The association between agricultural conditions and multiple dimensions of undernutrition in children 6-23 months of age in Burkina Faso

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Abstract

Background. The quality and quantity of food available to children affect their nutritional status, with implications for long-term health and development. In Burkina Faso, households rely on rainfed agriculture, but climate change is making crop production unreliable. We explore spatial patterns of growing season quality on dimensions of nutritional status and complementary feeding practices in children 6–23 months. Methods. The 2017 Performance Monitoring and Accountability 2020 (PMA2020) nutritional survey was spatially integrated with a contemporaneous remotely sensed drought indicator, the Water Requirement Satisfaction Index (WRSI), which captures local anomalous growing season conditions. Multi-level mixed-effects logistic regression models were estimated to explore the effects of WRSI on child mid-upper arm circumference (MUAC) score (indicating malnutrition), and two components of complementary feeding practices, adjusting for demographic and household characteristics. Results. The data set included 1,721 children. Higher WRSI values (better agricultural conditions and crop performance) were associated with 3% lower odds of malnutrition (Odds Ratio (OR) = 0.971; 95% confidence interval (CI): [0.942, 1.00]) and 7% higher odds of a child attaining minimum dietary diversity (OR = 1.07; 95% CI: [1.01, 1.14]). Undernourished mothers were significantly (p < 0.001) more likely to have an undernourished child. Minimum dietary diversity met for the child was protective against malnutrition; the association between WRSI and malnutrition persisted after adjustment. Conclusions. WRSI was associated with the child’s dietary diversity and malnutrition, highlighting the importance of seasonally and spatially varying local agricultural production and the relationship between growing season conditions and child nutritional status, with dietary diversity providing a potential mechanism for intervention.

Background

In 2019, an estimated 8.9% of people on the planet were undernourished [1]. Food insecurity outcomes, like undernourishment, increase the risk of morbidity and mortality and result from complex multi-dimensional factors and processes varying over space and time [2, 3]. In low-income countries dependent on rainfed agriculture, key components of food security, food availability, and accessibility can vary dramatically between and within communities in response to fine-scale variation in climate and growing season conditions (e.g., rainfall and temperature) [2, 4–6]. In these settings, adoption of healthy infant and young child feeding (IYCF) practices, including exclusive breastfeeding and introduction of solid, semi-solid, or soft foods at 6–8 months, can be critical to ensuring children attain their nutritional needs and meet growth metrics [7, 8]. It is possible, however, that individuals employ IYCF practices in different ways based on local food conditions, and, specifically, available food. The body of research exploring the relationships between local agricultural...
conditions, food availability, IYCF practices, and child health outcomes is rapidly growing [9, 10]; however, a significant gap in literature remains, especially in terms of the role of seasonal climate and weather factors as they relate to health outcomes and associated behaviors in rainfed agriculture-dependent settings [11, 12].

In this study, we investigate the ways that local agricultural conditions are associated with malnutrition in children 6–23 months in Burkina Faso by integrating newly developed and unique data sets—spatially referenced health survey data from the Performance Monitoring and Accountability (PMA) 2020 project—with an operational, remotely sensed indicator of agricultural conditions commonly used by USAID’s Famine Early Warning Systems Network (FEWS NET). Nutrition behavior survey data often do not include geographic or spatial information, making this type of integration by location impossible. Burkina Faso is an ideal setting for this study because the vast majority of households rely on rainfed agriculture for a low-cost source of calories [10, 13]. Households vary in their livelihood strategies; some (subsistence farmers) consume what they produce, while others rely on low-cost grains purchased at the market. The short growing seasons and highly spatially variable rainfall, however, result in large variations in agricultural production. A poor agricultural growing season reduces production and can result in reduced food availability.

