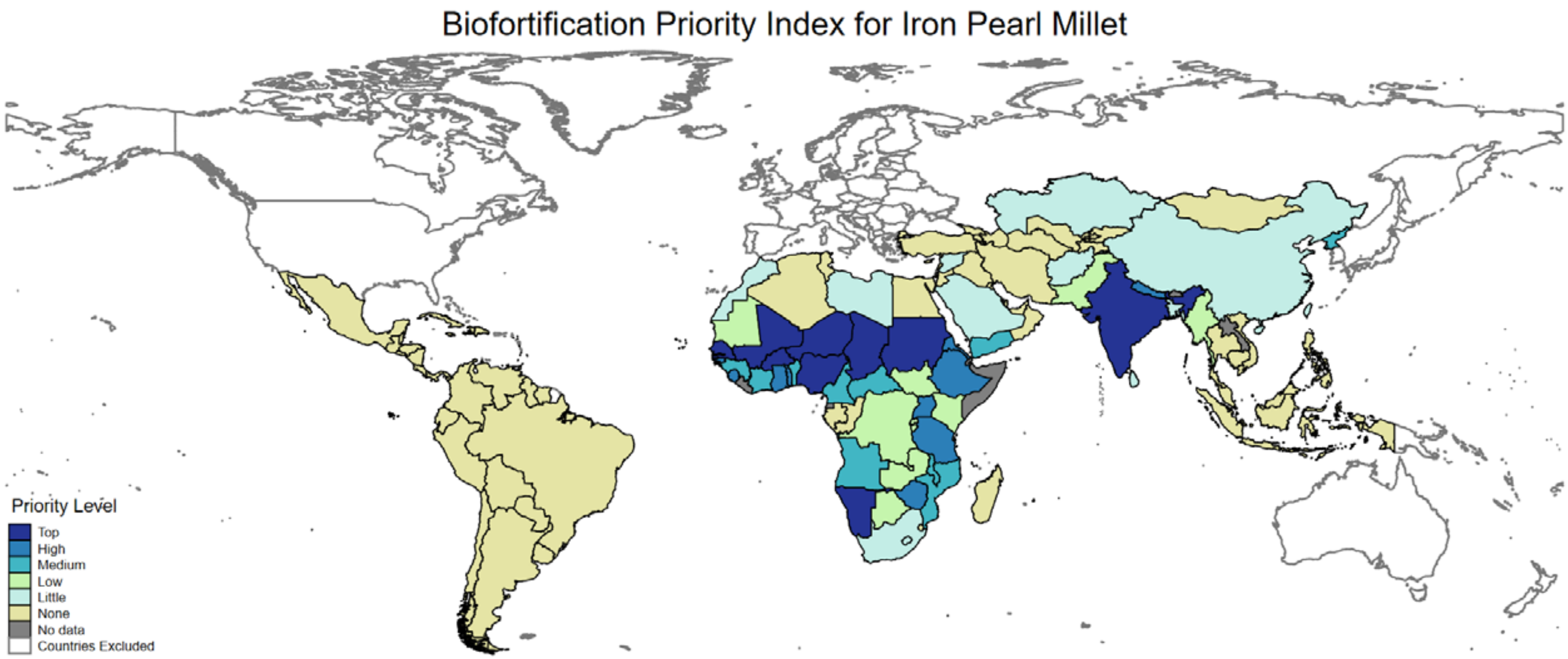


Figure 6: BPI Map for Zinc Wheat

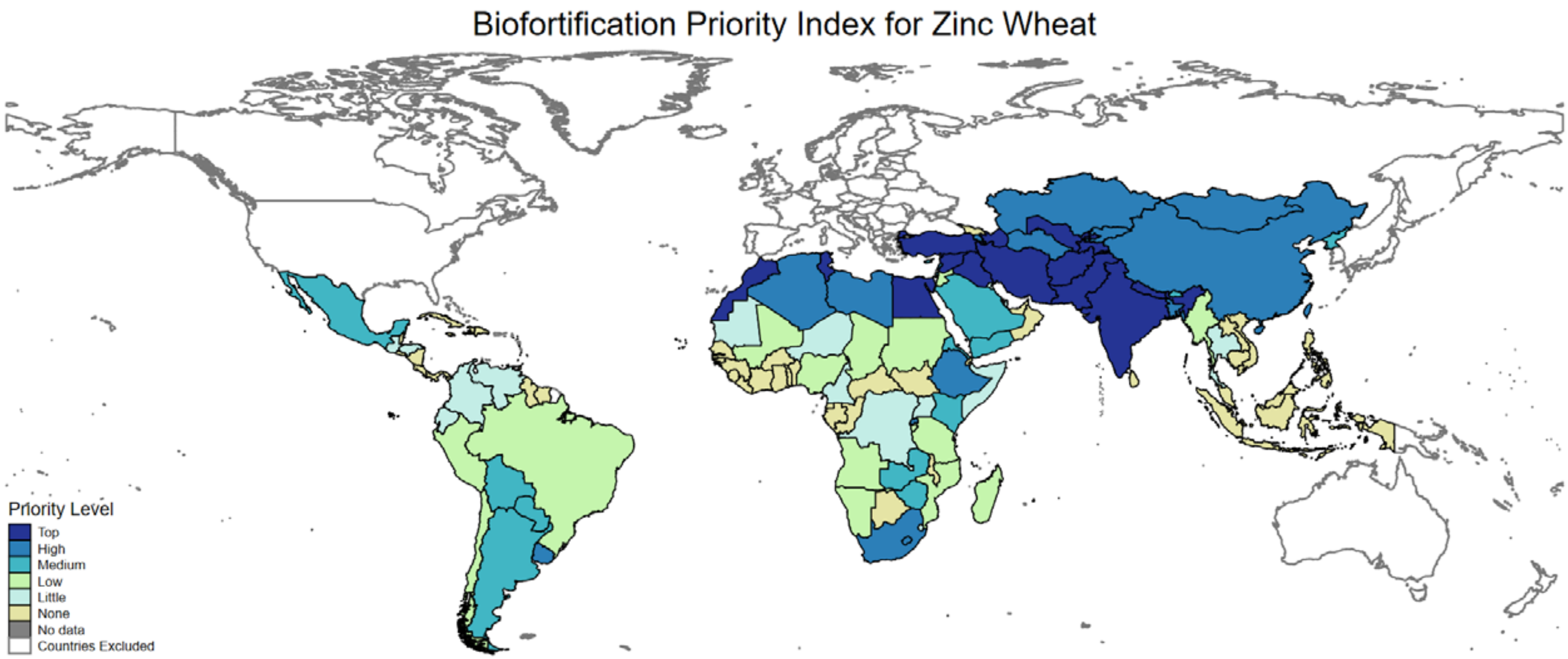


