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Diet quality over time is associated with better development in rural Nepali children

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Abstract

Developmental delays affect between 150 and 200 million children <5 years of age worldwide. Outside of diet supplement studies, relatively little is known about the relationships between diet quality and developmental status in resource-poor settings. We examined associations between different aspects of dietary quality (dietary diversity score [DDS] and animal-source food [ASF] consumption) and child development (assessed using the Ages and Stages Questionnaire-3 [ASQ-3]) among children whose families were enrolled in a community development intervention trial (implemented by Heifer Nepal) in western Nepal. Two sets of analyses were performed: (a) cross-sectional Sample (N = 629) seen at the endline survey and (b) longitudinal sample (N = 269) with complete dietary records (six surveys over 48 months). In both samples, child development was significantly related to household wealth, maternal education, and especially home environmental quality. In the cross-sectional sample, greater consumption of eggs (adjusted odds ratio [aOR] 0.80, p = .04) or dairy products (aOR 0.95, p = .05) over the previous 7 days significantly reduced odds of low total ASQ score, by logistic regression analysis. In the longitudinal sample, only egg consumption and cumulative DDS and ASF scores were associated with significantly reduced odds of low total ASQ score (aORs 0.59–0.89). In adjusted linear regression analysis, both cumulative DDS (β [CI]: 1.92 [0.4, 3.5]) and ASF scores (2.46 [0.3, 4.7]) were significantly associated with greater continuous total child development. Programmes targeting child development must address home environmental quality as well as long-term diet quality.

1 | BACKGROUND

Early childhood development plays a crucial role in enabling children to acquire the needed intellectual skills and creativity to function as successful adults (Black et al., 2017). Yet more than 200 million children less than age 5 years in low- and middle-income countries are at risk of not achieving their full developmental potential (Black et al., 2017; Grantham-McGregor et al., 2007; Walker et al., 2007; Walker et al., 2011). Recognition of the breadth and severity of this problem is reflected by the inclusion of early child development as part of the Sustainable Development Goals (Dua et al., 2016).

Undernutrition, particularly in the early life, is strongly associated with loss of developmental potential. During this period of most rapid brain growth, undernutrition inhibits gene expression regulating brain development, resulting in reduced brain size, DNA content, myelinization, cortical dendritic growth, synaptogenesis, and neurotransmitter content (Nyaradi, Li, Siobhan, Foster, & Oddy, 2013; Johnson, Riis, & Noble, 2016. Young children suffering from undernutrition have poorer school achievement, diminished cognitive and language ability, and more behavioural problems (Lange, Froimowitz, Bigler, & Lainhart, 2010 ; Nelson & Deutschberger, 1970; Handler, Stoch, & Smythe, 1981; Ivanovic et al., 2002; Ivanovic, Perez et al., 2004; Grantham-McGregor et al., 2007; Schoenmaker et al., 2015; Wright & Emond, 2015). In Guatemala, S. Africa, Philippines, Jamaica, and Brazil, early cognitive development predicts later school outcomes (reviewed in Grantham-McGregor et al., 2007). Thus, early undernutrition is associated with life-long problems: Adults who were malnourished in childhood have less economic productivity and increased incidence of health problems (hypertension and glucose intolerance as well as worse maternal reproductive outcomes; Stoch & Smythe, 1976; Stoch, Smythe, Moodie, & Bradshaw, 1982; Alderman, Hoddinott, & Kinsey, 2003; Victora et al., 2008; Dewey & Begum, 2011; Fink et al., 2016). This has consequences for the next generation (Hamadani et al., 2014).

Undernutrition is strongly tied to poverty. Children in poorer families face many additional risk factors, which can impair their developmental progress. Low levels of parental education, lack of stimulation, and ill health are among the many difficulties faced by these children and their families and represent potential paths through which poverty may influence child development (Black et al., 2017; Dua et al., 2016; Grantham-McGregor et al., 2007; McCoy et al., 2016; Walker et al., 2011). Overall, "poverty deprives the [developing] brain of key stimuli and increases its exposure to negative inputs" in an environment where individuals have access to fewer buffering resources (Johnson et al., 2016). Therefore, there is an urgent need to better understand the relationship between these environmental factors and child development (Johnson et al., 2016).

