Research Square

Preprints are preliminary reports that have not undergone peer review. They should not be considered conclusive, used to inform clinical practice, or referenced by the media as validated information.

Young Children Who Eat Animal Sourced Foods Grow Less Stunted: Findings of Contemporaneous and Lagged Analyses from Nepal, Uganda and Bangladesh

Sonia Zaharia (sonia.zaharia@tufts.edu)
Friedman School of Nutrition Science and Policy, Tufts University https://orcid.org/0000-0002-1011-7582
Shibani Ghosh
Friedman School of Nutrition Science and Policy, Tufts University
Robin Shrestha
Friedman School of Nutrition Science and Policy, Tufts University
Swetha Manohar
Johns Hopkins Bloomberg School of Public Health
Andrew Thorne-Lyman
Johns Hopkins University https://orcid.org/0000-0001-5917-4126
Bernard Bashaasha
Makerere University
Nassul Kabunga
Feed the Future Innovation Lab for Nutrition
Sabi Gurung
Johns Hopkins Bloomberg School of Public Health
Grace Namirembe
Friedman School of Nutrition Science and Policy, Tufts University
Katherine Heneveld
Friedman School of Nutrition Science and Policy, Tufts University
Lichen Liang
Friedman School of Nutrition Science and Policy, Tufts University
Patrick Webb
Tufts University, Medford, United States https://orcid.org/0000-0002-9857-3354

Article

Keywords: animal-sourced food, child growth, anthropometric outcome

Posted Date: September 23rd, 2020

DOI: https://doi.org/10.21203/rs.3.rs-74484/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Version of Record: A version of this preprint was published at Nature Food on April 21st, 2021. See the published version at https://doi.org/10.1038/s43016-021-00259-z.

Young Children Who Eat Animal Sourced Foods Grow Less Stunted: Findings of Contemporaneous and Lagged Analyses from Nepal, Uganda and Bangladesh

Sonia Zaharia[1,2,*], Shibani Ghosh[1,2], Robin Shrestha[1,2], Swetha Manohar[2,3], Andrew L Thorne-Lyman[2,3], Bernard Bashaasha[2,4], Nassul Kabunga[2], Sabi Gurung[2,3], Grace Namirembe[1,2], Katherine Heneveld[1,2], Lichen Liang[1,2], and Patrick Webb[1,2]

1. Friedman School of Nutrition Science and Policy, Tufts University, Boston, MA, USA
2. Feed the Future Innovation Lab for Nutrition
3. Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA
4. Makerere University, Kampala, Uganda

To whom correspondence should be addressed: Dr. Sonia Zaharia, Address: 150 Harrison Ave, Boston, Massachusetts; Email: Sonia.Zaharia@tufts.edu

Abstract

In resource constrained countries, animal-sourced foods (ASFs) are an important nutrient-dense source of vitamins, minerals and macronutrients. While several studies have suggested the value of ASFs to child growth, most empirical evidence is based on cross-sectional data which can only provide information about the contemporaneous relationship between diet and anthropometric outcomes. This study uses longitudinal panel data for Nepal, Bangladesh, and Uganda to assess the association between contemporaneous as well as past ASF consumption and linear growth of children aged 6-24 months. Fixed effects models found that ASF consumption was significantly correlated with lower stunting, with a decline in stunting prevalence as high as 10% in Nepali children who had consumed any ASF in the previous year. Consuming two or more ASFs showed an even higher magnitude of association, ranging from a 10% decline in prevalence of stunting associated with lagged consumption in Bangladesh to a 16% decline in Nepal.

In 2020, despite improving trends globally, there are an estimated 144 million stunted children under 5 years of age (~22%). The largest burden is in South Asia and Sub-Saharan Africa, which together account for over 85% of global prevalence[1, 2]. Child stunting may adversely affect physical and cognitive development, future health, income earnings and labor productivity [3, 4]. While many factors contribute to stunting, including *in utero* insults, poor birth outcomes, inadequate caring practices, and infections, a low-quality diet, including a lack of sufficient energy, vitamins, minerals (zinc, iron), quality protein and essential amino acids is important, given its role in supporting optimal child growth [5, 6, 7, 8].

Several multi-country studies and supplementation trials have investigated the relationship between ASFs and stunting. In a 180-country analysis, Ghosh et al. (2012)[9] demonstrated that the quality of protein consumed (ASF versus plant-based) was significantly associated with the prevalence of stunting. Using Demographic and Health Survey data from multiple countries, Krasevec et al. (2017)[10] and Headey et al. (2018)[11] found that eating more than one type of any ASF was associated with a reduction in stunting in young children. Trials and observational studies have generated mixed evidence of the association between ASF consumption and child growth in different contexts. While many studies reported a positive association between linear growth in children and consumption of dairy [12, 13, 14], meat [15, 16, 17], fish [18, 19], and eggs [20, 21], some did not find significant effects [22,23].

Despite documented associations, most multi-country studies are cross-sectional and test the contemporaneous relationship between diet and stunting. This analysis responds to an important gap. It tests empirically the hypothesis that ASF consumption is associated with reduced stunting over time. Using large longitudinal panels from three low-income countries (Nepal, Bangladesh and Uganda), we examined anthropometric outcomes (stunting and length-for-age z-scores) in relation to both contemporaneous and past consumption of various ASFs by young children, controlling for relevant confounding factors. We made use of repeated observations on the same child to test both contemporaneous and lagged effects.

