Subnational Prioritization for Biofortification Interventions in Nigeria

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Abstract:

Globally, two billion people suffer from micronutrient malnutrition. Biofortification, the process of breeding staple food crops to have higher micronutrient content, has proven to be efficacious and cost-effective in addressing micronutrient malnutrition. To determine where and in which crop-micronutrient combinations to invest, a global Biofortification Prioritization Index (BPI) was developed (Asare-Marfo et al., 2013). While a country's rank in the global context is useful, it is not granular enough to develop strategies within heterogenous countries. Therefore, this paper utilizes methodology to develop a subnational-level BPI for Nigeria, a country which shows promise for biofortified crops. The subnational BPI is based on three sub-indices: production, consumption, and micronutrient deficiency. In addition, targeted areas are classified as areas of: (1) impact and intervention, (2) impact, or (3) intervention. Sensitivity analyses tested the robustness of BPI results on single sub-index parameters. For vitamin A maize's introduction, the North East and North West zones offer the most promise while the southern zones generate the greatest impact for the introduction of vitamin A cassava. Concentrating vitamin A sweet potato investments in the North Central zone is the most effective while focusing in the North West is the most promising strategy for iron pearl millet.

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Keywords: biofortification, Nigeria, subnational BPI, food balance sheet

1. INTRODUCTION

One in three individuals suffers from micronutrient malnutrition, also known as hidden hunger, with the most common deficiencies being vitamin A, iron, iodine, and zinc (FAO, IFAD, and WFP, 2015). The majority of the world's hidden hunger cases occur in developing countries where access to a diverse diet is limited. Instead, diets in developing countries are often characterized by a high intake of staple food crops instead of micronutrient-rich foods. Hidden hunger, also caused by disease, impedes proper health and development in children and limits normal physical and mental function in adults, which can lead to a lifetime of income losses (Alderman et al., 2006).

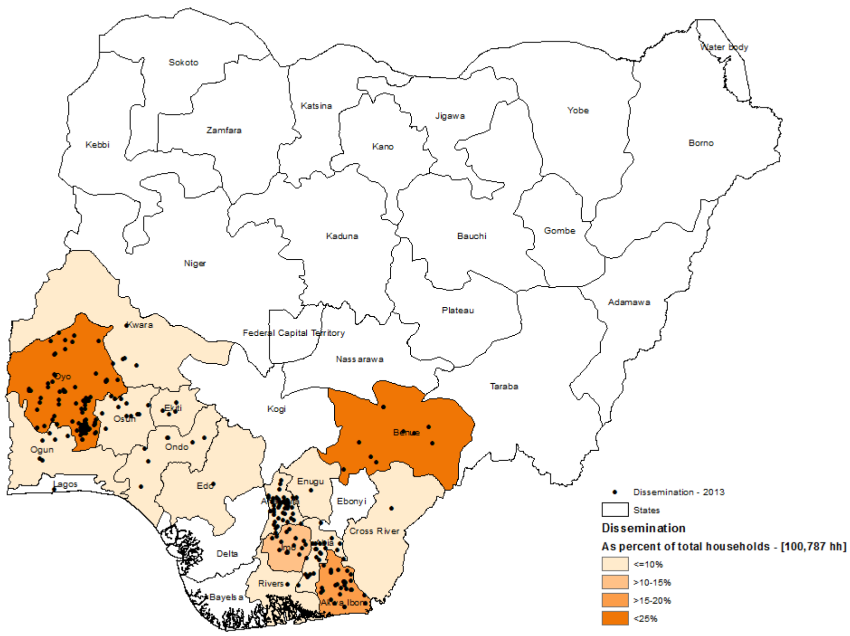
In the long-term, it is the hope that all people will have access to and the ability to afford a diverse diet, rich in micronutrients and minerals. However, in the near-term, food fortification, supplementation, and biofortification can address hidden hunger. Biofortification has comparative advantages over supplementation and fortification with its ability to reach the rural population and its long-term cost effectiveness (Bouis, 2017). Biofortification is the process of breeding staple food crops to have higher levels of micronutrients and minerals, while still maintaining agronomic and consumption traits that farmers prefer. In a global Biofortification Priority Index (BPI), Nigeria ranks as a high priority country for the introduction of vitamin A cassava, vitamin A maize, and vitamin A sweet potatoes while the country ranks as a top priority for the introduction of iron pearl millet (Asare-Marfo, 2013).

In Nigeria, vitamin A deficiency is a severe public health problem, affecting thirty percent of preschool-aged children nationwide (Maziya-Dixon et al., 2006). Vitamin A deficiency lowers immunity, impairs vision, and can lead to blindness. Furthermore, vitamin A deficiency can increase the severity of diseases, such as diarrheal disease and measles, which can result in death (WHO, 2017).

Iron deficiency is also serious in Nigeria as the WHO classifies the country as having a severe anemia problem for children ages 6-59 months and for non-pregnant women 15-49 years of age (WHO, 2015). The 2015 Nigeria Malaria Indicator Survey reports 69 percent of children under five years of age, suffer from anemia (NMEP, NPC, NBS, and ICF International, 2016). Anemia is used as a proxy for iron deficiency as iron deficiency is the most common cause of anemia in Nigeria (NMEP, NC, NBS, and ICF International, 2016). Iron is essential for red blood cell formation and deficiency therefore, impairs mental development and learning capacity in children while impairing physical labor in adults (NPC and ICF International, 2014). Additionally, severe anemia increases the risk of women dying in childbirth.

Through the work of HarvestPlus, the global leader in the technology and policy of biofortification, and its partners, three biofortified provitamin A (yellow) cassava varieties were introduced in Nigeria in 2011, followed by an additional three in 2014. These second wave provitamin A cassava varieties, provide up to 40 percent of daily vitamin A needs when integrated into existing cassava consumption patterns. Delivery of vitamin A cassava in 2013, is shown in Figure 1 below. Additionally, not only are the varieties nutritious, they are also high yielding and virus resistant. Beginning in 2012, biofortified provitamin A (orange) maize was also introduced into Nigeria. These orange maize varieties provide up to 25 percent of a person's daily vitamin A needs. Furthermore, the varieties are also high yielding, drought tolerant, and disease and virus resistant. Through the efforts of the International Potato Center, the provitamin A (orange) sweet potato has been released in Nigeria as well. Pearl millet, enhanced with iron, is currently being tested in the country for release.

Figure 1: 2013 Vitamin A Cassava Dissemination



**Source: Authors*

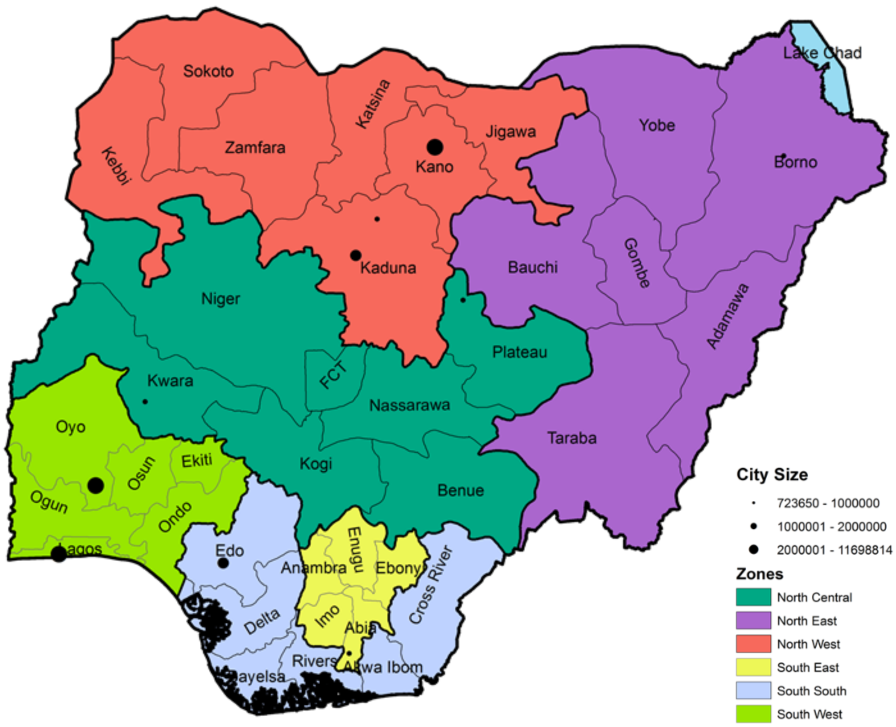
As already evidenced, there is great need to overcome vitamin A and iron deficiency in Nigeria. While biofortification is making great strides to combat hidden hunger with 20 million farming households growing these crops, the complexity and heterogeneity of Nigeria requires thoughtful strategy to maximize the impact of biofortification. Therefore, this paper seeks to review the production and consumption evidence of maize, cassava, sweet potatoes, and millet at the state-level and Federal Capital Territory, as well as the figures for vitamin A and iron deficiency. Analyzing these factors at a subnational scale through the creation of the subnational Biofortification Priority Index (BPI) will enable decision makers to make informed decisions regarding the delivery of biofortified crops, prioritizing states where the impact will be the greatest.