Figure 7: BPI Map for Zinc Rice

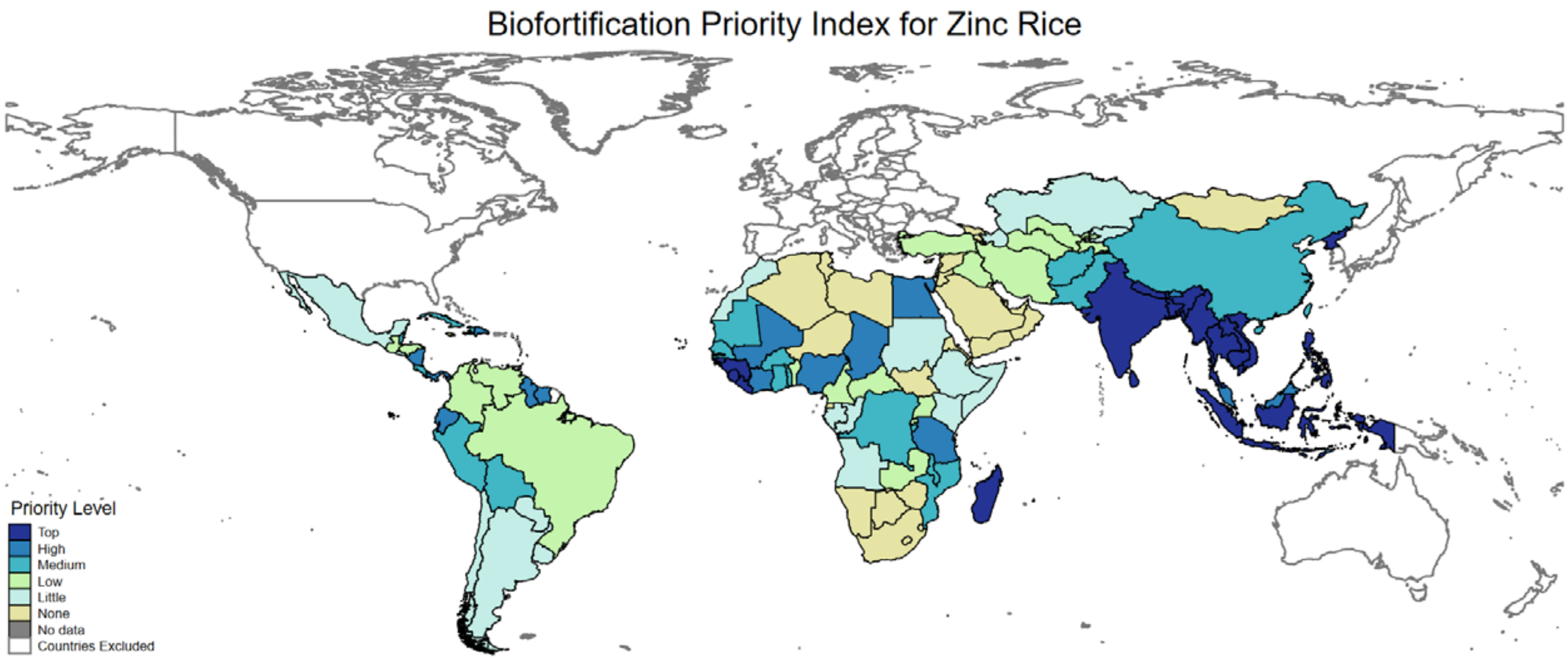
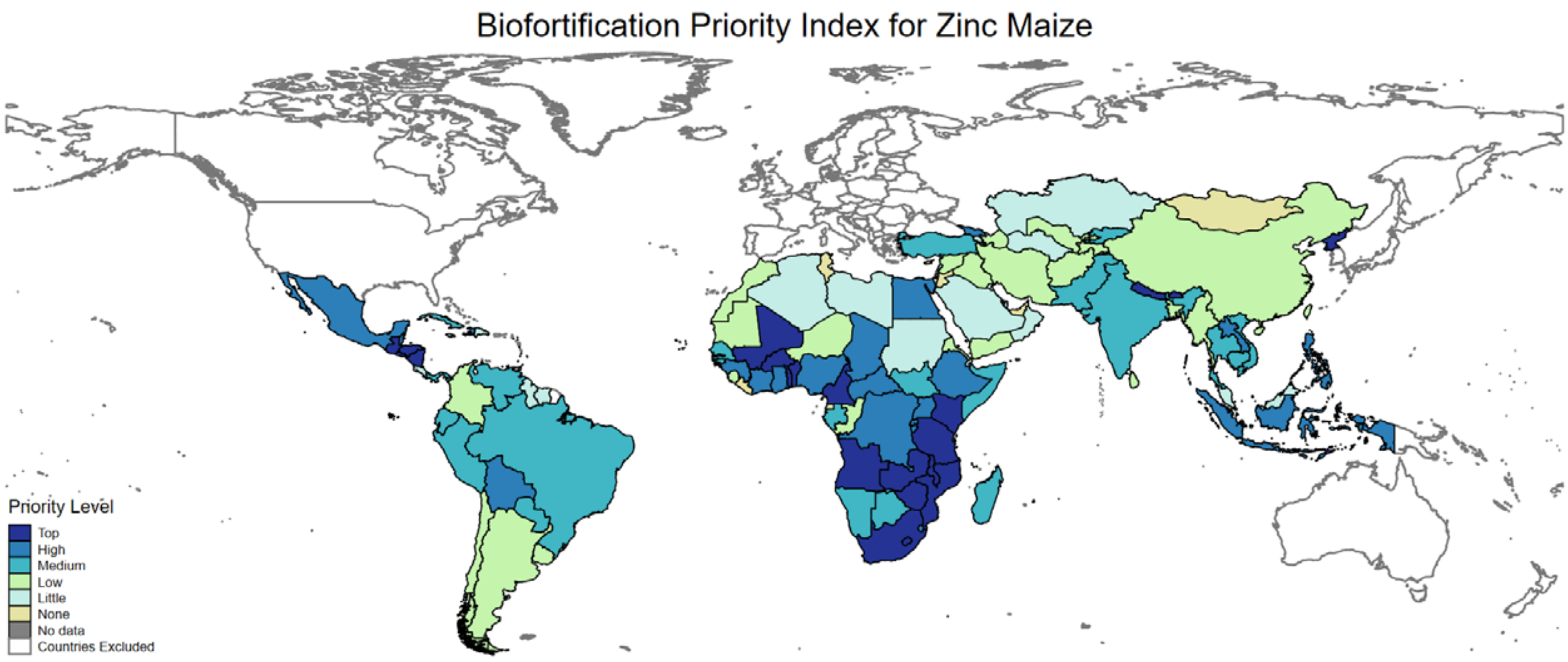