We found a significant positive association between a child's ASF consumption and length-for-age z-score (LAZ), and a negative association with stunting. This holds both for contemporaneous and lagged ASF consumption, with the strongest results observed in relation to lagged effects. This outcome makes biological sense given that child growth is a cumulative process. Our findings suggest an aggregating benefit to past and ongoing ASF consumption on length-for-age z-scores and reduced stunting. Confirming findings from Headey et al. (2018)[11], we found the association between ASF consumption and LAZ/stunting was larger if two or more different types of ASFs were consumed. A critical finding not reported previously is that while dairy was positively correlated with growth across the three different countries, other ASFs were also associated with growth outcomes and these differed by country, with meat in Nepal, fish in Uganda, and eggs in Bangladesh.

Results

Models were estimated using fixed effects (FE) panel regressions and are presented in Tables 2-4. All models adjust for consumption of other food groups, age, gender, illness, maternal height and education, and household sanitation. In alternative specifications that include household wealth index instead of mother's education and household sanitation, most, but not all results hold. Our preferred specification uses education and sanitation which are correlated with a household's wealth index but more proximal correlates of stunting. In each table, Panel A presents results on LAZ and Panel B on stunting.

Any Contemporaneous ASF Consumption and LAZ or Stunting

Contemporaneous consumption of any ASF was positively associated with LAZ in all three countries (Table 2), adjusting for district-survey round fixed effects, other food groups and control variables. In Nepal and Uganda, we also found a negative association with stunting in infants aged 6 to 12 months.

In Nepal, LAZ scores were significantly higher (ß=0.12, $p<0.1$, 95% CI (-0.03, 0.27)) in infants and young children aged 6 to 24 months who consumed any ASF relative to those who did not, adjusting for consumption of other food groups, age, gender, illness, maternal height and education, household sanitation, and time-varying district characteristics. Coefficients for other food groups are presented in Supplementary Table 4. Dark green leafy vegetables, vitamin A-rich fruits and vegetables, and legumes, nuts and seeds were all associated with better LAZ. This speaks to the important point that different foods contain different types and concentrations of key vitamins and minerals and that diet diversification matters not just because of including one or other food group, but to enhance the range and quality of foods consumed every day. Using child and survey round fixed effects (Supplementary Table 4, Panel A, model 2) there was a stronger association between LAZ and any ASF consumption (ß=0.11, $p<0.05$, 95% CI (0.03, 0.19)). Disaggregated by age group, consumption of any ASF by Nepali infants 6-12 months was associated with a 0.23 higher LAZ ($p<0.05$, 95% CI (0.07, 0.39), Supplementary Table 4, Panel

A, Model 5). We found a negative association between ASF consumption and stunting in infants aged 6-12 months with a 5% drop in prevalence associated with any ASF consumption ($p<0.05$, 95% CI (-0.09, -0.02), Supplementary Table 4, Panel B, Model 5).

In Bangladesh, infants and young children aged 6 to 24 months who consumed any ASF had significantly higher LAZ scores (ß=0.12, $p<0.01$, 95% CI (0.05, 0.19)) than those who did not (Table 2, Panel A). In models disaggregated by age group, the contemporaneous association between ASF consumption and LAZ in the 13 to 24 months age group was positive and statistically significant ($p<0.05$). The Z-score of those who consumed any ASF was 0.14 SD higher than with no ASF (95% CI (0.03, 0.25), Supplementary Table 5, Panel A, model 7). We also found a positive association (ß=0.15, $p<0.1$, 95% CI (-0.01, 0.32)) between LAZ and staples consumption but not with other food groups. ASF consumption was relatively high in Bangladesh, some of which was in the form of fish, which might explain why the additional impact on nutrition of consuming other food groups was not significant.

In Uganda, LAZ was 0.14 Z-scores higher ($p<0.1$, 95% CI (-0.00,0.28)) in children aged 6 to 24 months who consumed any ASF (Table 2, Panel A). The results appear to be driven by the 13 to 24 months age group, where the LAZ was 0.2 Z-scores higher ($p<0.05$, 95% CI (0.04,0.37)) in those that consumed any ASF versus those that did not (Supplementary Table 6, Panel A, Model 5). We found a negative association between stunting and ASF consumption in the Ugandan children aged 6-24 months (ß=-0.03, $p<0.1$, 95% CI (-0.07,0.01), Table 2) which appears to be driven by the statistically significant coefficient obtained in the 6-12 months age group (ß =-0.09, $p<0.01$, 95% CI (-0.15,-0.04), Supplementary Table 6, Panel B, Models 1 and 3).

Number of ASFs and LAZ or Stunting

Consumption of two or more different types of ASFs had a stronger association with LAZ and stunting than just one type in all countries. In Nepal, infants and young children that consumed two or more types of ASFs had mean Z-scores 0.26 SD higher ($p<0.01$, 95% CI (0.10,0.42)) than no ASF consumption (Table 2, Panel A, Nepal, Model 2). In Bangladesh, children who consumed two or more ASFs had mean LAZ scores that were 0.24 SD higher ($p<0.01$, 95% CI (0.14,0.34)) and a prevalence of stunting 7% lower ($p<0.01$, 95% CI (-0.12,-0.02)) than those who consumed no ASF (Table 2, Panel A and B, Bangladesh, Model 2). In Uganda, while only 3% of children consumed two or more types of ASF (Supplementary Table 3), the positive association with LAZ and negative association with stunting was larger in magnitude and statistically significant in children aged 6 to 24 months (Table 2, Panel A and B). The LAZ scores of Ugandan infants, 6 to 12 months, who consumed two or more ASFs was 0.54 SD higher ($p<0.1$, 95% CI (-0.01,1.09)) than no ASF consumption (Supplementary Table 6, Panel A, Model 4) and the likelihood of being stunted was lower by 11% ($p<0.05$, 95% CI (-0.21,-0.01)) (Supplementary Table 6, Panel B, Model 4).