2. DISTRIBUTION OF PEOPLE, PRODUCTION, AND CONSUMPTION OF STAPLE FOOD CROPS IN NIGERIA

2.1 People distribution

Nigeria, the most populous country in Africa, is one of the fastest growing countries in the world with an average growth rate of 2.3 percent per year (NBS, 2014). Nigeria's 2017 population is estimated to be 193,842,000 (FAO, 2017b) and continues to grow steadily with a high fertility rate of 5.7 births per woman (NBS, 2016). As shown in Figure 2, Nigeria is subdivided into six geopolitical zones. In terms of land mass, the Northern zones outweigh the South. The North West and South West zones are the most populous zones within the country.

Figure 2: Nigeria's Geopolitical Zones and Most Populous Cities



Source: Authors

Children under five and women of child-bearing age disproportionately suffer from micronutrient deficiency. Children under five years of age account for 17 percent of the Nigerian population while 23 percent of the population are women of child-bearing age (UN, 2014). Therefore, these two groups, living in rural areas, are the target population for HarvestPlus' dissemination of biofortified crops in Nigeria.

2.2 Agricultural production

Agriculture is a cornerstone of the Nigerian economy, contributing 21.5 percent of Nigeria's gross domestic product (NBS, 2017) and accounting for 28 percent of employment (World Bank, 2017). Specific crop production varies across Nigeria due to the seven different agroecological zones ranging from semiarid in the North to tropical and humid in the South allowing for a diverse food production landscape. In 2015, 80 percent of available land was dedicated to agriculture (FAO, 2017b). The top five crops grown, based on land area allocation, are maize, cassava, guinea corn, yams, and beans (NBS, 2017).

Maize: Maize is grown in all Nigerian agroecological zones and seasons, allowing for two harvests a year. It is estimated that maize production in 2015 was 10.5 million tons, steadily increasing from recent years (NBS, 2017). The Northern zones account for the states with the largest land area under cultivation (NAERLS and FDAE, 2014). However, Plateau has the highest percentage of its agricultural land area dedicated to the cultivation of maize (authors' own calculations based on NAERLS and FDAE, 2014, and NBS, 2017).

Maize is the most popular crop in the country, grown by roughly 48 percent of farming households, on average, each cultivating 0.3 hectares of maize (NBS, 2017). Based on the Nigeria FAO Food Balance Sheet, approximately 54 percent of domestic supply is kept for food (FAO, 2017a).

Cassava: Nigeria is the world's leading cassava producer, supplying both food and feed needs (CGIAR, 2017). In 2015, Nigeria cultivated approximately 6,216,434 hectares of cassava, translating to 57,643,271 tons of production (NBS, 2017). Of all Nigerian farming households, 42 percent grew cassava in 2015 on approximately 0.2 hectares of land per household (NBS, 2017). Cassava is grown throughout the country, though the highest land area dedicated to its cultivation is in Benue (485,000 had), Taraba (482,000 ha), and Enugu (411,000 ha) (NAERLS and FDAE, 2014). In 2014, Cross River was the state with the largest percentage of its agricultural land area sown to cassava (authors' own calculations based on NAERLS and FDAE, 2014 and NBS, 2017). Based on the Nigeria FAO Food Balance Sheet, approximately 39 percent of cassava domestic supply goes towards food (FAO, 2017a).

Millet: Millet is used as a proxy for pearl millet as specific pearl millet data is not available. Though not produced in all Nigerian states, millet is considered a primary crop and is grown by roughly 25 percent of farming households (NBS, 2017). In 2015, national land area under millet cultivation was estimated to be 1,591,803 hectares with a production of 1,485,387 tons (NBS 2017). Production is highest in the North East zone with the largest land areas dedicated to millet production being in Adamawa (159,000 ha), Yobe (135,000 ha), and Gombe (109,000 ha). Yobe was the state with the highest portion of its agricultural land dedicated to millet production based on the 20 millet-producing states in the country (authors' own calculations based on NAERLS and FDAE, 2014 and NBS, 2017). Of total domestic millet supply, 84 percent is dedicated to food, 8 percent is lost during post-harvest handling and storage, and the remainder goes towards feed and seed (FAO, 2017a).

Sweet potatoes: Less information is available on sweet potatoes are they are a minor crop. They are not covered in the Agricultural Performance Survey of the 2014 Wet Season in Nigeria (the latest available) or the 2016 Annual Abstract of Statistics Report. The FAO estimates that in 2014, Nigeria dedicated 1,480,569 of land area to sweet potato cultivation (FAO, 2017a). Based on 2010 estimates, the last available state-level estimates, Enugu had the largest land area dedicated to sweet potato production followed by Niger, and Benue (HarvestChoice, 2014). Based on the FAO Food Balance Sheet, 70 percent of domestic supply quantity goes towards food (FAO, 2017a).

2.3 Consumption

Food choices are often dictated by what is produced in the locality of the market as consumption comes from own production or market purchases. Per capita consumption estimates at the state-level are given below from analysis conducted using the 2015-2016 Living Standards Measurement Study General Household Survey in Nigeria. The LSMS GHS is representative at the national, sector (rural versus urban), and zonal levels.

Maize: The national per capita consumption of maize is 37.63 g/day. At the national level, rural per capita consumption of maize was higher than urban consumption (48g/day versus 23 g/day), statistically significantly different at the 1 percent level. The consumption of maize is much higher on a per capita basis in the North Central, North East, and North West zones compared to the three zones located in the

South, likely due to the North being an area for large maize cultivation. Per capita consumption at the zone level was statistically significantly different at the one percent level.

Cassava: Cassava is a heavily consumed staple crop with estimates of 294 g/day per capita consumption. The highest per capita consumption was in the South South (461 g/day), statistically different than all other zones at the one percent level, except the South East. Next, is the South East with 428 g/day, the North Central zone with 325 g/day, and the South West zone with 323 g/day per capita consumption. On the low end was the North East and North West zones with 111g/day and 108g/day per capita consumption, respectively. The North East and North West zones are statistically lower than all other zones at the one percent level, except with one another where no significant difference was found.

Millet: Millet was found to only be produced in the North. Per capita consumption was highest in the North West zone with an average of 111 g/day per capita consumption, statistically different than all other zones at the one percent level, followed by the North East at 64 g/day. Almost no consumption of millet was found to occur in the Southern zones. Sokoto, in the North West, had the highest per capita consumption of millet in the country at 227 g/day.

Sweet potatoes: Since sweet potatoes are considered a minor crop in Nigeria and not grown throughout the country, the LSMS GHS population-based survey likely gives downward biased numbers since it's sampling frame may not have been powered to assess the consumption of minor crops. The highest per capita consumption of sweet potatoes occurred in the North West with 5.55 g/day consumption, statistically different than all other zones except the North East at the one percent significance level. Following the North West in per capita consumption was the North East with 4.83 g/day per capita consumption. Nationally, rural per capita consumption was higher than urban per capita consumption, 3.2 g/day versus 2.2 g/day, respectively, statistically different at the 5% significance level.