Climate, agriculture, and nutrition are tightly linked, particularly in rainfed, subsistence agricultural regions like Burkina Faso [9]. Precipitation and evaporative demand (driven by solar radiation, air temperature, humidity, and wind) are integral components of agricultural production. FEWS NET has refined a quantitative tool—the Water Requirement Satisfaction Index (WRSI)—to combine these climatological inputs for use in agricultural monitoring [14]. If agricultural water demands are not met, crop productivity may decrease, resulting in insufficient quantities and varieties of food available to meet nutritional requirements. The WRSI was designed as a means for calculating the water stress experienced by a crop during an agricultural growing season due to plant and atmospheric demand greater than the water availability. It has been shown to be an effective means of distinguishing between water-limited and water-unlimited cropping areas in Ethiopia [15], for determining the drought risk of maize in Brazil and South Africa [16–18], and it is positively correlated with crop yield in various African settings [15, 18–20]. Quality of the agricultural season may also cause economic impacts, especially for agricultural households who have no surplus to sell [21]. These households may struggle to afford supplemental foods or healthcare services that often include nutritional interventions or guidance [9]; this economic insecurity impacts health outcomes, including malnutrition [6]. Correspondingly, the WRSI is commonly used to identify areas at greatest risk for food insecurity, particularly when other sources of data (e.g., crop yield or health data) are sparse [15, 22–24].

Poor or inconsistent agricultural conditions can contribute to food insecurity and child malnutrition because they reduce the yields that farmers can sell or consume. Human behavior related to feeding and caretaking practices may be effective in mediating these effects [6, 8, 25]. Global child health and nutrition programs aim to foster IYCF practices—including exclusive breastfeeding and safe preparation, quantity, and diversity of complementary foods—to help ensure that children grow and develop healthily [7, 26]. Two key indicators of complementary feeding are minimum dietary diversity (MDD) and minimum meal frequency (MMF). Each of these captures an aspect of IYCF practices, adjusted for age and breastfeeding; together, they comprise a minimum acceptable diet (MAD) [26]. In Burkina Faso, a significant portion of the population does not achieve these key indicators [27].

Evidence of the links between anthropometric measures of malnutrition and indicator are mixed; a recent multi-country analysis found that children 6–23 months who did not meet MAD were significantly more likely to be stunted, but found no relationship between MMF and stunting [28]. A study from Bangladesh found a strong association between dietary diversity score (a measure similar to MDD) and stunting, as consumption of a higher number of food groups was associated with improved nutritional adequacy of the diet [29]. The different associations for MDD and MMF may be attributed to the inherently subjective nature of indicators like food diversity or the challenges in recall [30, 31]. Therefore, while behavioral measures capture some potentially important aspects of food and nutrition security, anthropometric measures, including mid-upper arm circumference (MUAC), continue to provide important insight into health and well-being [32].

We explore the association between a community’s agricultural season quality (estimated via WRSI anomalies), IYCF practices (MDD and MMF), and anthropometric measures of malnutrition (measured by MUAC) in children 6–23 months of age. This research provides an approach for assessing the relationship between agricultural quality and child nutrition that considers behavioral aspects of child health-related to food security, as well as anthropometric measures. The analysis [1] can be replicated in other settings, [2] may be useful to inform the development of more targeted nutrition-sensitive interventions, and [3] highlights caretaking strategies that seem to protect children in a context of reduced seasonal agricultural yields.
Data and measures

Health and nutrition survey data
In 2017, the Performance Monitoring and Accountability 2020 (PMA2020) project conducted a rapid survey regarding nutrition indicators in Burkina Faso from June to September, coinciding with the lean season—the period of time before the current harvest when food stores from the prior year’s harvest tend to run low. The PMA2020 nutrition survey included questions regarding mother and child feeding practices, key demographic characteristics, and anthropometric measures. A two-stage cluster sampling design with urban-rural strata was implemented, comprised of 83 enumeration areas (42 rural and 41 urban areas) and 89 households randomly selected per enumeration area. Each enumeration area is spatially referenced, but to preserve confidentiality, each location is displaced up to 2km for urban and 5km for rural locations [33].