In a prior analysis of a cohort of Nepali children at ages 23–38 months, we found that consumption of animal-source foods (ASFs), vegetables, and a more diverse diet assessed on three occasions over the previous 16 months was associated with better total child development scores (Thorne-Lyman, et al., 2019). This association was attenuated after controlling for socioeconomic status (SES) but remained significant. We continued to monitor child diet at intervals over an additional 32 months and then assessed the developmental status of an enlarged group of children to address several additional questions in this paper:

1. Do the associations between different aspects of dietary quality and child development persist into later childhood?
2. Could these findings be confirmed in a larger cross-sectional group of children with a broader range of ages?
3. Do these associations persist after adjusting for other potential confounders such as the quality of the home environment (not included in the prior analysis)?

Key messages

- Child development in low-resource settings relate to a constellation of factors.
- Developmental performance in young children is related to child diet quality as measured by consumption of animal source foods and diet diversity over time, as well as household wealth, maternal education, and home environmental quality.
- Assessment of dietary quality over longer time periods may identify important relationships between food intake and child developmental outcomes.

2 | METHODS

2.1 | Ethics

This investigation was approved by the Nepal Health Research Council, as well as the Human Investigation Review Board of Tufts University, and was registered at ClinicalTrials.gov (NCT03516396).

2.2 | Study design

This study of child development was nested within a larger community mobilization intervention trial implemented by Heifer Nepal in Banke district in western Nepal, an area largely populated by low-income subsistence farmers. Heifer Nepal is a nongovernmental organization concerned with poverty alleviation via livestock management practices and community empowerment. This larger study was designed as a longitudinal-controlled impact evaluation (Habicht, Victora, & Vaughan, 1999) to assess the contributions of in-depth community mobilization activities plus training in family nutrition and livestock management on household sociodemographic outcomes, as well as child growth and diet. Three nonadjacent communities from the same agro-ecological zone were identified based on similar sociodemographic characteristics. The communities were randomly assigned to one of three conditions: (a) full Heifer intervention package, including community development, livestock management training, and nutrition education (full package); (b) livestock management training and nutrition education only (partial package); or (c) control (no inputs; details are provided in) Miller, et al., 2020. Partial package and control communities received the Heifer full intervention package after the fifth round of data collection (1 year before the developmental assessments were completed). Six household visits were conducted over 48 months (Figure 1). At all six visits, household demographics and diet information were collected (described below). At endline, developmental testing was performed, and additional information was obtained about the quality of the home environment (described below).

2.3 | Participants

Children between 23 and 66 months of age at the final round of data collection (Round 6) were eligible for inclusion in the developmental study (Figure 1). Child age was determined by inspection of the birth or the vaccine certificate; either or both of these documents were available for all children. Exclusion criteria were physical or neurologic handicaps that prevented ingestion of a normal diet for age or children with severe intercurrent illnesses at the time of survey; however, no children met these criteria. All 629 children within the target age range at Round 6 were included in the cross-sectional sample. This group included the 269 children that comprised the longitudinal sample (described below), as well as all 360 children in the project area who were within the target age range. The household and child characteristics in the longitudinal and the cross-sectional samples at Round 6 are shown in Table 1. As certain measures were obtained only at Round 6 (household environmental quality and 7-day diet recall, both described below), we used the cross-sectional sample to evaluate developmental outcomes in relation to these and other child and household characteristics.

In addition to this cross-sectional sample, we also analysed the relation between diet and child developmental performance in a longitudinal sample (Figure 1). At baseline, 4 years earlier, 349 children between 6 and 18 months of age were enrolled; these children reached the target age of 23–66 months for developmental testing by the sixth household visit. Over the 4 years of the study, 80 children were lost to follow-up. Thus, 269 children remained in the study (77%) and completed all six visits. The baseline sociodemographic characteristics (household land or animal ownership, wealth score, income per family member, or maternal educational achievement) of the 269 children in the longitudinal sample did not differ from the 80 children who were lost to follow-up (Table S1). The longitudinal sample allowed an examination of the relationship of longer-term diet intake (over 4 years) on child developmental performance in 269 children with complete dietary records at all six household visits.