3. METHODOLOGY & DATA

3.1 Concept of the Unweighted BPI

To determine the suitability of biofortified staple food crop interventions within Nigeria, the subnational BPI follows the same approach and conceptual framework as the global BPI, with slight modifications (Asare-Marfo et al., 2013). The BPI is a composite, crop-specific index which accounts for the intensity and level of supply and demand of a specific crop *j*, in a given geographical unit, and the micronutrient deficiency levels for the micronutrient(s) with which the specific crop(s) can be enriched. There are three necessary conditions which must be met for a geographical areal unit, a Nigerian state in this respect, to be considered for the introduction of a biofortified staple food crop:

1. The geographical unit must be a producer of the specific crop (Pi),
2. The geographical unit's population must consume a large portion of the specific crop (Ci), and
3. The geographical unit's population suffers from micronutrient and mineral deficiencies, namely vitamin A, iron, and zinc (Mi).

The final BPI is calculated as:

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

A geometric mean is used for the subnational BPI analysis. This is done so that the indices complement rather than serve as substitutes for one another since all three indices are necessary conditions for successful implementation of a biofortified staple food crop intervention.

3.2 Linear transformation of the sub-indices

The variables used for the construction of the three sub-indices are bound by different units of measurements. Therefore, for mathematical addition and aggregation of the variables into sub-indices and later into one index, they are converted into new variables with no units of measurement. Similar to the method employed in the Human Development Index, all variables are converted to a common unitless measurement by being rescaled to a range between 0 and 1 by employing the below formula.

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

A heuristic approach is used by employing an arbitrary set of weights for weighing individual indicators for the computation of the three sub-indices. Equations with the superscript, r, indicate the variable has been rescaled.

3.3 Definition of the Sub-indices

Each index is specific to each crop-micronutrient combination at the state-level within Nigeria.

a. Consumption sub-index

The consumption index measures the intensity of consumption of the specific crop within each Nigerian state through per capita consumption of crop *j*. The higher the per capita consumption of crop *j*, the easier it is to improve an individual's micronutrient intake through biofortified crop *j*, given the individual meets condition number 3 above.

$$Consumption\ index\ (Ci) = (Consumption\ per\ capita)^{r}$$

b. Production sub-index

Two variables are used to construct the production index: the share of land area harvested for crop *j* in state *i*, out of total land area harvested for all crops in state *i*; and per capita area harvested estimated through the land area allocated to crop *j* in state *i*, divided by the total population in state *i*. These two variables are a way to measure the importance of crop *j* in state *i*'s agricultural sector. The formula used to calculate the subnational production index is detailed below.

$$Production\ index\ (Pi) = \left(\frac{1}{2} * per\ capita\ area\ harvested\ of\ crop\right)^{r} * \left(\frac{1}{2} * share\ of\ area\ allocated\ to\ crop\right)^{r}$$

For crop development and delivery costs associated with the introduction of biofortified crops, utilizing economies of scale would lead to lower per hectare unit costs of seed multiplication and delivery efforts of crop *j*, the higher the quantity of land area allocated to crop *j*. 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 state *i*. A crop which has a high land-to-labor ratio is likely to be important for the total food supply in a state and will likely be given greater political importance in the agricultural sector. Greater political importance would decrease the barriers to entry for biofortified varieties of the specific crop.

c. *Micronutrient deficiency sub-index*

Two separate micronutrient deficiency indices were created for this analysis, one for vitamin A and one for iron. Each index measures the extent to which the population in state *i*, is deficient in iron or vitamin A. Biofortified maize, cassava, and sweet potatoes are enriched with vitamin A while pearl millet is enriched with iron. Due to constraints of available state-level data, the methods used in constructing the micronutrient deficiency indices differ from that of the global BPI.

The vitamin A micronutrient deficiency index is calculated using three variables: (1) 100 minus the proportion of children ages 6-23 months that consumed foods rich in vitamin A within the last 24 hours, (2) 100 minus the percentage of children ages 6-59 months who were given vitamin A supplements within the last 6 months, and (3) the proportion of children under 5 years of age who had diarrhea in the last two weeks. Equal weights were given to each of the three variables. However, five and ten percent weight adjustments were made through 12 iterations, 6 for 5 percent weight changes and 6 for 10 percent weight changes, to analyze the sensitivity of the index calculations. The results from using equal weights for each variable matched the most often with the results from the 12 weight adjustments.

$$Vitamin\ A\ deficiency\ index\ (MAi) = (\frac{1}{3} * (100 - \%\ children\ eating\ food\ rich\ in\ vit.A)) + (\frac{1}{3} * (100 - \%\ children\ receiving\ vit.A\ supplements)) + (\frac{1}{3} * (prevalence\ of\ diarrhea))$$

The iron deficiency index is calculated using three variables: (1) 98 minus the percentage of women who took greater than or equal to 90 iron syrup tablets during pregnancy, (2) the prevalence of anemia (moderate or severe) among children under 5 years of age, and (3) 98 minus the percentage of children that consumed iron-rich foods in the last 24 hours. Instead of using a full count of the population to estimate the percentage of individuals at risk of iron deficiency anemia, 98 percent was used as the phenotype of sickle cell is present in approximately 2 percent of the Nigerian population (WHO, 2006). These three variables are given equal weights in the calculation of the index. As was done with vitamin A, the weights given to these three iron index variables were adjusted by 5 and 10 percent carried out through 12 additional iterations to determine the sensitivity of the index. Similar to vitamin A, the results from using equal weights for each iron deficiency variable matched the most often with the results from the 12 weight adjustments. The iron deficiency index, and therefore the resulting iron pearl millet BPI is only representative of a portion of HarvestPlus' target population, pregnant women and children under five years of age, due to data constraints which will be explained in greater detail below.

$$Iron\ deficiency\ index\ (MIi) = (\frac{1}{3} * (98 - \%\ children\ eating\ food\ rich\ in\ iron)) + (\frac{1}{3} * (98 - \%\ women\ who\ took\ 90\ or\ more\ iron\ tablets\ during\ pregnancy)) + (\frac{1}{3} * (prevalence\ of\ moderate\ or\ severe\ anemia\ in\ children\ under\ 5))$$

3.4 Calculation of Weighted BPIs

The BPI calculation deliberately avoids including variables which measures a state's size in absolute terms, such as quantity produced or the size of the population, as the unweighted BPI seeks to measure a state's potential for biofortification irrespective of its size or population. However, in some cases, factoring in these size-specific variables may prove to be beneficial for certain stakeholders, depending on their definition of "success". Therefore, two alternative indices that take land area and size of the target population into account are calculated by following the below equation.

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

Where A is a weight measuring the size of a state in relation to all states in Nigeria.

The population-weighted crop-nutrient-specific BPI estimation accounts for HarvestPlus' target population for biofortification. The target population for the Program is women of child-bearing age (15-49 years), and children under five years of age, living in rural areas. The analysis was constrained as no state-level data on these target groups was available. Therefore, the national percentage of these two groups was applied to each state's population. However, in reality, the percentage allocation will vary at the state level, more so for rural versus urban than for the percentage breakdown of age. Therefore, the population-weighted BPI will mostly be driven by areas of high population as no variability in target population exists among states due to data constraints.

The area-weighted crop-nutrient-specific BPI estimation considers the relative importance of a particular crop within the national agricultural sector, determining where the crop is most important throughout the country. For example, the higher the percentage of cassava land area cultivated in state *i*, of national land area dedicated to cassava cultivation, the higher the weight will be given to state *i*. Therefore, in the area-weighted BPI, production indicators carry more weight than consumption of the crop or micronutrient deficiency and larger geographic states will have an advantage as will states which have low crop diversity.