Type of ASF and LAZ or Stunting

In Nepal, meat and dairy consumption were significantly correlated with higher LAZ (meat: ß=0.13, $p<0.05$, 95% CI (0.02,0.24); dairy: ß=0.12, $p<0.05$, 95% CI (0.00,0.23)) (Table 3). Dairy was of importance among infants (6 to 12 months) and meat among young children (13 to 24 months) (Supplementary Table 7). Dairy products (mainly milk) were the most commonly consumed ASF in Nepal, consumed by roughly 50% of children compared with 7% who consumed eggs and 11% who consumed meat (Supplementary Table 1). In Bangladesh, both dairy and egg consumption were associated with higher LAZ scores (dairy: ß=0.13, p<0.05, 95% CI (0.03,0.24); egg: ß=0.14, p<0.1, 95% CI (-0.01,0.27)) and lower stunting (dairy: ß=-0.04, p<0.1, 95% CI (-0.08,0.00); egg: ß=-0.04, p<0.1, 95% CI (-0.09,0.00)) (Table 3). The results were driven by the 13 to 24 months age group (Supplementary Table 8). In Uganda, consuming dairy (ß=0.21, p<0.05, 95% CI (0.02,0.40)) was associated with higher LAZ scores in children aged 6 to 24 months (Table 3). Fish was also important for higher LAZ scores in children between 13 and 24 months old (ß=0.44, p<0.05, 95% CI (0.10,0.78)) (Supplementary Table 9).

Lagged ASF Consumption and LAZ or Stunting

We tested whether anthropometric outcomes were correlated with prior ASF consumption. The lagged analysis was conducted only on the Nepal and Bangladesh data but not Uganda as the surveys were conducted every two years. In Nepal, the LAZ scores of children (6-24 months of age) who consumed any ASF in the prior year were 0.26 SD higher (p<0.05, 95% CI (0.04,0.47)) while stunting rates were 10% lower (p<0.05, 95% CI (-0.18,-0.02)) (Table 4, Panels A and B, Nepal Model 1). The association of stunting and number of ASFs consumed in the prior year was strong with stunting being 16% lower (p<0.01, 95% CI (-0.24,-0.08)) for those who consumed two or more types of ASF in the prior year relative to those with no ASF consumption (Table 4, Panel B, Nepal Model 2). In Bangladesh, any ASF consumption 6 months prior to LAZ measurement was associated with a 0.14 SD higher LAZ (p<0.01, 95% CI (0.04,0.24)) (Table 4, Panel A, Bangladesh Model 1). LAZ was 0.23 SD higher (p<0.01, 95% CI (0.13,0.33)) and stunting 10% lower (p<0.01, 95% CI (-0.14,-0.06)) in children who had previously consumed two or more ASFs (Table 4, Panels A and B, Bangladesh Model 2).

Testing lagged and contemporaneous associations

To further assess the relationships, we examined contemporaneous consumption in the same individuals that were included in the lagged consumption models for Nepal and Bangladesh (Supplementary Tables 10 and 11). This was to test for differences in contemporaneous associations in the sub-sample of children included in the lagged models. Finally, we ran regressions that include both the lagged and contemporaneous ASF consumption to determine whether each is related to the outcome in addition to the other (Supplementary Tables 10 and 11).

In Nepal, in models with both lagged and contemporaneous ASF consumption variables, we found a significant positive association between lagged consumption of any ASF and LAZ ($ß=0.26$, $p<0.05$, 95% CI (0.05,0.47)) but not contemporaneous consumption. Lagged consumption of 1 type of ASF was associated with a significant positive association ($ß=0.26$, $p<0.05$, 95% CI (0.02,0.49)) (Supplementary Table 10, Panel A, Models 5 and 6). Similarly, lagged consumption of any ASF was negatively associated with stunting, while lagged consumption of 1 or 2 or more types of ASF was associated with lowered risk of stunting (Supplementary Table 10, Panel B, Model 5 and 6).

In Bangladesh, we found positive statistically significant associations among LAZ, contemporaneous and lagged ASF consumption in the same model (Supplementary Table 11, models 9-12). Past ASF consumption was positively related to LAZ, which was 0.13 SD higher ($p<0.05$, 95% CI (0.03,0.23)) with any ASF consumption, while contemporaneous ASF consumption was associated with 0.14 higher LAZ ($p<0.01$, 95% CI (0.06,0.22)) (Supplementary

Table 11, Panel A, Model 9). The results were not significant using child fixed effects (Supplementary Table 11, Model 10). Consumption of 2 or more ASFs, both lagged and contemporaneous, was significantly associated with 0.19 SD higher LAZ score ($p<0.01$, 95% CI (0.08,0.31)) and 0.22 SD higher LAZ-score ($p<0.01$, 95% CI (0.09,0.35)), respectively (Supplementary Table 11, Panel A, Model 11). A lower stunting prevalence was found in those consuming two or more ASF types, both six months earlier (ß=-0.09, $p<0.01$, 95% CI (-0.13,-0.05)) and at the time of measurement (ß=-0.07, $p<0.1$, 95% CI (-0.13,0.00)) (Supplementary Table 11, Panel B, Model 11).

Discussion

Reducing stunting is a key public health policy priority with global targets set for 2025 and beyond[24]. Improving the quality of diets available to children is an important contributor to the achievement of such a target. Given the ongoing global debate about the negative contribution of high meat diets and associated livestock production to greenhouse gas emissions[25,26], a rigorous evidence-based understanding of the role of meat and other forms of ASF in the diets of undernourished children in resource-poor settings is more critical than ever. The policy goal of optimizing dietary intakes globally to improve human health and the world's chances of mitigating climate change requires a balanced approach; one that seeks to moderate ASF consumption in high- and middle-income settings where levels are already high and growing, as well as increasing intake where diets are still widely deficient in both the quantity and quality of key nutrients.