2.4 | Field procedures

Each family was visited six times over 48 months at intervals between 6 and 15 months (spread due to political unrest or natural disasters). Three rounds were conducted in the preharvest season and three in the postharvest season. Field enumerators travelled in pairs to conduct the visits during which a 145-item questionnaire was completed with the female head of household or her designee; a supervisor was also present for part of each visit. The core of the questionnaire was based on the Nepal Demographic and Health Survey (Ministry of Health and Population Nepal, New ERA and ICF International Inc, 2017) with additional modules to assess child development, the home environment, and other relevant indicators as described below.

2.5 | Diet (cross-sectional sample, *N* = 629)

Respondents were asked at each survey round if each participating child in the household had consumed any of 12 specific foods/food groups within the past 24 hr (Kennedy, Ballard, & Dop, 2013). These foods were then aggregated into eight food groups based on the FAO/FANTA dietary diversity score (DDS): starchy staples (grains and white potatoes); vitamin A-rich fruits and vegetables (including dark leafy green vegetables); other fruits and vegetables; offal, meat, and

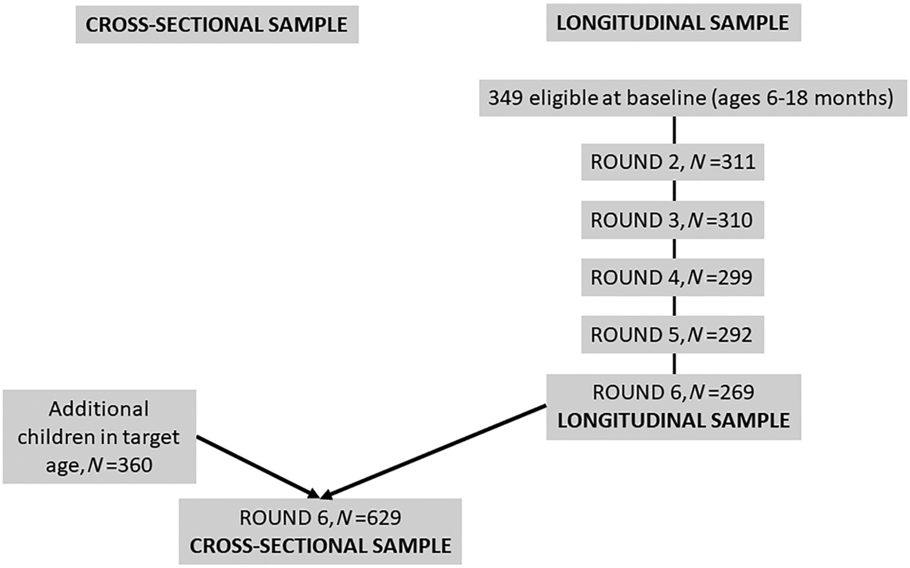

FIGURE 1 Study design. Two samples were constructed within the target age for developmental testing (23–66 months): a cross-sectional sample consisting of all children within this age range at Round 6 (*N* = 629) and a longitudinal sample (*N* = 269) including all children with complete diet records over 4 years. At baseline, there were 349 children who were 6–18 months of age; these children were 23–66 months at Round 6. As shown in the figure, there was gradual loss to follow-up of these children over the course of the study; 269 (77% of the starting group) remained at Round 6

fish; eggs; legumes, nuts, and seeds; milk and dairy products; and oils (Swindale & Bilinsky, 2006; United Nations Standing Committee on Nutrition, 2006).

These results were the basis for three variables describing the child's dietary intake:

1. DDS, sum of the eight food group categories consumed at each round of data collection (0–8).
2. ASF sum, the number of ASF groups (meat, fish, offal, eggs, milk, other dairy products; range 0–6) consumed in the previous 24 hr by each child, recorded at each round of data collection (Ruel, 2003; Steyn, Nel, Nantel, Kennedy, & Labadarios, 2007).
3. Number of times in the previous week that the child consumed each of the eight food groups, collected at Round 6 only.