3.5 Data sources

a. Consumption data

The data used for the subnational consumption index came from the World Bank Living Standards Measurement Studies – General Household Surveys. Specifically Wave 3 data, 2015-2016, post-planting (lean season) and post-harvest (abundant season) questionnaires were used to smooth any seasonal variation. Initial data comes from the sections on Food Expenditure in each questionnaire as food consumption quantity at the household level is contained within. Food items whose raw products are maize, cassava, millet, and sweet potatoes were kept for analysis, this included millet, maize flour, unshelled maize, shelled maize still on the cob, shelled maize off the cob, cassava flour, cassava root, white gari, yellow gari, and sweet potatoes. Food conversion factors were estimated and applied to obtain an aggregate level of weekly household consumption for each product: maize, cassava, millet, and sweet potatoes. Following this, per capita daily consumption was estimated by dividing the weekly household consumption total by 7 and the household size. Outliers were identified by 1.5 multiplied by the interquartile range and replacements were made with the unconditional mean of the corresponding state-level, excluding outliers. Results for the post-planting and post-harvest surveys were combined and divided by two and data was weighted accordingly.

While the level of analysis for the subnational level BPI in this paper is states, the LSMS consumption level data is only representative at the zonal level and not state level. Therefore, spatial econometric methods were used to "smooth" the per capita consumption variables at the state level. Specifically, the state-level consumption data of crop *j* was "smoothed" by creating spatially lagged variables based on the information of the surrounding neighbors of state *i*. Locally weighted averages are used where the observation for state *i* is replaced by an average based on observations that include surrounding locations, or neighbors. In this case, neighbors were defined by contiguity, sharing a common boundary, known as the queen method. For a sensitivity check, the k-nearest neighbors (where k=6) was also used to define neighbor relation. When employing the spatial econometric lagged queen method and k-nearest neighbors method, the vitamin A maize BPI results for quintiles shows zero variation. For the vitamin A cassava BPI, quintiles 5 and 4, representing top and high priority levels for the introduction of vitamin A cassava remained the same, while there is slight variation in the results in the lesser-priority quintiles. No change is found in any quintiles for vitamin A sweet potato and iron pearl millet introduction between the two methods. Given the similarity in results, the queen contiguity method is given priority as it is based upon shared borders instead of imposing an arbitrary number of surrounding states.

b. Production data

Production data came from multiple sources. State-level land area cultivated for maize and millet was obtained from the Agricultural Performance Survey of the 2014 Wet Season in Nigeria (NAERLS and FDAE, 2014). However, only a national figure was given for cassava land area and sweet potatoes were not included as they are a minor crop. The national figure for total land area sown to sweet potatoes in Nigeria was obtained from FAOSTAT. State-level sweet potato data was obtained from the International Food Policy Research Institute's 2010 SPAM database, the most recent data available (HarvestChoice, 2014). Due to data constraints, it was assumed that state-level sweet potato land area allocation was the same in 2014 as it was in 2010. Therefore, the 2010 state-level percentages of the national sweet potato land area was applied to the 2014 FAOSTAT Nigeria figure for sweet potato land area cultivated.

Though state-level land area allocation to cassava was not given in the 2014 Agricultural Performance Survey report, it was in the previous four reports. Therefore, the percentage of cassava land area allocated to each state out of the total land area sown to cassava was calculated for 2010, 2011, 2012, and 2013 and then applied to the 2014 Agricultural Performance Survey report's national figure.

To calculate per capita land area, state-level population was obtained from the 2016 Annual Abstract of Statistics Volume 1 Report, produced by the National Bureau of Statistics in Nigeria. To match the timeframe of production estimates, 2014 population figures were used. The percentage land area allocated to a given crop of interest, of total agricultural land area cultivated in a state was estimated by summing all crop land areas outlined in the 2014 Agricultural Performance Survey report. We recognize that the percentages may have upward biasness since not all crops were included in the report. However, total land area cultivated at the state-level was not available.

c. *Micronutrient deficiency data*

Micronutrient data was obtained from the 2013 Demographic and Health Survey (DHS) and the 2015 Nigeria Malaria Indicator Survey (MIS). The vitamin A and iron indicators were selected based on available data at the state-level; in a few instances, suboptimal indicators were used.

The percentage of children with moderate (7-9.9g/dl) or severe (below 7.0g/dl) anemia data was obtained from the 2015 Nigeria MIS. The percentage of children that consumed iron-rich foods in the last 24 hours came from the 2013 DHS. Unfortunately, anemia prevalence in women was not available. As a substitute, 98 minus the percentage of women that took 90 days or more of iron tablets during their last pregnancy was used, sourced from the 2013 DHS. Therefore, results for the iron pearl millet BPI are representative of only a portion of HarvestPlus' target population.

d. *Weighted BPI calculation data*

Additional data was needed to calculate the population- and area-weighted indices. For the population-weighted BPI, the percentage of the population that are HarvestPlus' target groups, children under five years of age and women of child-bearing age, was needed. This data was obtained from the United Nations Division of Economic and Social Affairs' World Population Prospects: The 2017 Revision for 2014 to maintain the same reference year throughout analyses. In the case of the area-weighted BPI, the total land area dedicated to crop *j* in Nigeria was obtained from the 2014 Agricultural Performance Survey Report.

3.6 Target Area Classification

Complementary to the subnational BPI results, the states are further classified into geographic target areas which identifies areas of impact and intervention (Funes et al., 2015). Specifically, states are disaggregated into three categories: (1) area of impact and intervention, (2) area of impact, and (3) area of intervention. These classifications follow the rules stated below:

$$1)\quad Areas\ of\ impact\ and\ intervention \begin{cases} Ci > Mdcj \\ Pi > Mdpj \\ Mi > Mdmk \end{cases}$$

$$2)\quad Areas\ of\ impact \begin{cases} Ci \geq Mdcj \\ Pi \leq Mdpj \\ Mi \geq Mdmk \end{cases}$$

$$3)\quad Areas\ of\ intervention \begin{cases} Ci < Mdcj \\ Pi > Mdpj \\ Mi < Mdmk \end{cases}$$

Where Mdcj is the median consumption of commodity j; Mdpj is the median production of commodity j, and Mdmk is the median estimated risk of micronutrient deficiency k.

Areas of impact and intervention, "hot spots", are areas of high production, high consumption, and high micronutrient deficiency. Areas of impact have high consumption and high micronutrient deficiency, but have low or no production while areas of intervention are defined by having high production but low levels of consumption and micronutrient deficiency.

In terms of policy, likely the easiest areas to introduce biofortified crops, are in the areas of both intervention and impact. Additionally, through this classification, potential trade flows can be identified from areas of intervention (food-surplus producing states) to areas of impact (crop-deficient states), allowing the population with the greatest need for the micronutrient in question to benefit. The trade flow is possible if (1) there is a demand for crop *j* in the location(s) of the destination, (2) there is market-surplus supply of crop *j* in the location(s) of origin, and (3) the transportation cost between origin and destination is not prohibitive.

4. RESULTS AND DISCUSSION

This portion of the paper reviews the empirical results of the analyses. The data on consumption, production, and micronutrient deficiency are used to estimate state-level, plus the FCT, rankings of the potential impact of biofortification. The rankings are then presented at quintile levels. Four combinations of biofortified crops are proposed: vitamin A maize, vitamin A cassava, vitamin A sweet potato, and iron pearl millet. Two maps are presented for each of the crops illustrating the BPI results and the geographic classification results. The BPI results are divided into five quintiles from little, low, medium, high, and top priority. The geographic classification results are split into the three aforementioned categories. Area- and population-weighted BPI results are also shared.

4.1 Unweighted BPI Results

Vitamin A Maize: States in the North Central zone and the southern part of the North East zone rank highest in the maize production index (Table 1). Some cross-over exists among the highest per capita maize consumption states and highest-ranking states in the production index, such as Plateau and Taraba.