Nutritional outcome measures
In the PMA2020 survey, MUAC scores are collected in centimeters. According to the United Nations Children’s Fund (UNICEF), which has defined global measures for malnutrition, MUAC measurement under 11.5cm in children indicates severe undernutrition and under 12.5cm indicates acute undernutrition [32]. Measurements between 12.5 and 13.5cm refer to people “at risk” of acute undernutrition. Many recent papers have argued that 11.5 or 12.5cm are too low and therefore fail to properly identify undernourished children [34–36]. For the purposes of this analysis, we created a dichotomous variable using a threshold of 13.5 cm to include at-risk children that would benefit from programmatic intervention.

MDD, MMF, and MAD are indicators used by the World Health Organization (WHO) to assess multiple components of IYCF practices [26]. If a child receives foods from five or more food groups the previous day, out of eight different categories (breast milk; grains, roots and tubers; legumes and nuts; dairy products; flesh foods; eggs; vitamin A-rich fruits and vegetables; other fruits and vegetables) they have achieved MDD. For a child to achieve MMF, they must receive solid, semi-solid, or soft foods a specific number of times in the previous day—two times for breastfed infants 6–8 months, three times for breastfed children 9–23 months, and four times for non-breastfed children 6–23 months. Each of these is a dichotomous variable to denote whether the child meets each requirement. MAD is a composite indicator of MDD and MMF. We present findings for MDD and MMF only since MAD is a combination of these and yields similar results. MAD results are available from the authors. Figure 1 highlights which food groups are consumed from each category by child’s age.

Socio-demographic characteristics
In this analysis, we included a range of independent variables that capture variation in the outcome variables. We included a composite indicator of household assets, defined as household wealth tercile from the PMA survey, as well as total number of children residing in the home, and perceived food insecurity (none, moderate, or severe). We also included several variables regarding the child’s mother (the survey respondent)—such as the mother’s age and if she had completed some education (dichotomous variable). We categorized mother’s MUAC score into three levels to denote normal (>25 cm), moderate malnourished (25–22 cm), and severely malnourished (≤22cm), since studies have linked maternal nutritional status with her child’s. Child-specific variables included

Figure 1. Food groups reportedly consumed in the previous 24 h (the eight components of minimum dietary diversity [MDD] indicator) by age group for children ages 6–23 months.
child’s age and recent diarrheal illness. Recent studies have linked these variables with child malnutrition, therefore we adjusted for them in the analysis.

In addition, we also included livelihood-zone information. Livelihood zones capture the general strategies for procuring income and food in an area and are widely used in climate-health research [21, 37]. Consistent with related research, we collapsed these groups based on the similarities between them into three broad groups from the original nine detailed [38]—urban, agricultural, or agropastoral/pastoral. We included both urban and rural households because of the potential for rainfed urban agriculture to have an impact on child health.

WRSI
The Water Requirement Satisfaction Index (WRSI) is an indicator of crop performance based on the availability of water to the crop during a growing season [22, 39]. In this study, we used Climate Hazards InfraRed Precipitation with Stations (CHIRPS) [40] and the NOAA ESRL PSD Global Reference Evapotranspiration for the FEWS NET Science Community (RefET) [41] for the rainfall and atmospheric water demand inputs, respectively, to calculate the WRSI. The reference crop used for adjusting the reference evapotranspiration was millet [15, 42]. Standard WRSI calculations use a single dominant crop as the reference crop. The use of millet as the reference crop may impact the median WRSI in an area, but preliminary research suggests that the correlation between WRSI and local yields does not change when using a different reference crop. In other words, using WRSI as a comparative (over space and time) measure of seasonal yield is not sensitive to the reference crop.

The WRSI data is available at the spatial scale of 0.1 degrees (10km). While the year of interest corresponding to the sampling and nutrition survey was 2017, WRSI values were calculated for 1981 to 2019 to establish a long-term average (1981–2019 median). WRSI anomalies used in this analysis are measured by subtracting the 2017 value from this average; positive values represent better-than-typical crop performance in that year, whereas negative values suggest worse than typical. A map of WRSI anomaly values per enumeration area/cluster is presented in figure 2.