The value of animal sourced foods (ASFs), such as meat, fish, dairy and eggs, in delivering these crucial nutrients along with other bio-active factors like lactoferrin, lysozyme, and growth factors such as insulin-like growth factor-1 has been documented [27,28, 29, 30]. While sufficient quantity and diversity of non-ASF (i.e. plant-based foods) also contributes many of the micro and macronutrients needed for optimal growth (as shown in our results), ASFs deliver a greater density of many such nutrients (per 1000 calories of food consumed), along with growth factors and certain enzymes that are not available in plants.

Using longitudinal data, we identified strong correlations between ASF consumption and LAZ or stunting in children aged 6 to 24 months. Both contemporaneous and lagged associations were observed across all three countries. Any ASF consumption was associated with a 0.12 to 0.14 SD higher LAZ across the three countries. The association was stronger with the number of ASFs consumed; children consuming 2 or more types of ASFs demonstrated 0.26 to 0.47 SD higher LAZ scores across all three countries. With respect to the contemporaneous relationship of ASF consumption and stunting, we observed a 7 to 13% reduction in stunting with the consumption of 2 or more types of ASF in Bangladesh and Uganda, respectively.

The magnitude of lagged ASF consumption effects on LAZ were large, ranging from 0.26 SD in Nepal to 0.23 SD in Bangladesh for 2 or more types of ASF. We found strong correlations where more than one type of ASF was consumed and where lagged effects were taken into account. Dairy had the strongest associations with growth across all three countries with a range of 0.12-0.22 SD Z-scores, but intake of meat, fish and eggs also played a role.

Some strengths of our study were the use of data from three longitudinal studies that were implemented with rigor, collected exposure data over multiple time points and had large sample sizes, allowing for the assessment of contemporaneous and lagged effects. However, there are some limitations in terms of being unable to control fully for all potential confounders, and the use of different survey time periods across the three country settings. Broad generalizability of our findings is also important to consider: the Nepal study was designed to be nationally representative, while the Bangladesh and Uganda studies were representative of a specific area of the country that was the focus of Feed the Future initiative. Other potential limitations included the lack of information on quantity and caloric value of foods consumed and possible misclassification of "usual diet" caused by the short recall period of 24 hours[31, 32].

To our knowledge, this is one of the first studies to rigorously assess empirically the relationship between child growth and both contemporary and prior ASF intake measured over varying time periods. Shapiro et al. (2019) reported that most of the longitudinal cohort studies included in their systematic review found "nonsignificant relations between ASF consumption and indicators of height"[33]. Our analysis focused on diet quality and growth in multiple countries demonstrates significant correlations. This could be a reflection of the management of confounders and use of robust analytical techniques rooted in rigorous econometric methodology.

ASFs can play a critical role in the diets of children at risk of the serious physical and cognitive impairment. While increasing the supply and affordability of a wide range of plant-based options to improve diet quality should be part of a public health policy agenda across low-income countries (and for low-income populations in emerging economies and wealthy nations), the value of raising low intakes of ASFs should not be ignored. Improving efficiencies in livestock, poultry and fish systems is an important agenda, but one that must be pursued alongside policy and programming initiatives to support dietary choices for all households regardless of location and income-level. In rural areas of Uganda, Nepal and Bangladesh, the choice includes optimal, rather than less, intake of diverse forms of ASFs in the diets of young children after they have been exclusively breastfed for 6 months from birth.

Future research is needed to define what optimal levels of ASF intake are at various stages of child growth for two reasons: to prevent stunting and support ideal linear growth and to assess interactions between linear growth and cognitive outcomes. Additional research is needed to establish the degree to which various ASFs may substitute for each other at different ages and to identify the ideal interactions among ASFs and non-ASFs in the diet, since consumption of other nutrient-rich foods also matters for optimal growth, health and cognition.

Methods

The analysis uses longitudinal panel data from 3 countries. Data from Nepal were derived from the Policy and Science for Health, Agriculture and Nutrition (PoSHAN) research, an annual nationally representative series of surveys (2013-2016) of 5000 households with preschool aged children (6-59 months) in 7 village development committees (VDCs) sampled across three agroecological zones (plains, mountain and hills) in Nepal[32]. Data from Uganda were used from the three biennial (2012-2016) surveys of 3600 households with preschool aged children (6-59 months) in 6 districts (4 from northern Uganda and 2 from south-western) in Uganda[34]. Data from Bangladesh were used from the Bangladesh Aquaculture-Horticulture for Nutrition

Research (2016-2017) that included three bi-annual (2016-2017) surveys of 3167 households with preschool aged children (6-59 months) in three divisions (Dhaka, Khulna and Barisal) of south-western Bangladesh. The three surveys used here were all designed under the auspices of a large-scale global research agenda run by the Feed the Future Innovation Lab for Nutrition. The aim across these individual country studies was to rigorously elucidate pathways by which investments in agriculture may or may not improve diets and nutrition in low-income settings. While each country had particular sub-questions relevant to context, the main community, household and mother-child dyad surveys were similar in design and content, and the core investigative team was the same across all studies. The number of children aged 6-24 months included in this analysis were 1564 in Nepal, 2413 in Bangladesh and 2370 in Uganda.

The outcome variables of interest were length-for-age z-score (LAZ) and whether a child is stunted or not (a binary variable). LAZ was computed from recumbent length (all children are under 2 years of age) and expressed as the number of standard deviations below or above the median of a reference population, adjusted for child age and sex using the WHO defined protocols[35]. We excluded children with missing LAZ scores or with LAZ scores that have biologically implausible values (LAZ<-5 or LAZ >5). Stunting was computed using a binary variable: a child was classified as stunted if her LAZ<-2 and not stunted if her LAZ≥-2, as per WHO 2006 guidelines [36].