Table 1: Top Ranking States for Individual Indices - Maize

Rank	Maize Production Index	Maize Consumption Index	Vitamin A Deficiency Index
1	Taraba	Plateau	Yobe
2	Plateau	Adamawa	Jigawa
3	Kogi	Bauchi	Zamfara
4	FCT	Taraba	Kano
5	Niger	Gombe	Kebbi

**Source: Authors' calculations.*

The 36 states, along with the FCT, were ranked according to their BPI score (Table 2). The top five states identified as the most promising for the introduction of vitamin A maize are Plateau, Yobe, Zamfara, Jigawa, and Borno (Figure 3). Nationally, northern zones rank the highest for the biofortified maize intervention. For geographic classification (Figure 3), many states identified as locations for both impact and intervention (12 states). These twelve states are: Niger, Zamfara, Kaduna, Nassarawa, Kano, Jigawa, Bauchi, Plateau, Yobe, Borno, Gombe, and Taraba, located in the North West, North East, and North Central zones. The two states identified as geographic locations for the intervention of biofortified vitamin A maize, Kwara and Ekiti, are in the North Central and South West zones, respectively; while

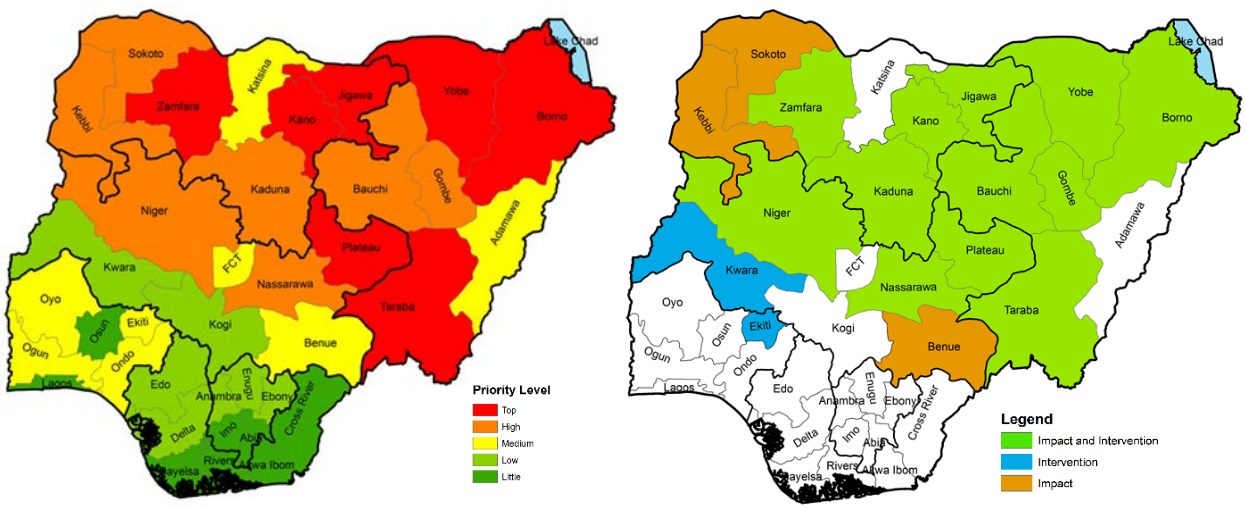
Sokoto and Kebbi, both in the North West zone, along with Benue in the North Central zone were identified as areas of impact.

Table 2: Vitamin A Maize State-level BPI

Rank	State	Zone	BPI Score
1	Plateau	North Central	100
2	Yobe	North East	95
3	Zamfara	North West	89
4	Jigawa	North West	88
5	Borno	North East	87

**Source: Authors' calculations.*

Figure 3: Geographic Targeting of Vitamin A Maize among States and Policy Intervention Areas



**Source: Authors*

Vitamin A Cassava: States ranking highest on the cassava production index are located in the eastern part of the South South zone, the South East zone, the southern part of the North East zone, and the eastern part of the North Central zone (Table 3). The highest levels of per capita cassava consumption were found to be located in the South South and South East zones. Of the top five ranking states among the production and consumption indices, the top two ranking states in both are Cross River and Enugu.

Table 3: Top Ranking States for Individual Indices - Cassava

Rank	Cassava Production Index	Cassava Consumption Index	Vitamin A Deficiency Index
1	Cross River	Cross River	Yobe
2	Enugu	Enugu	Jigawa
3	Kogi	Bayelsa	Zamfara
4	Taraba	Akwa Ibom	Kano
5	Imo	Rivers	Kebbi

**Source: Authors' calculations.*

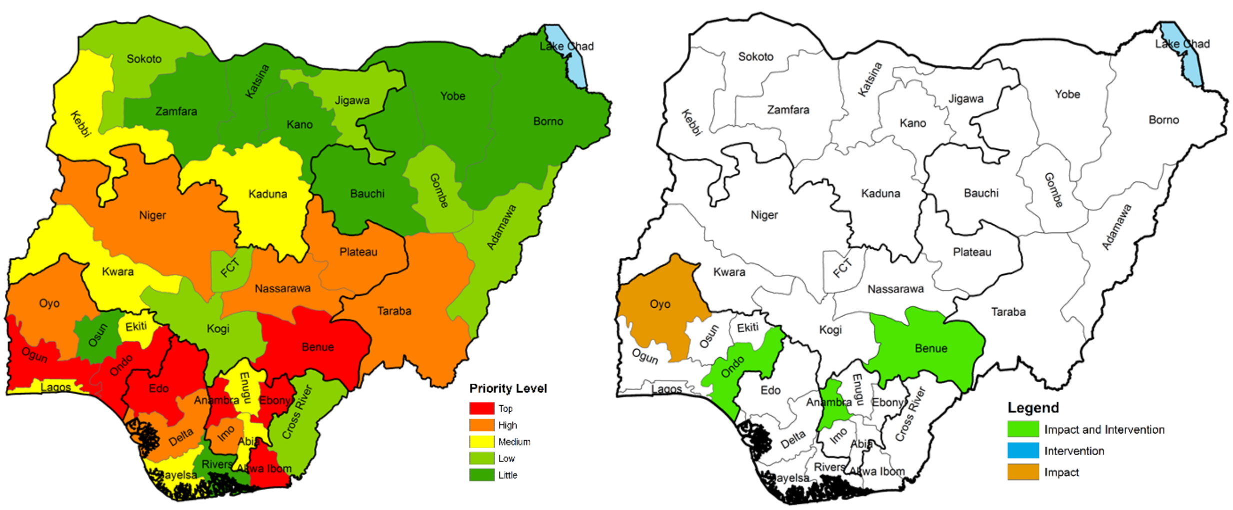
Table 4 outlines the best areas suited for the introduction of vitamin A cassava. Through the analysis, the southern zones were found to be the areas of best fit as opposed to the northern zones as was the case for vitamin A maize. The rankings of the vitamin A cassava BPI were largely driven by per capita consumption and production as the vitamin A deficiency highest ranking states are in a different part of the country. However, there is still potential benefit for addressing vitamin A deficiency as shown through the areas of geographic classification (Figure 4). Geographic locations identified for both impact and intervention include Ondo, Benue, and Anambra, all of which are included in the top 10 priority states based on the BPI for vitamin A cassava. No states identify as locations for intervention while Oyo identifies as the only state for impact.

Table 4: Vitamin A Cassava State-level BPI

Rank	State	Zone	BPI Score
1	Ogun	South West	100
2	Ondo	South West	88
3	Benue	North Central	86
4	Edo	South South	86
5	Ebonyi	South East	86

**Source: Authors' calculations.*

Figure 4: Geographic Targeting for Vitamin A Cassava among States and Policy Intervention Areas



**Source: Authors*

When comparing the results for priority areas for the introduction of vitamin A cassava to the delivery data shown in Figure 1 at the beginning of this paper, there is much cross-over. As of 2013, delivery was concentrated in the Southern zones with most dissemination taking place in Benue, Akwa Ibom, Anambra, Edo, Onodo, and Ogun, all of which are top priority states for the introduction of biofortified cassava. Much delivery has also taken place in Oyo state which is considered a high priority for the introduction of vitamin A cassava.