**Statistical methods**

We constructed two sets of multilevel mixed-effects logistic regression models. First, we explored the two IYCF practice variables, to understand factors associated with MDD and with MMF, including agricultural conditions.
as measured by WRSI anomaly. We do not present the model for MAD because the results are similar to MDD. These models also adjust for perceived household food insecurity (high, moderate, or low) if this may be associated with IYCF practices. Second, we explored the main outcome of malnutrition as measured by MUAC, adjusting for WRSI anomaly, and then also for MDD and for MMF. The MUAC models also adjust for two other variables that are highly associated with malnutrition: diarrhea in the last 2 weeks (dichotomous) and mother’s MUAC score category [43, 44]. In both models, the main outcome of interest was WRSI anomaly, to explore if agricultural conditions were associated with IYCF practices and/or malnutrition as measured by MUAC.

All of the models adjust for mother’s age, education (any versus none), child’s birth month, child’s age (6–12 months versus 12–23 months), survey month (June, July, or August), livelihood zone (3 categories), and total children in the home (1, 2, 3, 4+ children). The random component in the model is enumeration area to account for the similarities between households from the same enumeration area (e.g., the 83 enumeration areas used for sampling by PMA2020) [45].

Results

Our sample characterizes the nutritional status of 1,721 children 6–23 months of age, with descriptive statistics tabulated using a weighted proportion based on the cluster sampling design presented in table 1. Most mothers surveyed were 25–34 years old (47%), one third had some formal schooling (33%), and most had other children in the home (table 1). While most mothers had a healthy MUAC score (74%), 24% were moderately malnourished and 2% were severely malnourished; 34% of children were at risk or malnourished (<13.5cm). The proportion of malnourished children increased linearly as the mother’s malnourishment increased (figure 3).

Almost half (49%) of children met MMF guidelines, but only 15% met MDD guidelines—the combined indicator, MAD, was reached by only 10% of children. Over half (60%) did not perceive any household food insecurity at the time of the survey; however, 19% perceived moderate food insecurity, and one in five (21%) perceived severe food insecurity.

Factors associated with malnutrition (child MUAC score)

In table 2 we present the multi-level mixed-effects logistic regression model with child MUAC score as the outcome variable, capturing acute child growth conditions often used to indicate wasting. In model 1, the seasonal and place-based WRSI was significantly associated with children having a MUAC score<13.5cm indicative of experiencing acute poor growth (wasting) or considered at risk. This means that in places with a higher WRSI, relative to the mean, and with no adjustment for IYCF, the odds of a child having a low MUAC score decreased 3% (OR = 0.967; 95% CI: 0.937, 1.00) (table 2). For some children who are near the margin or threshold for intervention, seasonal variation in agricultural yield could therefore play an important role in shifting them from (or into) different risk categories. Notably, however, when including behavioral factors related to feeding and care (IYCF) in the regression models (Model 2 and 3), we observed that children who met MDD guidelines had 35% lower odds of a poor MUAC score (OR = 0.648; 95% CI 0.464, 0.906). MMF was not associated with MUAC. In other words, factors related to agricultural season and behavior are both significantly related to child health outcomes; however, the greatest impact results from feeding practices related to diversity, versus frequency, of food provided.

Factors associated with IYCF practice outcomes

The results from the multi-level model linking WRSI with the two different IYCF nutrition outcomes are presented in table 3. In Model 1, WRSI was not significantly associated with MMF, but in Model 2 WRSI was significantly associated MDD (table 3). As WRSI improved, suggesting improved crop production relative to average for the 10km² area, the odds of a child meeting MDD guidelines increased 7% (OR = 1.073; 95% Confidence intervals: 1.006, 1.145) (table 3). Both models adjust for WRSI, yet several associations persist. In these models, we include perceptions of household food insecurity. Even after adjustment for WRSI, the model results suggest that when mothers perceived their household to be severely food insecure their children had lower odds of achieving MDD (OR = 0.578; 95% CI: 0.371, 0.901) (table 3). Children of mothers who had any formal schooling were more likely to achieve MDD. Older children (12–17, or 18–23 months) were also more likely to meet MDD and MMF guidelines compared to children 6–11 months old.