For Nepal and Uganda, we asked if and how often they ate certain food items in the past 24 hours (no quantities were collected) and categorized food items into eight food groups as defined by the WHO: (1) starchy staples; (2) dark green leafy vegetables; (3) vitamin-A rich fruits and vegetables; (4) other fruits and vegetables; (5) meat and meat products including meat, fish, poultry; (6) eggs; (7) dairy; and (8) legumes, nuts and seeds. The Bangladesh panel used a classification of foods into six groups: (1) starchy staples; (2) fruits and vegetables; (3) meat and meat products including meat, fish, poultry; (4) eggs; (5) dairy; and (6) legumes, nuts and seeds. We aggregated meat and meat products, eggs and dairy for the variable 'animal sourced foods' (ASFs). In addition, we generated binary variables for each type of ASF consumed (e.g. meat and meat products, dairy, eggs, and fish in the case of Bangladesh only) for exploration in separate models. The survey provided individual- and household-level information that were included in the analysis including age, gender, number of illnesses in the past 7 days, maternal height and education, and household sanitation status (presence or absence of a latrine).

Supplemental Tables 1-3 report for each survey summary statistics of the variables used in the analysis. We computed summary statistics for the full samples, as well as disaggregated into two age groups, 6 to 12 months and 13 to 24 months.

Although there was variation in mean LAZ scores across the three country samples, they share a common pattern in that LAZ scores decrease with age, a phenomenon that is common across most low- and middle-income countries [37]. The same pattern holds for stunting prevalence, which is higher in the older age groups across all survey data sets. The average prevalence of stunting ranges from 26% in Bangladesh and Uganda to 30% in Nepal.

The consumption of ASFs also varies widely across the three countries. Uganda has the lowest average share of children consuming any ASF daily (23%), and only 3% of those children consume two or more types of ASFs. By contrast, Bangladesh has the largest average share of children who consume ASFs - 76% have consumed any ASFs, and 36% of them have consumed two or more types of ASFs. Additionally, there are differences across countries in the types of ASF most likely to be consumed: dairy in Nepal and Uganda compared to flesh foods (meat) in Bangladesh. Eggs are the least common form of ASF consumed by children in all three surveys.

We estimate the following model to examine the relationships between ASF consumption and child stunting:

$$Child\ outcome_{i,t} = \beta_1 ASF\ consumption_{i,t} + \sum_j \gamma_j Consumption\ of\ foods\ from\ group\ j_{i,t} + \mathbf{z}'_{i,t}\delta + \lambda\Phi_{d,t} + \varepsilon_{i,t} \tag{1}$$

Child outcome is either the length-for-age z-score of the child *i* in survey round *t*, or a binary variable that indicates whether the child is stunted or not. We are interested in the association between the two outcomes and children's consumption of ASFs, which we measure in two ways: (1) a binary variable that indicates whether a child consumed any ASFs or not, and (2) two binary variables that indicate whether a child consumed one type of ASF, or two or more types of ASFs.

Models were estimated using fixed effects (FE) panel regression. This implies a linear probability model with fixed effects for the binary outcome 'stunting'. Since we include fixed effects, a binary choice model like Probit would suffer from the incidental parameters problem[38]. We control for confounding factors potentially correlated with ASF consumption while also possibly affecting outcome variables. To adjust for potential contribution to the diet, and thus to nutritional status from foods other than ASFs, we include consumption of items from all the other food groups in the same 24-hour recall period j. We also control for a vector of individual characteristics, $\boldsymbol{z}'_{i,t}$, that includes child characteristics (age, gender, whether the child recently had diarrhea), maternal height and education, and household sanitation (whether the household has an improved latrine). We also tested alternative models that included the household's wealth index instead of mother's education and household sanitation. Most, but not all results were robust to the alternative specification. In our preferred specification we used education and sanitation which are correlated with the household's wealth index but more proximal correlates of stunting. We further include district*survey-round fixed effects, $\Phi_{d,t}$, which control for any local temporal shocks that are common to all children in a single district-round. This is important to capture variation at the local level in the food prices, market availability etc., and also the health environment and other observed or unobserved local conditions that affect children's outcomes. Where the data permit, we ran additional regressions that included child fixed effects to control for characteristics of a child that do not change over time, such as maternal health and nutrition during pregnancy or birth outcome, together with survey round fixed effects to account for temporal shocks that affect all children in a survey.

A child's diet today can have a lagged effect on her/his subsequent growth, which we test by regressing a child's outcome of interest on her consumption of ASFs and foods from other groups in the previous period:

$$
\begin{aligned}
Child\ outcome_{i,t} \\
&= \beta_1 ASF\ consumption_{i,t-1} \qquad (2) \\
&+ \sum_j \gamma_j Consumption\ of\ foods\ from\ group\ j_{i,t-1} + \mathbf{z}'_{i,t}\delta + \lambda\Phi_{d,t} + \varepsilon_{i,t}
\end{aligned}
$$

Depending on the dataset used, the lags range from six months to one year. Statistical analysis was performed using Stata 15.1 (StataCorp LP).

Acknowledgements:

The authors express gratitude to USAID's Bureau of Resilience and Food Security, the US Missions in all 3 countries included in this study, as well as USAID staff Dr. Maura Mack, Dr. Ahmed Kablan, Mr. Debendra Adhikari, and Dr. Osagie Aimiuwu. We also thank the study participants without whom this research would not have been possible. Support for the research was provided by the Feed the Future Innovation Lab for Nutrition, which is funded by the United States Agency for International Development (USAID), award AID-OAA-L-10-00006 (Nepal and Uganda), award AID-OAA-LA-14-00012 (Bangladesh) to the Friedman School of Nutrition Science and Policy at Tufts University. The opinions expressed herein are solely those of the authors.