Vitamin A Sweet Potatoes: Much variation exists among the top-ranking states for each sub-index in the vitamin A sweet potato analysis (Table 5). Among the top five states for each index, only three states appear in more than one index, with more cross-over between the consumption and vitamin A deficiency indices. Nationally, sweet potato production tends to take place in the middle to southern half of the country. Conversely, highest consumption occurs in the North West and North East zones. However, it is unclear what is driving this consumption as very little production occurs in these states; potentially, there is cross-border trade of sweet potatoes in these zones from Niger or Benin.

Table 5: Top Ranking States for Individual Indices – Sweet Potatoes

Rank	Sweet Potato Production Index	Sweet Potato Consumption Index	Vitamin A Deficiency Index
1	Enugu	Sokoto	Yobe
2	Taraba	Katsina	Jigawa
3	Ondo	Kebbi	Zamfara
4	Niger	Yobe	Kano
5	Benue	Kano	Kebbi

**Source: Authors' calculations.*

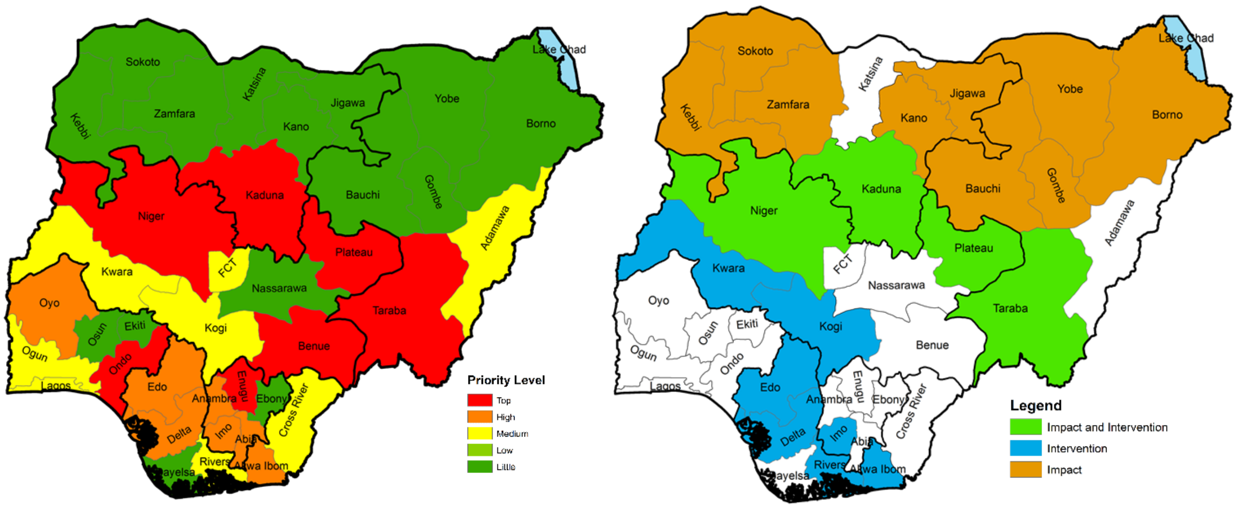
Based on BPI estimates, the middle portion of the country are the best locations for vitamin A sweet potato introduction (Figure 5). Due to the highest concentrations of vitamin A deficiency in the upper North East and North West, the highest sweet potato production occurring in the middle to southern zones, and the highest consumption being in the North West, there is little overlap in states ranking at the top for all three sub-indices. For instance, while the top state, Niger, is not among the top five in any of the individual indices, the state ranked within the top 10 of all three indices. Kaduna, a close second, ranked within the top 13 of all indices.

Table 6: Vitamin A Sweet Potatoes State-level BPI

Rank	State	Zone	BPI Score
1	Niger	North Central	100
2	Plateau	North Central	88
3	Taraba	North East	85
4	Kaduna	North West	76
5	Benue	North Central	63

**Source: Authors' calculations.*

Figure 5: Geographic Targeting of Vitamin A Sweet Potato among States and Policy Intervention Areas



**Source: Authors*

While the BPI is divided into quintiles, not all states cultivate sweet potatoes, resulting in the state receiving a zero for the production index. Due to the BPI's calculation, a zero in one sub-index automatically yields an overall score of zero. As evidenced in the map, forty percent (two quintiles), result in a BPI score of zero; therefore, the quintile representing "Low" priority is not shown. Furthermore, Figure 6 shows strategic areas for the intervention and impact of vitamin A sweet potato. Geographic areas suitable for both intervention and impact include Niger, Plateau, Kaduna, and Taraba, which reinforce findings from the BPI calculation. Unfortunately, areas of intervention and areas of impact are not geographically located near one another, making potential trade flows of vitamin A sweet potatoes, more difficult.

Iron Pearl Millet: The millet production index is highest in the North East and North West zones while consumption is also high in these same zones (Table 7), likely because the majority of consumption comes from own production or in market locations in these geographical locations. Iron deficiency is also heavily concentrated in the North West followed by the North East. Zamfara is the only state present within the top five ranking of all three indices while Sokoto, Yobe, Kebbi, and Jigawa are present in two indices.

Table 7: Iron Pearl Millet State-level Indices

Rank	Millet Production Index	Millet Consumption Index	Iron Deficiency Index
1	Yobe	Sokoto	Yobe
2	Adamawa	Kebbi	Jigawa
3	Gombe	Jigawa	Zamfara
4	Zamfara	Zamfara	Kano
5	Sokoto	Katsina	Kebbi

**Source: Authors' calculations.*

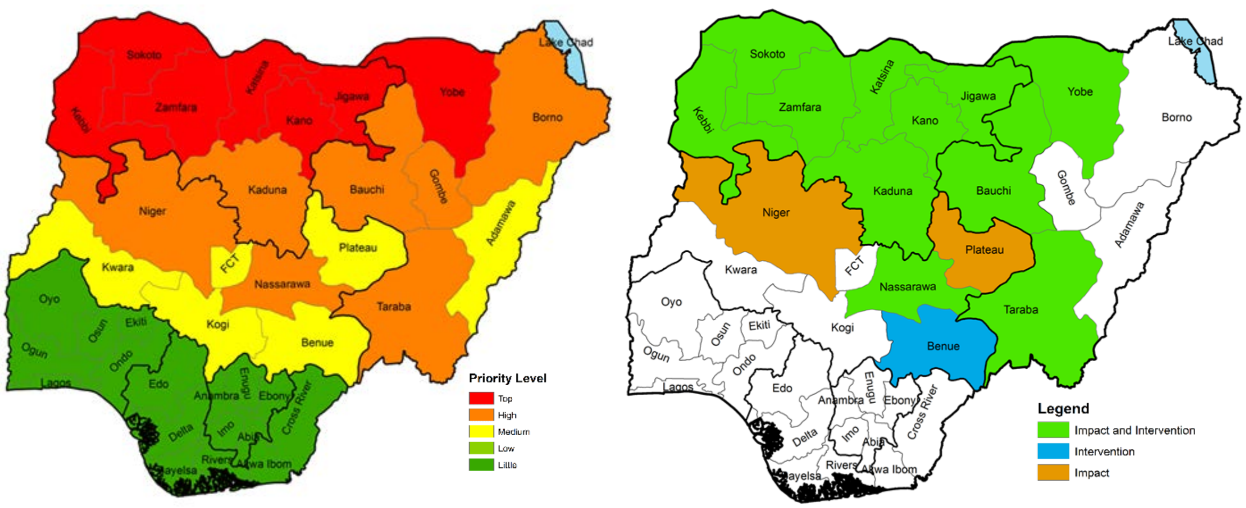
States within the North West and North East zones are the most promising for the introduction of iron pearl millet (Table 8, Figure 6). There is much overlap in the states of highest production, consumption, and iron deficiency. For instance, Zamfara, ranked as the highest priority state for the introduction of iron pearl millet, is among the top five states in each sub-index ranking.