Figure 8: BPI Map for Zinc Maize



APPENDIX C

SECONDARY BIOFORTIFIED CROPS TOP 5 UNWEIGHTED REGIONAL RANKINGS

Vitamin A Banana

Table 17: BPI Rankings for Top 5 Countries: Vitamin A Bananas in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Burundi	100.0	Burundi	100.0	Laos	50.7	Dominica	57.9
2	Rwanda	97.7	Rwanda	97.7	Bhutan	47.4	Saint Vincent & the Grenadines	56.6
3	Angola	94.9	Angola	94.9	Philippines	46.2	Haiti	49.0
4	Comoros	79.5	Comoros	79.5	India	42.7	Grenada	45.3
5	Central African Republic	76.6	Central African Republic	76.6	Oman	27.7	Dominican Republic	40.9

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Vitamin A Plantain

Table 18: BPI Rankings for Top 5 Countries: Vitamin A Plantains in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
1	Gabon	100.0	Gabon	100.0	Sri Lanka	25.9	Colombia	37.1
2	Ghana	87.7	Ghana	87.7	Philippines	24.5	Peru	33.4
3	Côte d'Ivoire	73.6	Côte d'Ivoire	73.6	Myanmar	21.0	Ecuador	32.2
4	Uganda	70.1	Uganda	70.1			Dominican Republic	29.2
5	Cameroon	51.2	Cameroon	51.2			Bolivia	28.0

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Iron and Zinc Cowpeas

Table 19: BPI Rankings for Top 5 Countries: Iron and Zinc Cowpeas in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
	Iron Comparison for Cowpeas							
1	Niger	100.0	Niger	100.0	Myanmar	11.9	Haiti	20.6
2	Burkina Faso	60.4	Burkina Faso	60.4	Sri Lanka	5.5	Peru	5.9
3	Nigeria	47.3	Nigeria	47.3	Cyprus	2.4	Trinidad & Tobago	4.9

4	Mali	39.4	Mali	39.4	Occupied Palestinian Territory	1.1	Guyana	3.2
5	Cameroon	25.8	Cameroon	25.8	Iraq	0.8	Jamaica	2.4
Zinc Comparison for Cowpeas								
1	Niger	100.0	Niger	100.0	Myanmar	13.8	Haiti	22.2
2	Burkina Faso	61.9	Burkina Faso	61.9	Sri Lanka	9.6	Peru	6.1
3	Nigeria	44.3	Nigeria	44.3	Cyprus	3.1	Trinidad & Tobago	4.6
4	Mali	35.7	Mali	35.7	Occupied Palestinian Territory	1.3	Guyana	2.5
5	Cameroon	31.8	Cameroon	31.8	Iraq	1.1	Jamaica	1.9

**Priority levels:* = Top, = High, = Medium, = Low, = Little, = None, = No data

Iron and Zinc Irish Potato

Table 20: BPI Rankings for Top 5 Countries: Iron and Zinc Irish Potatoes in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
Iron Comparison for Irish Potatoes								
1	Malawi	100.0	Malawi	100.0	Kyrgyzstan	73.2	Bolivia	77.5
2	Rwanda	82.1	Rwanda	82.1	Kazakhstan	70.1	Peru	59.7
3	Bolivia	77.5	Kenya	52.0	Nepal	56.5	Ecuador	29.0
4	Kyrgyzstan	73.2	Angola	48.0	Armenia	46.3	Chile	27.9
5	Kazakhstan	70.1	Tanzania	46.3	Azerbaijan	45.8	Venezuela	27.5
Zinc Comparison for Irish Potatoes								
1	Malawi	100.0	Malawi	100.0	Nepal	61.6	Bolivia	48.7
2	Rwanda	89.3	Rwanda	89.3	North Korea	52.6	Peru	47.4
3	Nepal	61.6	Lesotho	50.4	Bangladesh	47.6	Guatemala	27.5
4	North Korea	52.6	Kenya	41.3	Azerbaijan	46.9	Ecuador	23.7
5	Lesotho	50.4	Angola	40.1	Tajikistan	39.4	Colombia	21.2

**Priority levels:* = Top, = High, = Medium, = Low, = Little, = None, = No data

Iron and Zinc Lentil

Table 21: BPI Rankings for Top 5 Countries: Iron and Zinc Lentils in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
Iron Comparison for Lentils								
1	Nepal	100.0	Ethiopia	49.8	Nepal	100.0	Ecuador	15.9
2	Syrian Arab Republic	77.6	Morocco	35.7	Syrian Arab Republic	77.6	Peru	12.0

3	India	50.4	Kenya	13.9	India	50.4	Colombia	6.2
4	Ethiopia	49.8	Algeria	13.9	Turkey	47.8	Mexico	5.9
5	Turkey	47.8	Malawi	12.9	Yemen	32.3	Chile	5.4
Zinc Comparison for Lentils								
1	Nepal	100.0	Ethiopia	39.7	Nepal	100.0	Ecuador	11.9
2	Syrian Arab Republic	68.2	Morocco	28.7	Syrian Arab Republic	68.2	Peru	8.8
3	India	41.4	Malawi	11.8	India	41.4	Mexico	5.1
4	Ethiopia	39.7	Algeria	10.8	Turkey	39.5	Colombia	4.9
5	Turkey	39.5	Kenya	10.1	Bangladesh	30.3	Chile	2.0

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

Zinc and Iron Sorghum

Table 22: BPI Rankings for Top 5 Countries: Zinc and Iron Sorghum in Africa, Asia, and LAC

Rank	Global		Africa		Asia		LAC	
Zinc Comparison for Sorghum								
1	Burkina Faso	100.0	Burkina Faso	100.0	Yemen	48.6	El Salvador	37.8
2	Niger	97.0	Niger	97.0	India	28.8	Haiti	31.0
3	Chad	92.3	Chad	92.3	Myanmar	16.2	Belize	20.6
4	Sudan	87.4	Sudan	87.4	North Korea	13.4	Nicaragua	18.3
5	Mali	81.1	Mali	81.1	Pakistan	11.2	Honduras	16.4
Iron Comparison for Sorghum								
1	Burkina Faso	100.0	Burkina Faso	100.0	Yemen	42.2	El Salvador	33.5
2	Niger	99.4	Niger	99.4	India	25.1	Haiti	29.4
3	Chad	92.1	Chad	92.1	Myanmar	14.3	Belize	20.2
4	Mali	91.8	Mali	91.8	Pakistan	9.9	Nicaragua	12.7
5	Sudan	91.5	Sudan	91.5	Saudi Arabia	9.5	Honduras	12.5

**Priority levels: = Top, = High, = Medium, = Low, = Little, = None, = No data*

APPENDIX D

SECONDARY BIOFORTIFIED CROPS TOP 10 POPULATION-WEIGHTED COUNTRY RANKINGS

Table 23: Top 10 Ranking Countries for Population-weighted Secondary Biofortified Crops