Author Contributions:

PW conceived the study. SZ, PW and SG developed the methodology and SZ conducted the analysis; PW, SG and RS helped to refine the methodology and analytical method; SZ, PW and SG interpreted the results; SZ, PW and SG developed early drafts of the paper, and RS contributed to writing, reviewing and editing early drafts; SM, ATL, BB, SG designed the surveys and supervised the data collection; GS, SM, BB and RS led data collection; SM, KMH, LL, and GN performed the data curation. All authors reviewed the final manuscript.

Competing Interests Statements: The authors declare no competing interests.

References

1 UNICEF, WHO, IBRD & Bank, W. Levels and trends in child malnutrition: key findings of the 2019 Edition of the Joint Child Malnutrition Estimates. . 16 (UNICEF, WHO, IBRD, World Bank, Geneva, 2019).

2 Kinyoki, D. K. *et al.* Mapping child growth failure across low- and middle-income countries. *Nature* **577**, 231-234, doi:10.1038/s41586-019-1878-8 (2020).

3 Aguayo, V. M. & Menon, P. Stop stunting: improving child feeding, women's nutrition and household sanitation in South Asia. *Matern Child Nutr* **12 Suppl 1**, 3-11, doi:10.1111/mcn.12283 (2016).

4 Black, R. E. *et al.* Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet* **382**, 427-451 (2013).

5 Ahmed, T. *et al.* in *Hunter's Tropical Medicine and Emerging Infectious Diseases* (eds Ryan ET. *et al.*) 1034-1041 (2020).

6 Jeffery, K., Chatterjee, I., Lavin, T. & Li, I. W. Young lives and wealthy minds: The nexus between household consumption capacity and childhood cognitive ability. *Economic Analysis and Policy* **65**, 89-104, doi:https://doi.org/10.1016/j.eap.2019.11.002 (2020).

7 Han, V., Radford, B. & Awamleh, Z. in *Maternal-Fetal and Neonatal Endocrinology Physiology, Pathophysiology, and Clinical Management* (eds Kovacs CS & Deal CL) (2020).

8 Bhutta, Z. A. *et al.* Severe childhood malnutrition. *Nature Reviews Disease Primers* **3**, 17067, doi:10.1038/nrdp.2017.67 (2017).

9 Ghosh, S., Suri, D. & Uauy, R. Assessment of protein adequacy in developing countries: quality matters. *British Journal of Nutrition* **108**, S77-S87 (2012).

10 Krasevec, J., An, X., Kumapley, R., Begin, F. & Frongillo, E. A. Diet quality and risk of stunting among infants and young children in low- and middle-income countries. *Matern Child Nutr* **13 Suppl 2**, doi:10.1111/mcn.12430 (2017).

11 Headey, D., Hirvonen, K. & Hoddinott, J. Animal Sourced Foods and Child Stunting. *American Journal of Agricultural Economics* **100**, 1302-1319, doi:10.1093/ajae/aay053 (2018).

12 Hoppe, C., Molgaard, C. & Michaelsen, K. F. Cow's milk and linear growth in industrialized and developing countries. *Annu Rev Nutr* **26**, 131-173, doi:10.1146/annurev.nutr.26.010506.103757 (2006).

13 Ghosh, S., Suri, D. & Griffiths, J. Dairy consumption is associated with a lower risk of stunting in Ethiopian children 6-24 months of age (620.10). *The FASEB Journal* **28**, 620.610 (2014).

14 Dror, D. K. & Allen, L. H. Dairy product intake in children and adolescents in developed countries: trends, nutritional contribution, and a review of association with health outcomes. *Nutr Rev* **72**, 68-81, doi:10.1111/nure.12078 (2014).

15 Mahmudiono, T., Sumarmi, S. & Rosenkranz, R. R. Household dietary diversity and child stunting in East Java, Indonesia. *Asia Pac J Clin Nutr* **26**, 317-325, doi:10.6133/apjcn.012016.01 (2017).

16 Neumann, C. G. *et al.* Animal Source Foods Improve Dietary Quality, Micronutrient Status, Growth and Cognitive Function in Kenyan School Children: Background, Study Design and Baseline Findings. *The Journal of Nutrition* **133**, 3941S-3949S, doi:10.1093/jn/133.11.3941S (2003).

17 Krebs, N. F. *et al.* Meat consumption is associated with less stunting among toddlers in four diverse low-income settings. *Food Nutr Bull* **32**, 185-191, doi:10.1177/156482651103200301 (2011).

18 Marinda, P. A., Genschick, S., Khayeka-Wandabwa, C., Kiwanuka-Lubinda, R. & Thilsted, S. H. Dietary diversity determinants and contribution of fish to maternal and under-five nutritional status in Zambia. *PLOS ONE* **13**, e0204009, doi:10.1371/journal.pone.0204009 (2018).

19 Kaimila, Y. *et al.* Consumption of Animal-Source Protein is Associated with Improved Height-for-Age z Scores in Rural Malawian Children Aged 12–36 Months. *Nutrients* **11**, 480 (2019).

20 Iannotti, L. L. *et al.* Eggs in Early Complementary Feeding and Child Growth: A Randomized Controlled Trial. *Pediatrics* **140**, e20163459, doi:10.1542/peds.2016-3459 (2017).

21 Shivakumar, N. *et al.* Protein-quality evaluation of complementary foods in Indian children. *The American Journal of Clinical Nutrition* **109**, 1319-1327, doi:10.1093/ajcn/nqy265 (2019).

22 Iannotti, L. L. *et al.* Egg intervention effect on linear growth no longer present after two years. *Maternal & Child Nutrition* **16**, e12925, doi:10.1111/mcn.12925 (2020).