Discussion

When the WRSI was lower, a likely indication of reduced agricultural yields, children were both less likely to achieve dietary diversity (MDD) guidelines and more likely to have a low MUAC score indicating they face an increased risk of undernutrition. Potentially, better local agricultural conditions improve access to, and
availability of, a greater range of food required to achieve basic childhood nutrition. Our findings highlight the association between agricultural conditions (as measured by WRSI anomaly), IYCF, and undernutrition. Previous studies have found an association between meteorological conditions or remotely sensed data consistent with drought and malnutrition [46, 47]; however, few studies have also linked such objective measures of agricultural conditions with achievement of IYCF practices. Studies on this often rely on survey data [11] or focus on the relationship between IYCF practices and social and behavior change interventions [48].

Factors associated with malnutrition (child MUAC score)
As local agricultural conditions worsened, per WRSI anomaly measure, the odds of a child being at risk of or experiencing malnutrition increased significantly. This association persisted even after adjustment for complementary feeding practices such as MDD and MMF. This result could occur because of changes in food availability and associated market food prices (e.g., more grains reduce the prices of grains and allow families to buy a range of different foods with the money they would have spent on grains). While consuming a more diverse diet was protective against malnutrition, when WRSI and MDD were included in a statistical model together, WRSI anomaly continued to be associated with lower MUAC scores, suggesting additional factors may explain the relationship between agricultural season conditions and MUAC scores outside of IYCF practices.

### Table 1. Descriptive characteristics of respondents.

| Characteristics                        | No. | Weighted % |
|----------------------------------------|-----|------------|
| Demographics                           |     |            |
| Mother’s age in categories             |     |            |
| 15–20 years                            | 153 | 9%         |
| 20–24 years                            | 429 | 25%        |
| 25–34 years                            | 816 | 47%        |
| 35+ years                              | 322 | 19%        |
| Mother ever attended school            | 634 | 33%        |
| Total children in household            |     |            |
| 1                                      | 574 | 31%        |
| 2                                      | 631 | 38%        |
| 3                                      | 278 | 17%        |
| 4+                                     | 238 | 14%        |
| Livelihood zone                        |     |            |
| Agricultural                           | 929 | 59%        |
| Urban/Ouagadougou                       | 284 | 12%        |
| Agropastoral or pastoral               | 508 | 29%        |
| Child’s Age Category                   |     |            |
| 6–11 months                            | 644 | 38%        |
| 12–17 months                           | 603 | 34%        |
| 18–23 months                           | 474 | 28%        |
| Nutrition Indicators                   |     |            |
| Mother MUAC category                   |     |            |
| Mother healthy (MUAC ≥ 25)             | 1,260| 74%        |
| Mother moderate malnourished (MUAC >22 & <25) | 418 | 24%        |
| Mother severe malnourished (MUAC ≤ 22) | 36  | 2%         |
| Child MUAC undernourished + at risk (MUAC ≤ 13.5) | 573 | 34%        |
| Child had diarrhea in last 2 weeks     | 578 | 33%        |
| MMF: Minimum meal frequency among 6–23 months | 828 | 49%        |
| MDD: Consumed minimum diversity foods  | 270 | 15%        |
| MAD: Minimum acceptable diet among 6–24 months | 171 | 10%        |
| Perceived household food insecurity    |     |            |
| No perceived household food insecurity | 1,025| 30%        |
| Moderate perceived household food insecurity | 309 | 19%        |
| Severe perceived household food insecurity | 387 | 21%        |
Other factors were associated with poor MUAC score after controlling for WRSI anomaly and complementary feeding practices. These include recent diarrhea, mother’s nutritional status, and education, which have all been highlighted in the literature. First, having diarrhea in the last 2 weeks was highly associated with malnutrition. Diarrheal diseases and infections have long been linked with malnutrition, creating a cycle that results in poor health and growth [49]. Diarrhea is both a cause and an effect of malnutrition; malnutrition increases the frequency and duration of diarrheal illnesses, while diarrhea leads to poor absorption of nutrients [50]. Additional factors associated with malnutrition were related to the mother’s nutrition and education. The link between a mother’s MUAC score and her child’s MUAC score has been reported previously [44]. A mother’s education has also been linked to better nutritional and health outcomes for her child [43, 51, 52]. A randomized evaluation in Burkina Faso found that a 2-year integrated agriculture and nutrition program targeted to mothers reduced the mothers’ underweight and increased her empowerment [48]. Lastly, studies suggest older children are more likely to meet IYCF practice requirements [8]. Potentially, younger children are breastfeeding more and not getting as many or as varied supplemental meals [7]. A study in Bangladesh supports this, suggesting breastfed children have a lower diversity of complementary foods [29]. Other studies also found stunting to be higher among older children, with younger children less likely to meet recommended MDD and MMF [8, 28].