Table 8: Iron Pearl Millet State-level BPI

Rank	State	Zone	BPI Score
1	Zamfara	North West	100
2	Sokoto	North West	94
3	Kebbi	North West	89
4	Yobe	North East	85
5	Katsina	North West	82

**Source: Authors' calculations.*

Figure 6: Geographic Targeting of Iron Millet among States and Policy Intervention Areas



**Source: Authors*

Similar to the BPI map for vitamin A sweet potatoes, the iron pearl millet BPI map shows only four quintiles as forty percent of states' iron pearl millet BPI scores are zero due to no production of millet (Figure 6). Again, the "Low" priority quintile was left out. Several states standout as areas for intervention and impact for iron pearl millet, including: Bauchi, Jigawa, Kaduna, Kano, Katsina, Kebbi, Nassarawa, Sokoto, Taraba, Yobe, and Zamfara.

4.2 Weighted BPI Results

The below section presents the empirical results when the target population and share of cropped land area are factored into the BPI estimation. These analyses follow the methods shared in section 3.4.

a. Population-weighted BPI

As noted earlier, the population-weighted BPI is biased towards more densely population states. Not surprisingly, the top ten priority ranking for each crop reshuffles quite a bit from the unweighted BPI results (Table 9).

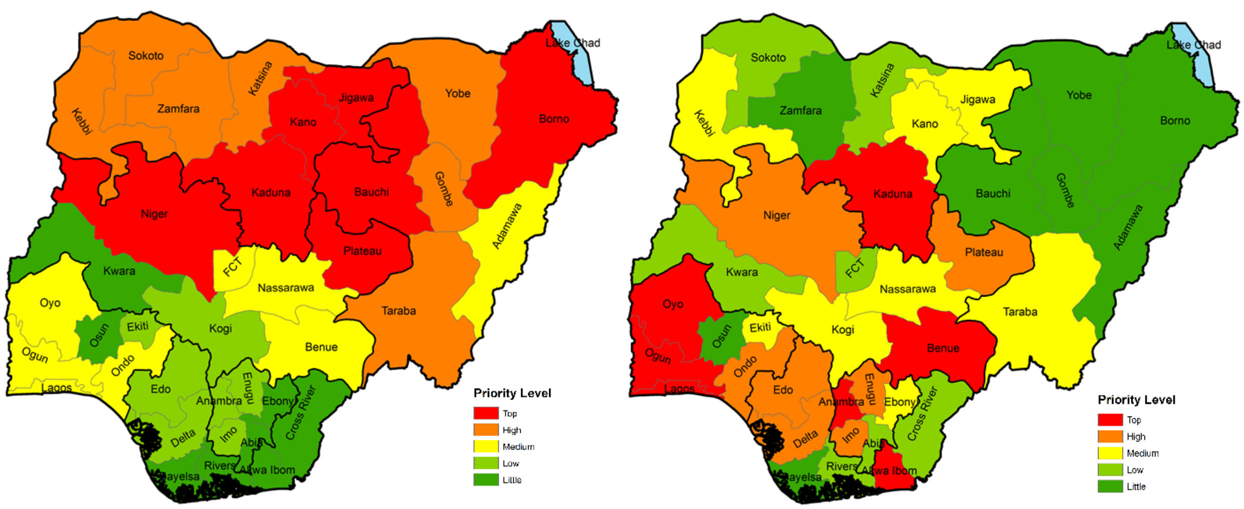
Table 9: Population-Weighted State-level BPIs, by Crops

Ranking	Vitamin A Maize	Vitamin A Cassava	Vitamin A Sweet Potatoes	Iron Pearl Millet
1	Kano	Lagos	Kaduna	Kano
2	Kaduna	Oyo	Niger	Katsina
3	Jigawa	Ogun	Plateau	Jigawa
4	Borno	Benue	Benue	Sokoto
5	Bauchi	Anambra	Taraba	Zamfara

**Source: authors' calculations.*

For the expansion of vitamin A maize, of the top five states, only two states are the same between the weighted (Figure 8a) and unweighted indices while five states are found in both indices' top ten ranking. Vitamin A cassava (Figure 8b) has a similar story with only two states crossing over in the top five ranking and five among the top ten ranking between the two BPI indices.

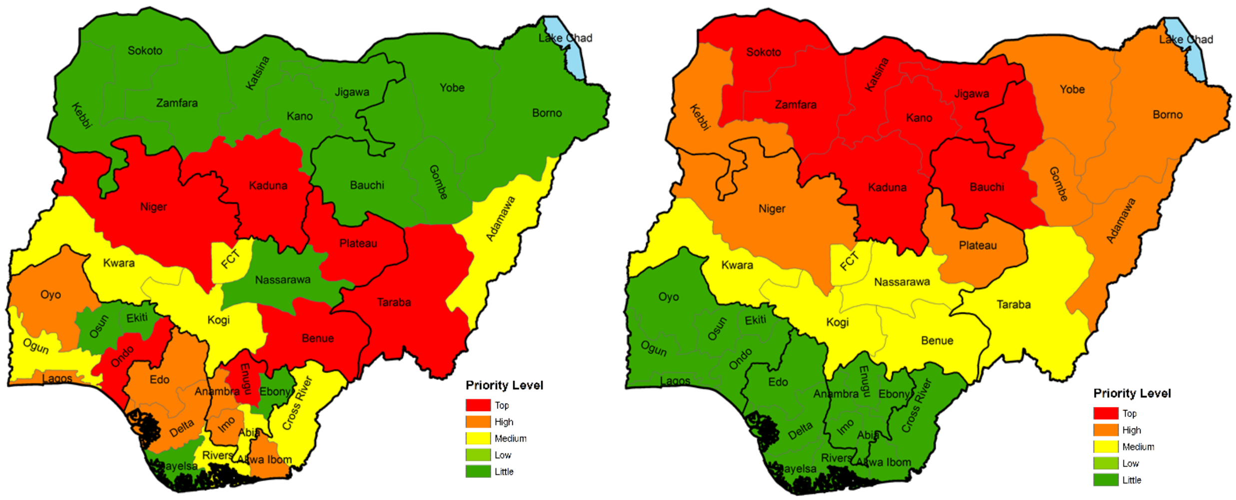
Figure 7: Population-weighted BPI among States for (a) Vitamin A Maize, (b) Vitamin A Cassava



**Source: Authors*

Due to less states producing sweet potatoes compared to maize and cassava, results from the population-weighted (shown in Figure 9a) and unweighted indices are similar; the top 5 states are the same in both indices, though reordered. Millet, like sweet potatoes, has more cross-over between the two indices than maize and cassava since the total pool of states to draw upon is less since not all states produce millet. Of the top five states, three are found in both indices (Figure 9b).

Figure 8: Population-weighted BPIs among States for (a) Vitamin A Sweet Potatoes, (b) Iron Millet



**Source: Authors*

b. Area-weighted BPI

The area-weighted BPI reshuffles results from the unweighted indices for each crop as states with larger land areas are given priority over smaller land areas. Additionally, those states which have lower crop diversity are also advantaged over states with high crop diversity. Results for the area-weighted BPI are shown in Table 10 below.