2.6 | Diet (longitudinal sample, *N* = 269)

Additionally, for the longitudinal sample (*N* = 269) who had complete dietary records at all six household visits (over 4 years), two additional constructs were created to summarize these diet quality indicators.

1. Cumulative DDS, the sum of the DDSs from each round (maximum of eight at each of six assessments, for a total maximum of 48 possible).
2. Cumulative ASF score, sum of all ASF groups consumed over all six rounds of data collection (maximum of six at each of six assessments, for total maximum of 36 possible).

2.7 | Child developmental assessment (cross-sectional sample, *N* = 629)

Child development was assessed using the Ages and Stages Questionnaire-3 (ASQ-3). This standardized screening instrument is used worldwide (including Nepal) to assess child development (Kerstjens et al., 2009; Kvestad et al., 2017; Strand et al., 2017; Thorne-Lyman et al., 2019; Shrestha et al., 2019). It is scored by observation (or parent report) and consists of 30 age-specific items within the domains of communication, gross motor, fine motor, problem solving, and personal–social skills. The instrument was translated and back-translated from English to Nepali; minor changes were made to adapt to local conditions, and it was pilot-tested for clarity.

The test was administered by field enumerators who received 7 days didactic and practical training before each round of testing; the training was conducted under the supervision of a Nepali child development paediatrician specialist. Interrater reliability exercises were conducted as part of the training for the four enumerators and two supervisors. At the end of the training period, seven children were assessed by each trainee (30 items per child); their results were compared with the results obtained by the child development expert (M. S.). Agreement between the assessments of the trainees and the expert was 96%. In addition, a child development nurse specialist accompanied the field enumerators to the study area and remained with them as an on-site supervisor for the first 2 weeks of the 4-week period of data collection. She also remained available to the field team by phone for consultations and problem solving. The results of the ASQ testing was assessed in two manners: (a) by total score and (b) by quartile (bottom quartile vs. top three quartiles). As no validated/standardized threshold to characterize poor development using the ASQ in Nepal, we defined children in the bottom quartile as having poorer development as we and other investigators have done previously in Nepal (Thorne-Lyman et al., 2019; Kvestad et al., 2017; Strand et al., 2017; Winje et al., 2018; Shrestha et al., 2019). This allowed us to focus attention on children with poorer development. As for many developmental tests administered in early childhood, little is known about the long-term predictive value of the ASQ (Spittle et al., 2013). However, low ASQ scores have been related to poorer language and school outcomes (Halbwachs et al., 2014; Rice, Taylor, & Zubrick, 2008).

2.8 | Household characteristics (cross-sectional sample, *N* = 629)

2.8.1 | Socioeconomic status

Multiple indicators of SES were collected including animal ownership (converted to a standardized score using FAO Global Livestock Units; Food and Agricultural Organization, 2003) and amount of land owned (square metres). Annual income (Nepali rupees) was calculated based on reports of the household's monthly expenditures. Wealth scores were based on household possessions and quality of housing (including toilet and water) using principal components analysis following DHS–Nepal guidelines (Ministry of Health and Population Nepal et al., 2012) and treated as quartiles for modelling purposes.

2.8.2 | Maternal education

Previous work indicated the important influence of the level of mother's education on child outcomes (Miller et al., 2017); therefore, this variable was incorporated into the analysis. The educational status of the mothers was classified as (a) none or simple literacy classes, (b) some or completed primary school, and (c) some or completed secondary school (or beyond).