Global Rank	Vitamin Banana	Vitamin A Plantain	Iron Cowpeas	Zinc Cowpeas	Iron Irish Potato	Zinc Irish Potato	Iron Lentils	Zinc Lentils	Zinc Sorghum	Iron Sorghum
1	India	Nigeria	Nigeria	Nigeria	India	India	India	India	India	India
2	China	Uganda	Niger	Niger	China	China	Ethiopia	Bangla-desh	Nigeria	Nigeria
3	Tanzania	DRC	Burkina Faso	Burkina Faso	Bangla-desh	Bangla-desh	China	Ethiopia	Ethiopia	Ethiopia
4	Philipp-ines	Philipp-ines	Tanzania	Tanzania	Pakistan	Pakistan	Bangla-desh	Nepal	China	China
5	Bangla-desh	Ghana	Kenya	DRC	Nigeria	Nigeria	Nepal	China	Sudan	Sudan
6	Indonesia	Tanzania	DRC	Kenya	Kenya	Indonesia	Pakistan	Pakistan	Niger	Niger
7	Kenya	Myanmar	Mozam-bique	Mozam-bique	Tanzania	Tanzania	Turkey	Turkey	Tanzania	Burkina Faso
8	Ethiopia	Côte d'Ivoire	Myanmar	Myanmar	Egypt	Kenya	Syria	Syria	Burkina Faso	Tanzania
9	DRC	Cameroon	Mali	Sudan	Ethiopia	Malawi	Iran	Iran	Pakistan	Pakistan
10	Egypt	Malawi	Sudan	Mali	Malawi	Nepal	Yemen	Yemen	Chad	Chad
% in un-weighted BPI top 10	10%	40%	60%	60%	20%	40%	80%	80%	50%	50%

APPENDIX E

SECONDARY BIOFORTIFIED CROPS TOP 10 LAND AREA-WEIGHTED COUNTRY RANKINGS

Table 24: Top 10 Ranking Countries for Land Area-weighted Secondary Biofortified Crops

Global Rank	Vitamin Banana	Vitamin A Plantain	Iron Cowpeas	Zinc Cowpeas	Iron Irish Potato	Zinc Irish Potato	Iron Lentils	Zinc Lentils	Zinc Sorghum	Iron Sorghum
1	Rwanda	Uganda	Niger	Niger	China	China	India	India	Sudan	Sudan
2	India	Côte d'Ivoire	Nigeria	Nigeria	India	India	Nepal	Nepal	Niger	Nigeria
3	Tanzania	Ghana	Burkina Faso	Burkina Faso	Malawi	Malawi	Turkey	Turkey	Nigeria	Niger
4	Burundi	Cameroon	Mali	Mali	Peru	Bangla-desh	Syria	Syria	India	Burkina Faso
5	Philippines	Colombia	Mozam-bique	Mozam-bique	Bangla-desh	Rwanda	Ethiopia	Ethiopia	Burkina Faso	India
6	Brazil	Nigeria	Cameroon	Cameroon	Bolivia	Peru	Iran	Iran	Mali	Mali
7	Angola	Tanzania	Tanzania	Tanzania	Rwanda	Nepal	Bangla-desh	Bangla-desh	Chad	Chad
8	Ecuador	DRC	Kenya	Kenya	Kazakh-stan	Bolivia	Morocco	Morocco	Ethiopia	Ethiopia
9	Cameroon	Philippines	Senegal	DRC	Nepal	Tanzania	China	Yemen	Cameroon	South Sudan
10	Uganda	Gabon	Sudan	Senegal	Nigeria	North Korea	Yemen	Pakistan	South Sudan	Cameroon
% in un-weighted BPI top 10	50%	50%	80%	80%	60%	70%	90%	90%	80%	80%