Table 10: Area-Weighted State-level BPIs, by Crops

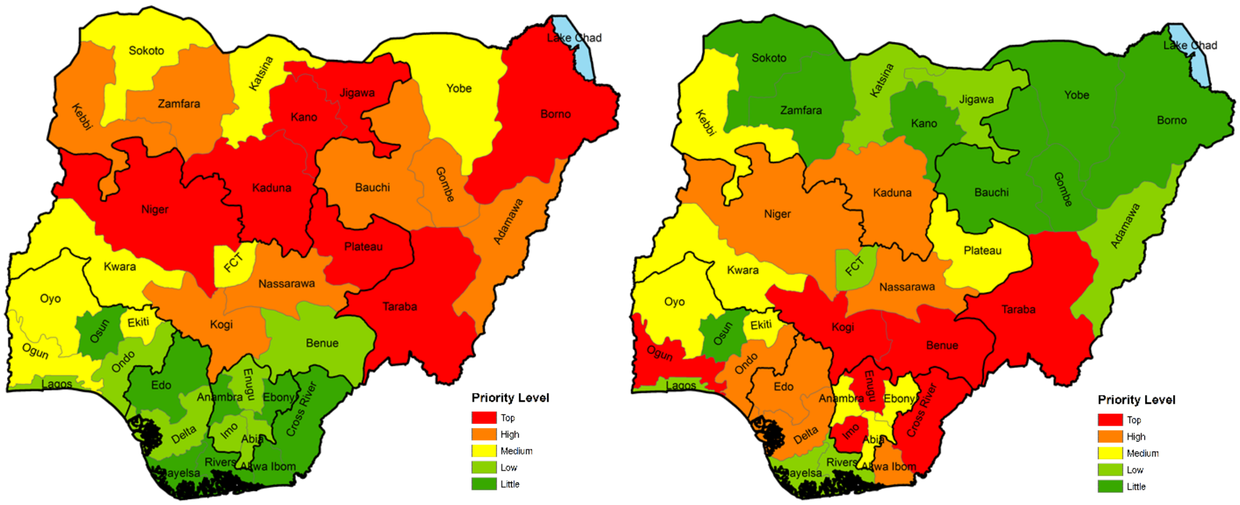
Ranking	Vitamin A Maize	Vitamin A Cassava	Vitamin A Sweet Potatoes	Iron Pearl Millet
1	Taraba	Benue	Niger	Yobe
2	Kaduna	Taraba	Taraba	Zamfara
3	Niger	Ogun	Benue	Sokoto
4	Borno	Enugu	Enugu	Kebbi
5	Plateau	Imo	Kaduna	Katsina

**Source: Authors' calculations.*

Of the vitamin A maize area-weighted BPI (Figure 9a) top five ranking results, only two states, Borno and Plateau, are present in the top five unweighted vitamin A maize BPI results, though nine are present within the top ten. A major difference in the rankings is that the second ranked priority state in the unweighted vitamin A maize BPI, Yobe, falls out of the top ten in the area-weighted ranking.

In the case of vitamin A cassava (Figure 9b), there is more cross-over between the unweighted and area-weighted BPI rankings. Of the top ten states in the unweighted BPI, six are present in the area-weighted BPI, with smaller geographical states falling out. Of the top five ranking, two states, Ogun and Benue, are present in both rankings.

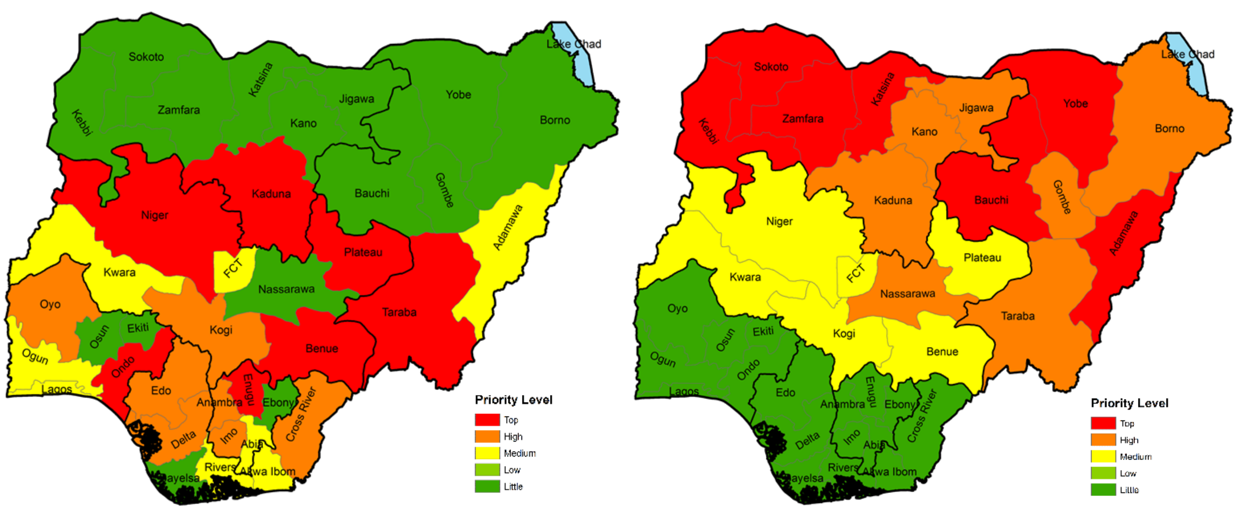
Figure 9: Area-weighted BPI among States for (a) Vitamin A Maize, (b) Vitamin A Cassava



**Source: Authors*

The last two crops, vitamin A sweet potatoes and iron pearl millet, have much overlap between their unweighted and area-weighted BPI results (Figure 10). Potentially this occurs due to less states growing these crops so production is already concentrated in only a portion of the states in the unweighted version of the rankings. In the case of vitamin A sweet potatoes, four of the top five states are present in both rankings while iron pearl millet's top five rankings in the unweighted and area-weighted BPIs, are a complete match while nine of the top ten states are present in both rankings.

Figure 10: Area-weighted BPI among States for (a) Vitamin A Sweet Potato, (b) Iron Millet



**Source: Authors*

5. CONCLUSIONS

This paper examines the introduction potential of four biofortified crops: vitamin A maize, vitamin A cassava, vitamin A sweet potatoes, and iron pearl millet. To inform the expansion strategy for vitamin A maize, cassava, and sweet potatoes and the introduction strategy for iron pearl millet, production and consumption information for each non-biofortified crop was built into sub-indices, along with vitamin A and iron deficiency indicators, to estimate a subnational Biofortification Priority Index (BPI). This paper's analyses are conducted at the state-level, plus the Federal Capital Territory, due to Nigeria being a very heterogenous country.

In addition to the subnational BPI, states are classified as being both impact and intervention states, intervention only states, and impact only states to identify areas which likely have the least barriers to entry, in terms of policy. These results can collectively be used to better inform decision-makers as to where biofortification investments should be focused as resources are finite. Evaluating states that are a high priority in the BPI and are considered areas of impact and intervention are the recommended states for biofortified crops' first introduction or expansion. Furthermore, if decision-makers have specific factors which they want to prioritize, the subnational BPI for the four crops analyzed in this paper are also estimated with area- and population-weighting.

Within Nigeria, results show that certain states are more well-suited for specific crop-micronutrient combinations than other states. For the expansion of vitamin A maize, the zones in the north, particularly the North East and North West, appear to be the most promising, though Plateau state in the North Central zone ranks as the highest priority. The specific states which appear to be the best entry points for the expansion of vitamin A maize are Zamfara, Kano, Jigawa, Plateau, Taraba, Yobe, and Borno as they are all high priority states and states of both impact and intervention. In the case of vitamin A cassava expansion, following an expansion strategy into the South West, South South, and South East zones would be most beneficial based on the subnational BPI estimations which confirms that HarvestPlus' initial delivery efforts throughout the South are efficacious. Combining the BPI results with the geographic classification areas of impact and intervention specifically identifies Ondo, Benue, and Anambra as the optimal states for the first step.

Unlike the other crops, the areas of high priority for sweet potatoes are not necessarily concentrated in one area, making geographical priorities difficult. However, concentrating efforts in the North Central zone would be a beneficial geographical area to begin in as three of the top five priority states are located within this zone and the two states remaining in the top five, neighbor the North Central zone. Working initially in the states of Niger, Plateau, Kaduna, and Taraba is recommended based on results. Once introduction and delivery of vitamin A sweet potatoes takes place in the North Central zone, moving southward to all states bordering North Central, whether in the South West, the South South, or the South East would be the most productive strategy. And finally, the introduction of iron pearl millet, should be concentrated in the North West, followed by the North East. Based on analyses, it is recommended to work specifically in Kebbi, Sokoto, Zamfara, Katsina, Kano, Jigawa, and Yobe.

While developing an expansion or roll-out strategy for biofortified crops depends on both tangible, such as where maize is grown, and intangible matters, such as the current geographic concentration of crime or nearest location to agricultural research centers, it is suggested that this subnational BPI and geographic classification be used as a starting place to serve as complementary information. Through the successful targeting and implementation of biofortified crops within Nigeria, nutritional status and health could greatly be improved without requiring major behavior changes, leading to a more sustainable intervention.

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