2.8.3 | Home environmental quality

The home environmental quality was assessed using components of the Nepali version of the UNICEF Multiple Indicator Cluster Survey (Nepal Central Bureau of Statistics and UNICEF Nepal, 2015). These components were as follows: availability of (homemade or purchased) toys, dolls, and books (verified by field enumerator);

interactive activities with the mother such as reading together, telling stories, singing together, naming objects, and playing (parent report); and child supervision (number of days per week that the child was left alone or under the supervision of another child, parent report; Kariger et al., 2012). Responses to these items were scored using the method adapted from (Jeong, McCoy, Yousafzai, Salhi, & Fink, 2016); a composite score incorporating these three categories was calculated. Scores were normally distributed (median 4, range −2 to 11) and treated as a continuous variable in models.

2.9 | Statistical analysis

Data were entered and analysed with JMP 13.1, SAS version 9.4, and Stata 15.0. Analysis was conducted at the community, household, and individual levels, starting with a descriptive analysis of the variables, including *t*-tests and analysis of variance, followed by a series of chi-square tests and correlations to assess collinearity. Continuous dependent variables were evaluated with histograms to verify normal distribution.

Standard methods were used to score the ASQ (Squires, Potter, & Bricker, 1995). A score of 10 was assigned if the child was observed/reported to "always" practise the behaviour, 5 if the child sometimes practised the behaviour, and 0 if the child could not/did not practise it. Contributing variables for each subdomain were evaluated, and those showing no variance were removed from the score, and the relative contribution of other items for that subdomain were weighted accordingly. Scores <50 points for total ASQ score were removed as these were felt to represent implausible scores.

Regression analyses were performed to consider a priori confounders of the relationship between diet and child development, including child age, maternal education, wealth quartile, and study arm assignment. Home environmental quality and child sex were also tested as potential confounders, but only home environmental quality was found to be a confounder, defined as altering the relationship between dietary diversity over time and total development by >10% when included in models. Therefore, in addition to the a priori variables described above, only home environmental quality was added to the models.

3 | RESULTS

3.1 | Child development and diet (cross-sectional sample, *N* = 629)

Household characteristics in the cross-sectional sample (*N* = 629) were compared for children scoring in the top three quartiles versus bottom quartile on ASQ scores, via *t*-tests for continuous variables and X^2 tests for categorical variables. Child developmental scores were significantly associated with household wealth, maternal education, and home environment, as well as DDS, ASF consumption, and consumption of dairy, eggs, and vitamin A-rich fruits/vegetables (Table 2). ASQ scores as a continuous variable were also significantly higher in children who had consumed milk, meat, eggs, or vitamin A-rich fruits/vegetables, compared with those who did not consume these items, respectively (mean [95% CI]: 211 [203, 219] versus 196 [192, 201], $p < .0001$; 207 [201, 214] versus 197 [192, 202], $p = .01$; 213 [204, 223] versus 198 [194, 203], $p = .01$; 206 [200, 212] versus 197 [192, 203], $p = .03$; data not shown).

Adjusted multivariable logistic regression analysis of the cross-sectional sample showed that greater consumption of eggs (aOR 0.80, $p = .04$) or dairy (aOR 0.95, $p = .05$) products over the previous 7 days significantly reduced odds of low total ASQ score, along with household wealth, maternal education, and home environmental quality. In addition, greater grain consumption significantly increased the odds of a low total ASQ score (aOR 1.09, $p = .02$), probably reflecting poorer diet diversity overall.

3.2 | Child development and diet (longitudinal sample, *N* = 269)

For the longitudinal sample (*N* = 269), the overall percentage of children consuming each food category varied considerably (grains and starchy staples [93%]; legumes, nuts, and seeds [89%]; oils [77%]; eggs [50%]; offal, meat, and fish [48%]; vitamin A-rich fruits and vegetables, including dark leafy green vegetables [31%]; other fruits and vegetables [27%]; and milk and dairy products [15%]). Median intake was low in quality and diversity, with relatively limited interquartile ranges (Figure 2). Out of the six observation days (during which 24-hr recall data were obtained), the median number of days the children consumed eggs, meat, milk, other vegetables, and vitamin A-rich fruits and vegetables ranged from 1 to 4. Children consumed oil or dal on 5 out of 6 days (median) and grains on 6 days (median). The median cumulative ASF score was 5 (maximum of six at each of six assessments, for total maximum possible of 36; inset, Figure 2). The median cumulative DDS (maximum of eight at each of six assessments, for total maximum of 48 possible) was 26 (inset, Figure 2). There was no difference between the three intervention clusters related to these cumulative diet intake scores. These dietary limitations were further emphasized when the number of times per week each individual food item was consumed was recorded at endline. Except for grain (median 21 times per week), dal (median 14), oil (median 12), and other vegetables (median 8), the median number of times per week other items were consumed was 0 or 1. (The frequency of consumption of each food group by children scoring in the upper three quartiles vs. bottom quartile of ASQ results is shown in Table S2, over the six rounds of data collection.)