APPENDIX F

BPI MAPS FOR SECONDARY CROPS

Figure 9: BPI Map for Vitamin A Banana

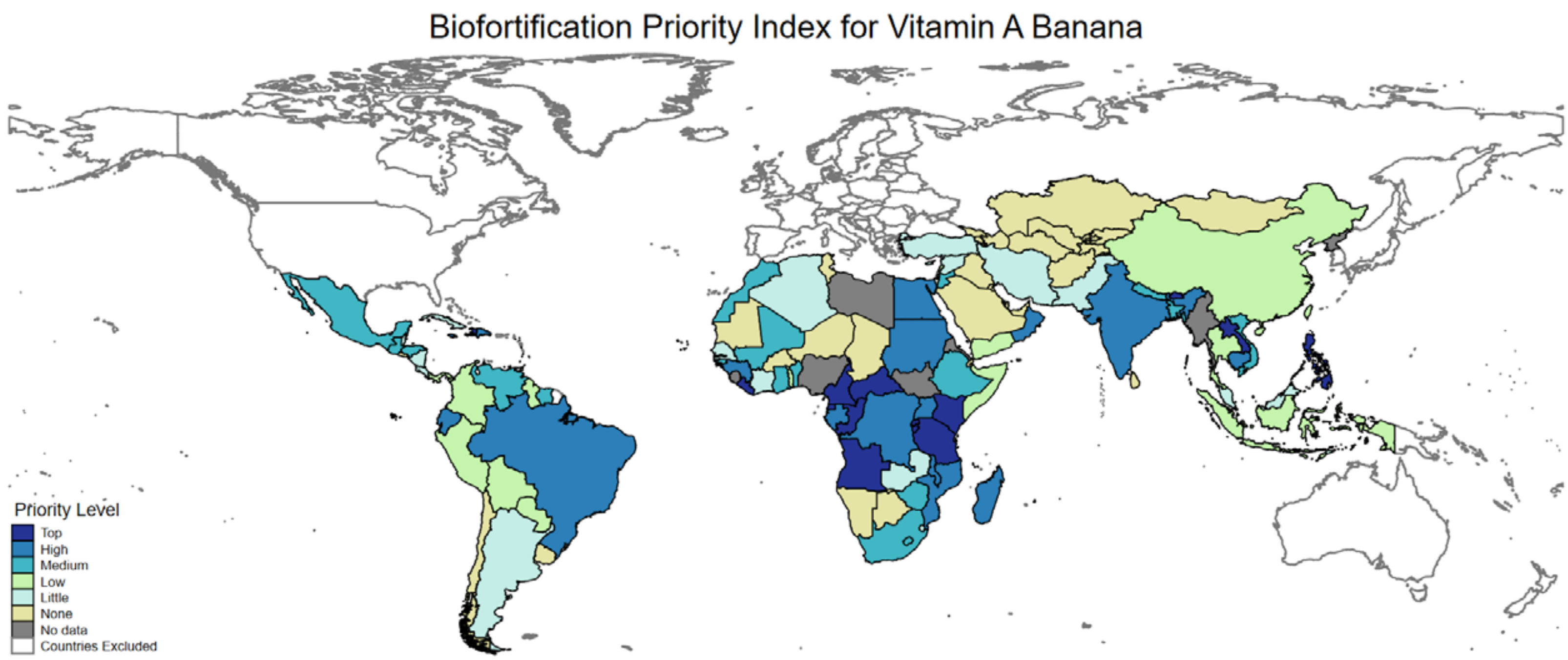


Figure 10: BPI Map for Vitamin A Plantain

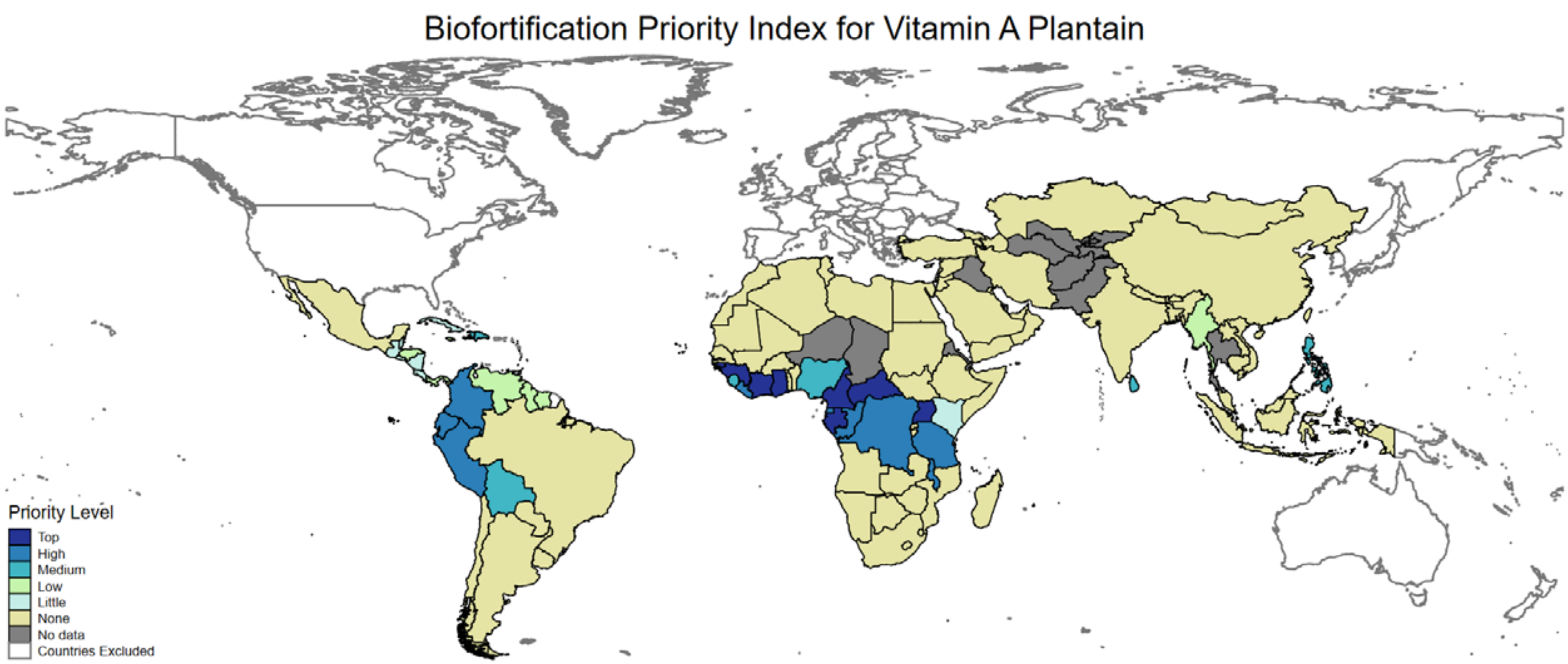