Factors associated with IYCF practice outcomes
The significant association of WRSI with MDD suggests that when the agricultural year is better, there may be more types of food to eat, meaning greater diversity in diet and greater ability to purchase food [27, 53, 54]. Mothers who perceived their household food insecurity level to be severe were significantly less likely to meet MDD requirements, but this was not significant for meal frequency as measured by MMF. This suggests that the types of foods available are perceived, by the respondent, as important to a child’s nutrition [53] while practices around meal timing/occurrence are not necessarily connected to an individual’s perception of food insecurity. Meal frequency may also be more subjective and challenging to measure or less likely to vary according to changes in food availability (e.g., if the mother was not with the child at every meal, or if smaller meals are not counted, or if meal times occur consistently, regardless of the quality/quantity of food available).

Overall, our data suggests more children consumed the recommended MMF (49%), while only 15% met MDD requirements and only 10% met the combined MAD requirements. Thus, regardless of the agricultural season, MMF may not be as closely associated with local agricultural season conditions. These results are similar to recently published estimates [27]. A recent analysis from Benin found that agricultural diversity and production, as well as income allocated to food purchase, were associated with MDD, while MMF was instead associated with factors such as ethnicity, caregivers’ occupation, and household size [55]. However, more research is necessary to understand the complex dynamics of agricultural productivity, other components of food security, and how these relate to behaviors around complementary feeding practices. More research
around how these behaviors vary by livelihood zone and urban or rural location may also be informative, as even for those households (urban or rural) not directly engaged in subsistence production, local growing season conditions likely impact food prices and food availability [56].

**Limitations**

This study has several limitations. First, we were not able to include the sex of the child (stunting prevalence in some studies is higher among male children) [57]. A variable for employment was not collected in the PMA2020 survey. Second, the feeding indicators may not be sensitive to chronic under-nutrition because they are assessed based on 24-hour recall, which may not capture the range of conditions the child experiences in terms of dietary intake. Also, these definitions are from UNICEF and WHO, not contextually defined for Burkina Faso. Third, the data are cross-sectional limiting our ability to draw causal conclusions. As with any survey data, there may be recall bias in survey responses. Lastly, we used a threshold of 13.5cm to include both children with acute malnutrition and those at risk of it. While other studies use different cut offs, we selected this because 1) MUAC was measured early in the hunger season, so a child at risk would likely require attention by the end of the season, and 2) other studies have suggested higher cut offs are required to identify all children that require intervention.