23 Stewart, C. P. *et al.* The effect of eggs on early child growth in rural Malawi: the Mazira Project randomized controlled trial. *The American Journal of Clinical Nutrition* **110**, 1026-1033, doi:10.1093/ajcn/nqz163 (2019).

24 de Onis, M. & Branca, F. Childhood stunting: a global perspective. *Maternal & Child Nutrition* **12**, 12-26, doi:10.1111/mcn.12231 (2016).

25 Willett, W. *et al.* Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet* **393**, 447-492, doi:10.1016/S0140-6736(18)31788-4 (2019).

26 Swinburn, B. A. *et al.* The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission report. *The Lancet* **393**, 791-846, doi:10.1016/S0140-6736(18)32822-8 (2019).

27 Michaelsen, K. F. Effect of Protein Intake from 6 to 24 Months on Insulin-Like Growth Factor 1 (IGF-1) Levels, Body Composition, Linear Growth Velocity, and Linear Growth Acceleration: What are the Implications for Stunting and Wasting? *Food and Nutrition Bulletin* **34**, 268-271, doi:10.1177/156482651303400224 (2013).

28 Milward, D. Nutrition, infection and stunting: The roles of deficiencies of individual nutrients and foods, and of inflammation, as determinants of reduced linear growth of children. *Nutrition Research Reviews* **30**, 50-72 (2017).

29 Murphy, S. P. & Allen, L. H. Nutritional Importance of Animal Source Foods. *The Journal of Nutrition* **133**, 3932S-3935S, doi:10.1093/jn/133.11.3932S (2003).

30 Hoppe, C. *et al.* Animal protein intake, serum insulin-like growth factor I, and growth in healthy 2.5-y-old Danish children. *The American Journal of Clinical Nutrition* **80**, 447-452, doi:10.1093/ajcn/80.2.447 (2004).

31 Thorne-Lyman, A., Spiegelman, D. & Fawzi, W. W. Is the strength of association between indicators of dietary quality and the nutritional status of children being underestimated? *Maternal & Child Nutrition* **10**, 159 (2014).

32 Klemm, R. *et al.* Pathways from agriculture-to-nutrition: design and conduct of the national PoSHAN surveys of Nepal. (2018).

33 Shapiro, M. J. *et al.* A Systematic Review Investigating the Relation Between Animal-Source Food Consumption and Stunting in Children Aged 6–60 Months in Low and Middle-Income Countries. *Advances in Nutrition* **10**, 827-847, doi:10.1093/advances/nmz018 (2019).

34 NIL. Innovation Lab for Nutrition Annual Report. 81 (2018).

35 WHO. *WHO Anthro (version 3.1, June 2010) and macros*, <http://www.who.int/childgrowth/software/en/> (2010).

36 WHO. *WHO Child Growth Standards: Methods and development: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age.*, <http://www.who.int/childgrowth/publications/technical_report_pub/en/index.html> (2007).

37 Leroy, J. L., Ruel, M., Habicht, J.-P. & Frongillo, E. A. Using height-for-age differences (HAD) instead of height-for-age z-scores (HAZ) for the meaningful measurement of population-level catch-up in linear growth in children less than 5 years of age. *BMC Pediatrics* **15**, 145, doi:10.1186/s12887-015-0458-9 (2015).

38 Greene, W. Estimating econometric models with fixed effects. *Department of Economics, Stern School of Business, New York University* (2001).

Tables

Table 1: Descriptive statistics by country

	Nepal		Bangladesh		Uganda	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Length for Age Z-score (6-24 months)	-1.41	1.19	-1.28	1.14	-1.15	1.45
Mean percent children stunted (6-24 months)	30%	46%	26%	44%	26%	44%
Mean percent children (6-24 months) consuming any ASF in past 24 hours	57%	50%	76%	43%	23%	42%
Number of observations	1564		2413		2370	

The table reports summary statistics of the datasets used in the main regressions (Tables 2 and 3). For each sample (Nepal, Bangladesh, and Uganda), the unit of the data is a child-survey wave pair. The datasets are unbalanced panels consisting of three annual surveys in Nepal (2014-2016), three bi-annual surveys in Bangladesh (2016-2017), and three biennial surveys in Uganda (2012-2016). The outcome variable Length for Age Z-score was computed from recumbent length (all children are under 2 years of age) and expressed as the number of standard deviations below or above the median of a reference population, adjusted for child age and sex using the WHO defined protocols[35]. We excluded children with missing LAZ scores or with LAZ scores that have biologically implausible values (LAZ<-5 or LAZ >5). Stunting was computed using a binary variable: a child was classified as stunted if her LAZ<-2 and not stunted if her LAZ≥-2, as per WHO 2006 guidelines [36]. We use a binary variable that indicates whether a child consumed any ASFs or not, where we aggregated meat and meat products, eggs and dairy for the variable 'animal sourced foods' (ASFs). More detailed summary statistics are reported in the Supplementary Tables.