Figure 11: BPI Map for Iron Cowpeas

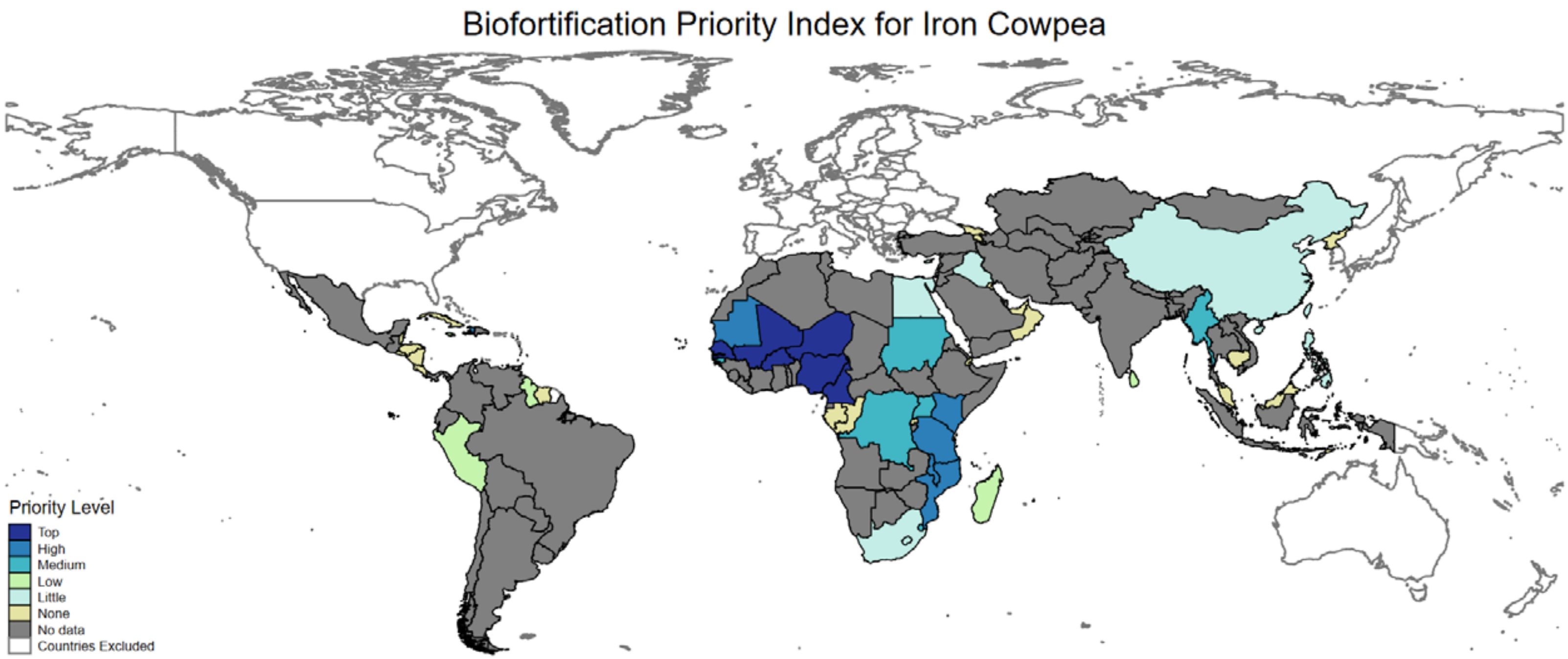


Figure 12: BPI Map for Zinc Cowpeas

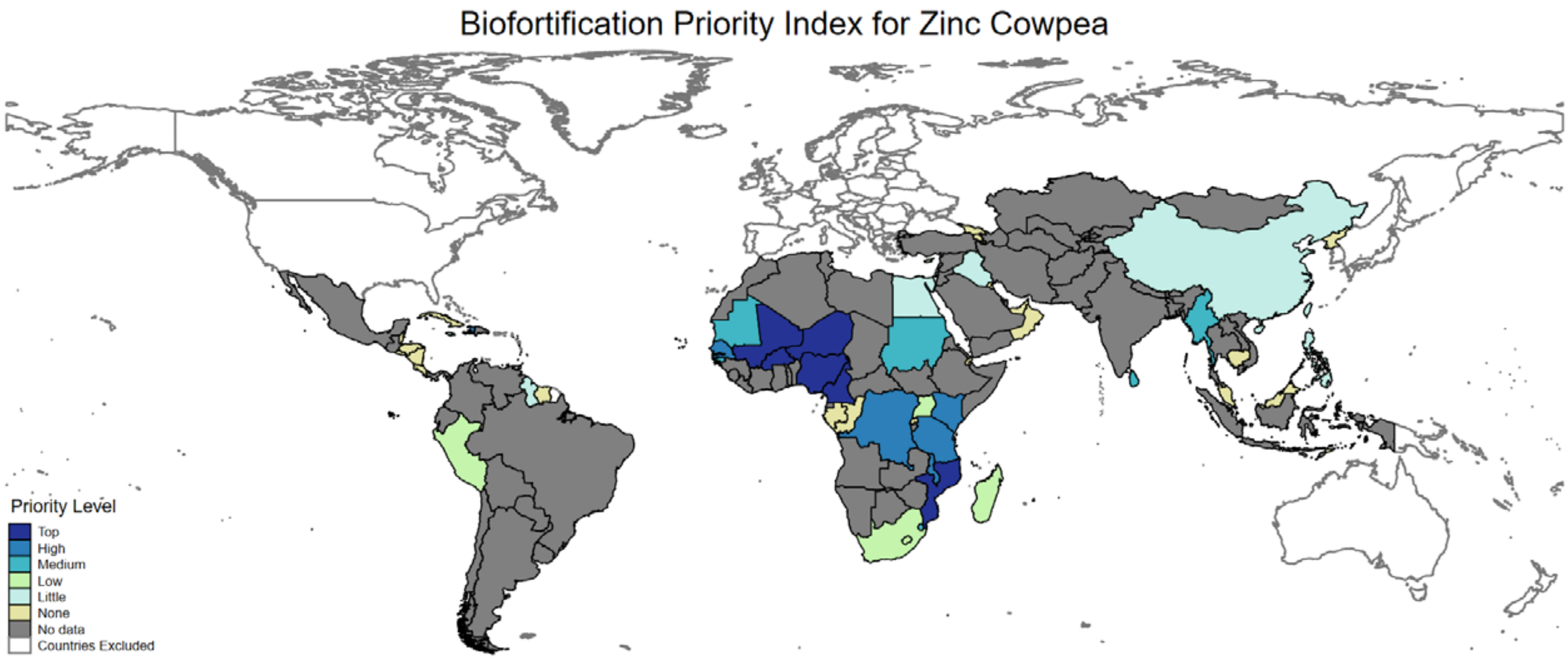


Figure 13: BPI Map for Iron Irish Potato