### Table 2

| VARIABLES                                    | Model 1 | Model 2 | Model 3 |
|----------------------------------------------|---------|---------|---------|
| WRSI Anomaly 2017                            | 0.967*  | 0.970   | 0.967*  |
| minimum dietary diversity (MDD)              |         | 0.648** |         |
| Minumum meal frequency (MMF)                 |         |         | 1.001   |
| Livelihood zones (Agricultural = REF)        | REF     | REF     | REF     |
| Urban/Ouagadougou                            | 1.057   | 1.050   | 1.057   |
| Agropastoral/pastoral                        | 1.205   | 1.190   | 1.205   |
| Mother’s age (35+ years = REF)               | 1.082   | 1.073   | 1.082   |
| 15–20 years                                  | (0.692–1.693) | (0.686–1.679) | (0.691–1.694) |
| 20–24 years                                  | 0.921   | 0.908   | 0.921   |
| 25–34 years                                  | 0.902   | 0.907   | 0.902   |
| Mother’s MUAC score (Normal = REF)           | REF     | REF     | REF     |
| Undernourished                               | 1.723** |         | 1.723** |
| (1.345–2.207)                                | (1.354–2.223) | (1.345–2.207) |
| Severely undernourished                      | 2.670** | 2.681** | 2.670** |
| (1.311–5.435)                                | (1.316–5.462) | (1.311–5.435) |
| Child has had diarrhea in the last 2 weeks   | 1.269*  | 1.249   | 1.269*  |
| (1.010–1.596)                                | (0.993–1.570) | (1.010–1.596) |
| Mother attended any school                   | 0.753*  | 0.771*  | 0.753*  |
| (0.585–0.970)                                | (0.598–0.993) | (0.585–0.970) |
| Number of other children at home (1 child = REF) | REF     | REF     | REF     |
| 2 children                                   | 1.091   | 1.078   | 1.091   |
| (0.831–1.432)                                | (0.821–1.416) | (0.831–1.432) |
| 3 children                                   | 1.087   | 1.077   | 1.087   |
| (0.771–1.533)                                | (0.764–1.519) | (0.771–1.533) |
| 4+ children                                  | 1.030   | 1.030   | 1.030   |
| (0.710–1.493)                                | (0.711–1.493) | (0.710–1.493) |
| Child’s age (6–11 months = REF)              | REF     | REF     | REF     |
| 12–17 months                                 | 0.842   | 0.882   | 0.842   |
| (0.655–1.083)                                | (0.684–1.136) | (0.654–1.083) |
| 18–23 months                                 | 0.866   | 0.920   | 0.886   |
| (0.677–1.160)                                | (0.702–1.207) | (0.675–1.161) |
| EA Random Effects                            | 1.235** | 1.217** | 1.235** |
| (1.075–1.418)                                | (1.064–1.591) | (1.075–1.419) |

*p < 0.05; **p < 0.001
Despite these limitations, the research expands the discussion of child nutrition by including several dimensions of food security at a fine-spatial scale — anthropometric measure of nutritional status (MUAC), behavioral practices related to child feeding, and a community-level, satellite-derived objective measure of growing season, the WRSI. Household food security is complex; while WRSI captures aspects of access and availability, it cannot capture other factors like food storage, transportation, food aid, market prices, and general childcare and feeding practices. While these other factors are important to childhood nutrition [6, 58, 59], merging the WRSI with household survey data provides a useful, fine-scale analysis of nutritional variation and agricultural productivity useful for expanding early warning nutrition systems and targeting interventions.

### Table 3. Multi-level mixed-effects logistic regression models of factors associated with minimum meal frequency, minimum dietary diversity, and minimum acceptable diet.