Table 2: Association between LAZ or stunting in children (6-24 months of age) and contemporaneous ASF consumption

	Nepal		Bangladesh		Uganda	
	(1)	(2)	(1)	(2)	(1)	(2)
PANEL A: LAZ AND CONTEMPORANEOUS ASF CONSUMPTION: AGES 6-24 MONTHS						
Child consumed any ASF	0.120*		0.116***		0.138*	
	(0.063)		(0.033)		(0.072)	
Child consumed 1 type of ASF		0.092		0.039		0.099
		(0.066)		(0.041)		(0.076)
Child consumed 2 or more types of ASF		0.258***		0.241***		0.467***
		(0.070)		(0.048)		(0.145)
N	1564	1564	2413	2413	2370	2370
adjusted R-square	0.288	0.289	0.169	0.174	0.232	0.234
PANEL B: STUNTING AND CONTEMPORANEOUS ASF CONSUMPTION: AGES 6-24 MONTHS						
Child consumed any ASF	-0.021		-0.027		-0.030*	
	(0.020)		(0.020)		(0.018)	
Child consumed 1 type of ASF		-0.014		0.000		-0.018
		(0.018)		(0.021)		(0.020)
Child consumed 2 or more types of ASF		-0.059		-0.070***		-0.134***
		(0.040)		(0.023)		(0.039)
N	1564	1564	2413	2413	2370	2370
adjusted R-square	0.176	0.176	0.110	0.115	0.157	0.159

The table reports estimation results using FE panel regressions. The outcome variable in Panel A is child's LAZ and a dummy variable equal to 1 if the child is stunted in Panel B. Co-variates and control variables: child consumed starchy staples, dark green leafy vegetables, vitamin A rich fruits and vegetables, other fruits and vegetables, legumes, nuts and seeds, child's age, age squared, age cube, a dummy variable equal to 1 if the child is a girl, a dummy variable equal 1 if the child had diarrhea in the past two weeks, the caregiver's years of education, the mothers height, a dummy equal to 1 if the household has an improved latrine. Data sources are POSHAN (Nepal), BAHNR (Bangladesh), Uganda Panel (Uganda). All regressions include control variables and District X wave fixed effects. Standard errors clustered by district are reported in parentheses.

*p<0.1, ** p<0.05, ***p<0.01

Table 3: Association between LAZ or stunting in children (6-24 months of age) and contemporaneous ASF consumption by type: Nepal, Bangladesh and Uganda

	Nepal	Bangladesh	Uganda
PANEL A: LAZ AND CONTEMPORANEOUS ASF CONSUMPTION BY TYPE			
Child consumed meat/meat products	0.128**	0.089	0.110
	(0.047)	(0.076)	(0.108)
Child consumed eggs	0.018	0.135*	-0.497***
	(0.093)	(0.067)	(0.186)
Child consumed dairy	0.118**	0.133**	0.211**
	(0.050)	(0.049)	(0.098)
Child consumed fish	0.019	0.037	0.166
	(0.117)	(0.040)	(0.135)
N	1564	2413	2237
adjusted R-square	0.288	0.174	0.242
Panel B: STUNTING AND CONTEMPORANEOUS ASF CONSUMPTION BY TYPE			
Child consumed meat/meat products	-0.033	-0.019	-0.053
	(0.039)	(0.022)	(0.033)
Child consumed eggs	-0.029	-0.044*	0.088
	(0.021)	(0.023)	(0.056)
Child consumed dairy	-0.026*	-0.039*	-0.044
	(0.012)	(0.021)	(0.027)
Child consumed fish	0.011	-0.003	-0.045
	(0.059)	(0.021)	(0.038)
N	1564	2413	2237
adjusted R-square	0.175	0.113	0.159

The table reports estimation results using FE panel regressions. The outcome variable in Panel A is child's LAZ and a dummy variable equal to 1 if the child is stunted in Panel B. Co-variates and control variables: child consumed starchy staples, dark green leafy vegetables, vitamin A rich fruits and vegetables, other fruits and vegetables, legumes, nuts and seeds, child's age, age squared, age cubed, a dummy variable equal to 1 if the child is a girl, a dummy variable equal 1 if the child had diarrhea in the past two weeks, the caregiver's years of education, the mothers height, a dummy equal to 1 if the household has an improved latrine. Data sources are POSHAN (Nepal), BAHNR (Bangladesh), Uganda Panel (Uganda).

All regressions include control variables and District X wave fixed effects. Standard errors clustered by district are reported in parentheses.

*p<0.1, ** p<0.05, ***p<0.01

Table 4: Association of LAZ or stunting in children (aged 6-24 months) and lagged ASF consumption in Nepal and Bangladesh

	Nepal		Bangladesh	
	(1)	(2)	(1)	(2)
PANEL A: LAZ AND LAGGED ASF CONSUMPTION: AGES 6-24 MONTHS				
Child consumed any ASF	0.257**		0.140***	
	(0.093)		(0.049)	
Child consumed 1 type of ASF		0.254**		0.095
		(0.102)		(0.061)
Child consumed 2 or more types of ASF		0.283		0.231***
		(0.162)		(0.048)
N	787	787	1381	1381
adjusted R-square	0.207	0.206	0.170	0.172
PANEL B: STUNTED AND LAGGED ASF CONSUMPTION: AGES 6-24 MONTHS				
Child consumed any ASF	-0.099**		-0.033	
	(0.034)		(0.024)	
Child consumed 1 type of ASF		-0.092**		-0.001
		(0.039)		(0.029)
Child consumed 2 or more types of ASF		-0.159***		-0.099***
		(0.036)		(0.019)
N	787	787	1381	1381
adjusted R-square	0.116	0.116	0.112	0.119

The table reports estimation results using FE panel regressions. The outcome variable in Panel A is child's LAZ and a dummy variable equal to 1 if the child is stunted in Panel B. Co-variates and control variables: child consumed starchy staples, dark green leafy vegetables, vitamin A rich fruits and vegetables, other fruits and vegetables, legumes, nuts and seeds, child's age, age squared, age cubed, a dummy variable equal to 1 if the child is a girl, a dummy variable equal 1 if the child had diarrhea in the past two weeks, the caregiver's years of education, the mothers height, a dummy equal to 1 if the household has an improved latrine. Data sources are POSHAN (Nepal), BAHNR (Bangladesh), Uganda Panel (Uganda). All regressions include control variables and District X wave fixed effects. Standard errors clustered by district are reported in parentheses.
*p<0.1, ** p<0.05, ***p<0.01

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementarytablesZahariaetal.pdf