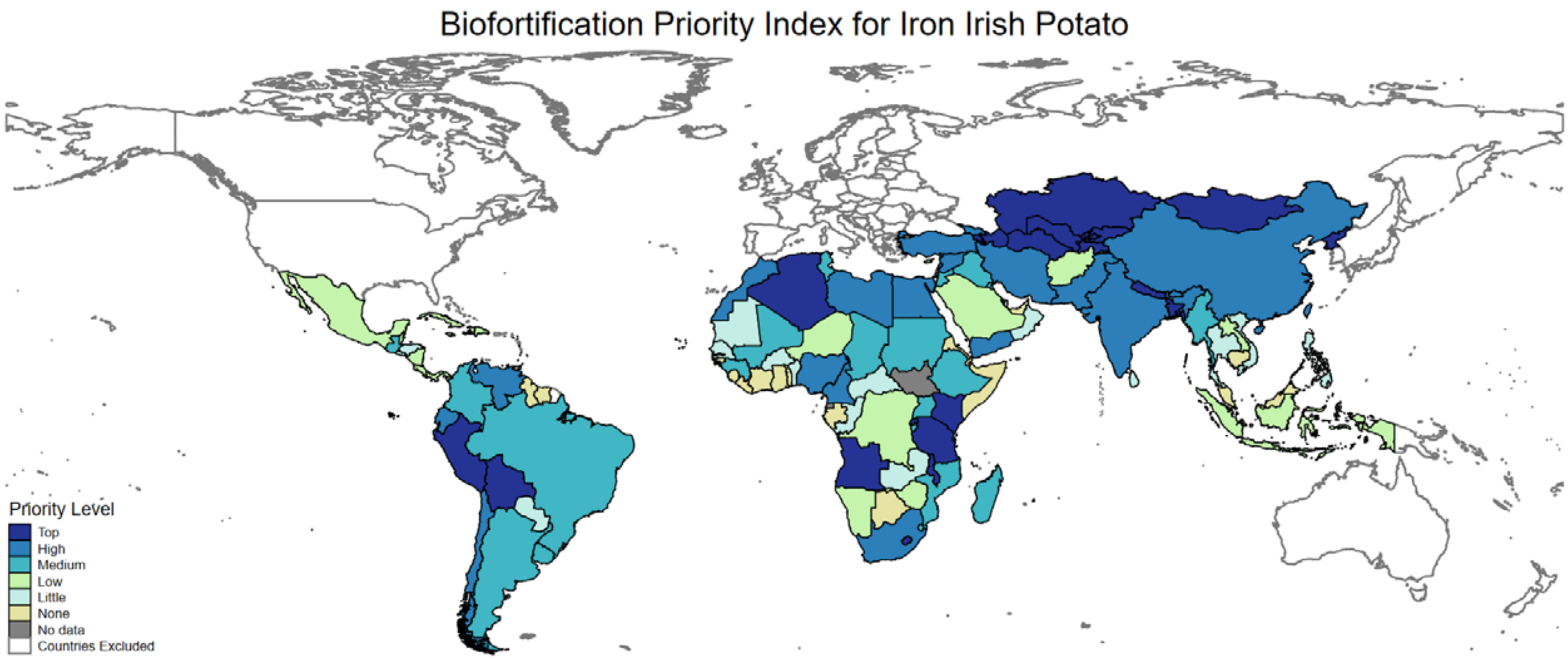


Figure 14: BPI Map for Zinc Irish Potato

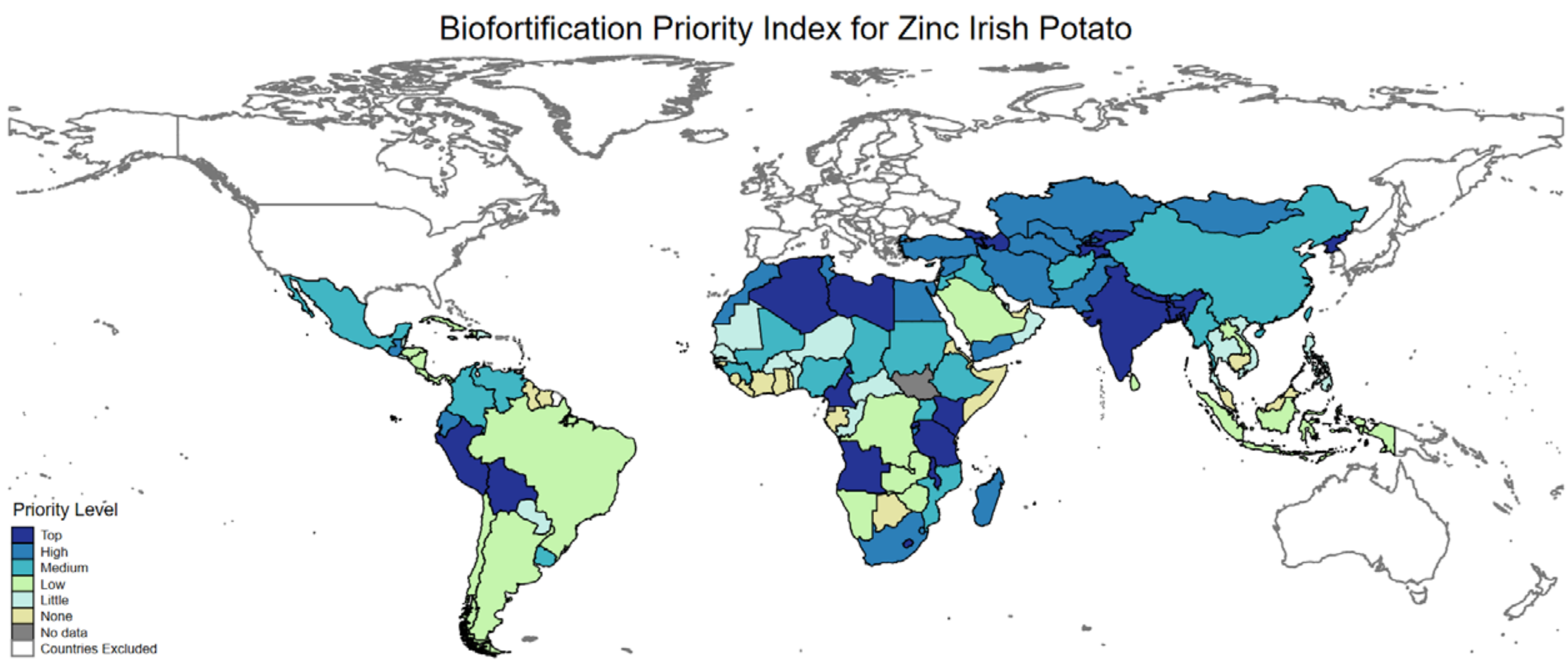


Figure 15: BPI Map for Iron Lentils

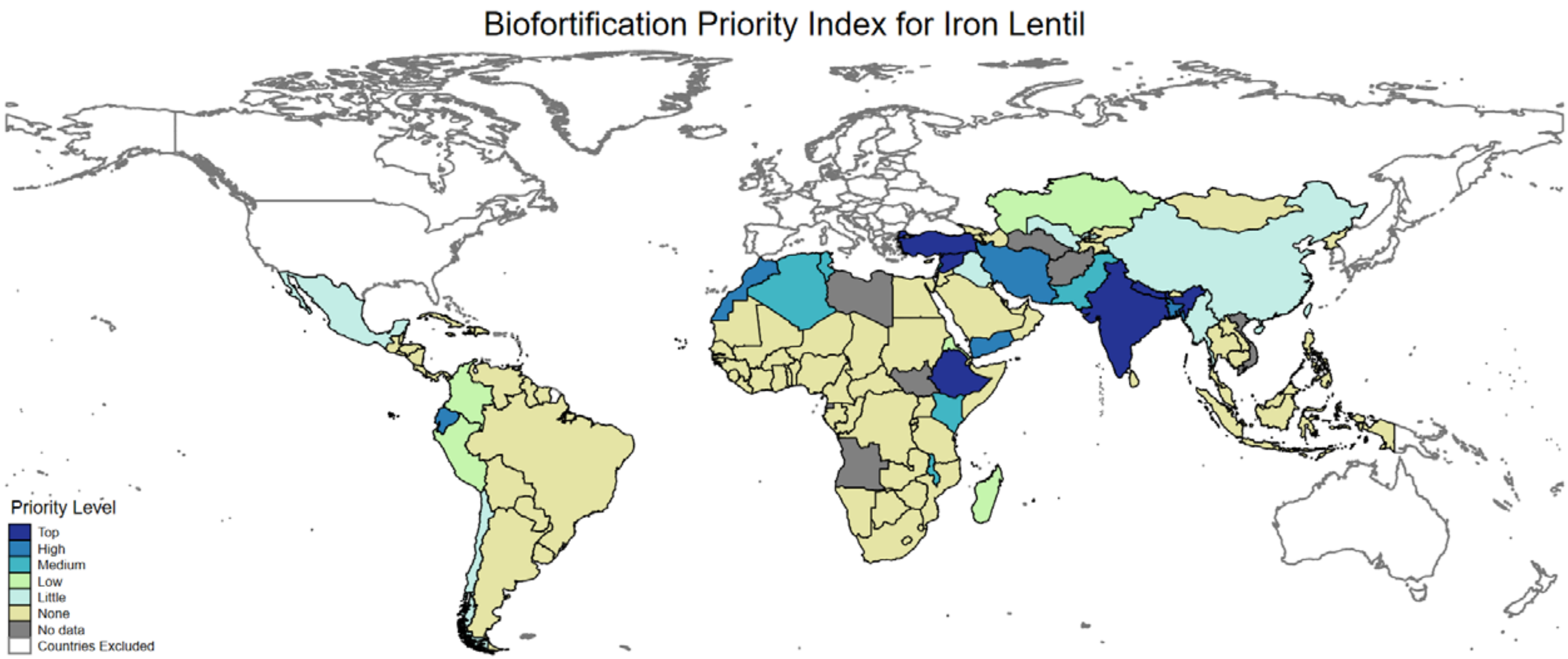