| VARIABLES | Model 1 Minimum meal frequency | Model 2 Minimum dietary diversity |
|-----------|--------------------------------|----------------------------------|
| WRSI Anomaly 2017 | 1.025 (0.979–1.075) | 1.073* (1.006–1.145) |
| Livelihood zones (Agricultural = REF) | | |
| Urban/Ouagadougou | 1.224 (0.676–2.217) | 0.874 (0.401–1.902) |
| Agropastoral/pastoral | 1.577 (0.944–2.633) | 0.845 (0.426–1.680) |
| Perceived food insecurity (None = REF) | | |
| Moderate | 0.897 (0.668–1.205) | 0.834 (0.544–1.277) |
| Severe | 0.920 (0.684–1.236) | 0.578* (0.371–0.901) |
| Mother’s age (35 + years = REF) | | |
| 15–20 years | 0.607** (0.387–0.951) | 0.765 (0.392–1.494) |
| 20–24 years | 0.792 (0.569–1.103) | 0.778 (0.479–1.262) |
| 25–34 years | 0.939 (0.705–1.253) | 1.088 (0.724–1.634) |
| Mother attended any school | 1.005 (0.780–1.295) | 1.639** (1.167–2.303) |
| Number of other children at home (1 child = REF) | | |
| 2 children | 0.885 (0.678–1.155) | 0.768 (0.529–1.113) |
| 3 children | 1.200 (0.851–1.691) | 0.855 (0.520–1.406) |
| 4+ children | 1.038 (0.713–1.513) | 0.885 (0.508–1.544) |
| Child’s age (6–11 months = REF) | | |
| 12–17 months | 1.432** (1.116–1.839) | 3.204** (2.189–4.688) |
| 18–23 months | 1.795** (1.377–2.340) | 2.903** (1.958–4.304) |
| EA Random Effects | 1.962** (1.446–2.663) | 2.938** (1.704–5.068) |

* p < 0.05; ** p < 0.001.

Despite these limitations, the research expands the discussion of child nutrition by including several dimensions of food security at a fine-spatial scale — anthropometric measure of nutritional status (MUAC), behavioral practices related to child feeding, and a community-level, satellite-derived objective measure of growing season, the WRSI. Household food security is complex; while WRSI captures aspects of access and availability, it cannot capture other factors like food storage, transportation, food aid, market prices, and general childcare and feeding practices. While these other factors are important to childhood nutrition [6, 58, 59], merging the WRSI with household survey data provides a useful, fine-scale analysis of nutritional variation and agricultural productivity useful for expanding early warning nutrition systems and targeting interventions.

### Conclusions & policy recommendations

To improve progress on child malnutrition in Burkina Faso, programs and policies must address the links between agricultural season quality, dietary diversity (MDD), and malnutrition (MUAC score). Agricultural productivity compared to local averages, measured here by WRSI anomaly, is associated with both the dietary diversity of children 6–23 months of age and with malnutrition. Agricultural productivity and dietary diversity
are independently associated with malnutrition, suggesting that a poor agricultural season may have diverse
effects on health and nutrition, but not only through dietary diversity pathways. Overall, addressing access to
high-quality and diverse foods is critical to reducing malnutrition, as well as taking steps to address climate
change and agricultural productivity, as most communities in Burkina Faso are subsistence farmers and highly
vulnerable to climatic and environmental shifts that impact agriculture. Maternal education and access to health
services, nutrition-sensitive programs, and distributions of food during insecure times may also improve
outcomes for both mother and child.

Remotely sensed products, such as WRSI, have the advantage of providing spatial continuous, quantitative
approaches for identifying potential areas of food insecurity, which is vital in regions where direct data retrieval
(through surveys, or other measures) are sparse. However, WRSI only captures meteorological reasons for
higher or lower agricultural yields, not the complex set of other factors that relate to food security. Agricultural
productivity is inherently necessary for food availability; however, many other factors may impact accessibility
and utilization including market prices, food storage, conflict, and human behaviors or practices around child
feeding. Studies have highlighted the infrastructural needs [6] and effectiveness of promoted IYCF practices on
child health [8, 60]. Future research that considers WRSI in combination with other dimensions of food security
could aim to further define the mechanisms through which WRSI affects malnutrition, identifying intervention
points to improve outcomes in children.

Ethics approval

This specific study did not collect primary data on human subjects therefore no ethical review committee (IRB)
was involved. The PMA2020 survey data are made publicly available following protocols from the Johns
Hopkins Bloomberg School of Public Health and local partner institution ethical review committees (https://
www.pmadata.org/data/about-data). The WRSI are satellite derived and do not contain human subject
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Data availability statement

No new data were created or analyzed in this study.

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