Figure 16: BPI Map for Zinc Lentils

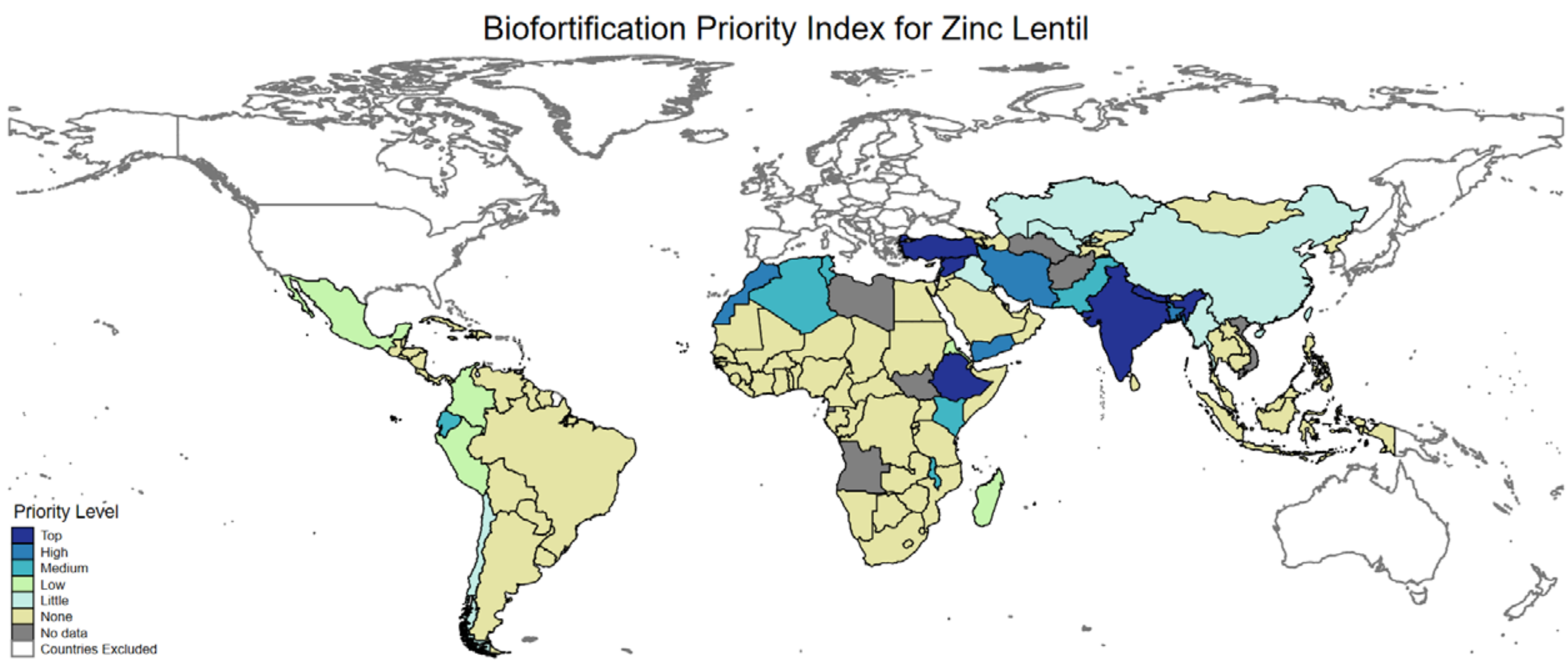


Figure 17: BPI Map for Zinc Sorghum

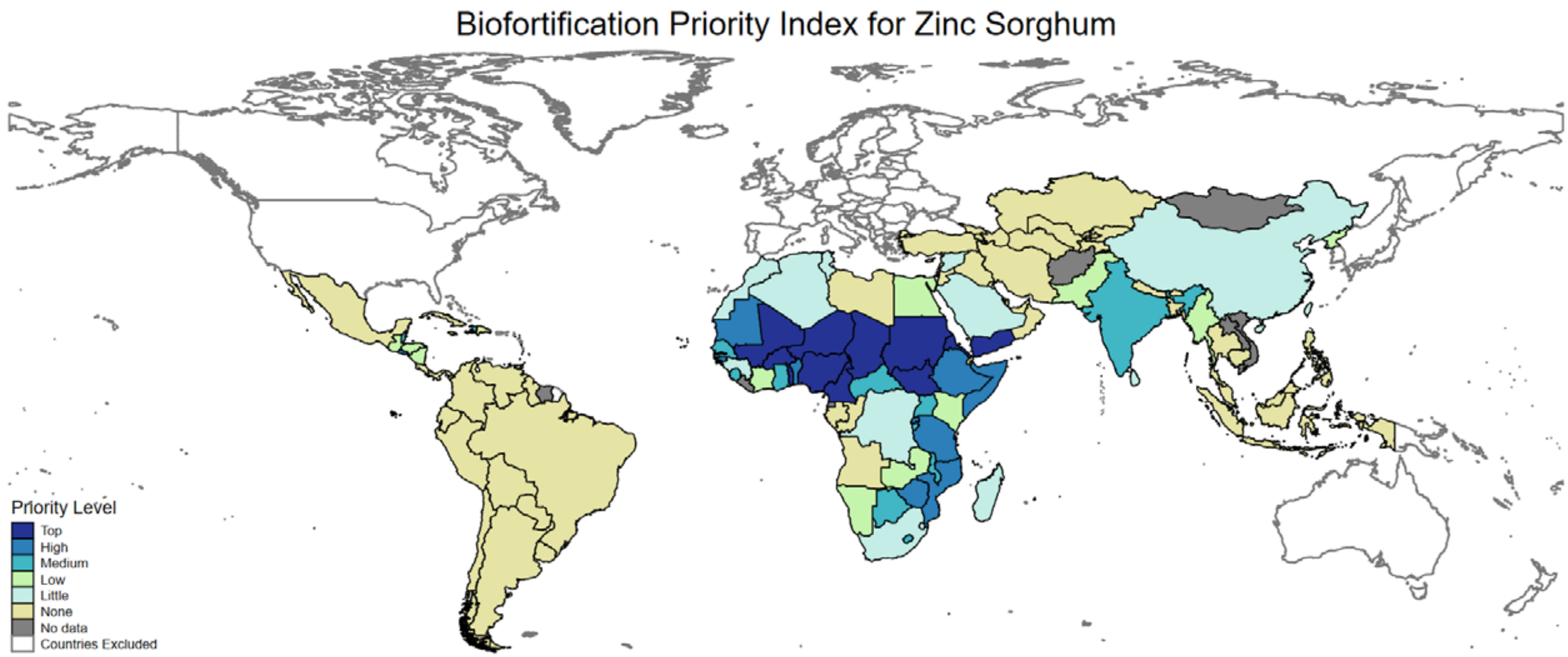


Figure 18: BPI Map for Iron Sorghum