In unadjusted logistic regression models, we found that consumption of vitamin A-rich fruit and vegetables, eggs, milk, grains, legumes, and any ASF was all associated with significantly lower odds of an ASQ score in the bottom quartile (with ORs ranging from 0.60 to 0.81; Table 3). After adjusting for maternal education, wealth quartile, child age, home environment, and study arm assignment (full package intervention, partial package intervention, and control), only egg

TABLE 1 Study population

	Cross-sectional sample	Longitudinal sample
	All children seen at Round 6	Children seen at all six rounds
	N = 629	*N* = 269
Gender M:F	317:312	143:126
Age (months)		
Mean ± *SD* [95% CI]	43.9 ± 13.5 [45, 43]	55.9 ± 6.5 [55, 57]
Range	23–66	45–66
ASQ scores		
Median (range)	206 (50–300)	205 (75–300)
Mean ± *SD* [95% CI]	203 ± 48 [205, 197]	204 [199, 210]
Maternal education (%)		
None/non formal education	77	76
At least some primary	19	19
At least some secondary	4	5
Land owned (m^2) mean ± *SD* [95% CI]	8,474 ± 9,861 [9,246, 7,701]	8,565 ± 10,492 [7,310, 9,820]
Animal ownership score[a] (mean ± *SD* [95% CI])	1.84 ± 1.87 [1.9, 1.7]	1.86 ± 1.96 [1.6, 2.1]
Wealth score[b] (mean ± *SD* [95% CI])	.02 ± .99 [.10, –.05]	.01 ± .99 [–.10,.13]
Income per household member (NPR)[3] (mean ± *SD* [95% CI])	28,806 + 20,950 [27,165, 30,446]	29,064 + 23,048 [26,308, 31,821]
Study area		
Control	34%	36%
Intervention	27%	30%
Partial intervention	39%	34%
Growth measurements (mean ± *SD* [95% CI])		
Height-for-age z score	−1.55 ± 1.02 [−1.47, 1.63]	−1.45 ± .97 [−1.56, −1.33]
Weight-for-age z score	−1.55 ± .87 [−1.48, −1.62]	−1.57 ± .84 [−1.67, −1.47]
Weight-for-height z score	−0.93 ± .92 [−0.85, −1.01]	−1.00 ± .87 [−1.12, −0.87]
Head circumference z score	−1.22 ± .95 [−1.15, −1.30]	−1.26 ± .92 [−1.37, −1.15]
Stunted (HAZ < −2)	32%	27%
Wasted (WHZ < −2)	13%	14%
Underweight (WAZ < −2)	30%	29%
Microcephalic (HCZ < −2)	21%	21%

Note. Cross-sectional sample (*N* = 629) compared with longitudinal sample (Children seen at all six rounds, *N* = 269) at Round 6.
[a]Number of livestock owned, converted to a standardized score using FAO Global Livestock Units (Food and Agricultural Organization 2003).
[b]Household wealth score was defined by principal components analysis of household possessions and quality of housing using DHS-methods
[c]Nepalese rupees
Abbreviations: ASQ, Ages and Stages Questionnaire-3; CI, confidence interval; SD, standard deviation.

consumption, cumulative DDS, and cumulative ASF scores retained statistical significance although the odds ratios for the other food categories were only slightly attenuated (results of linear regression are shown in Table S3).

In multivariable linear regression analysis, adjusting for maternal education, household wealth, the home environment, study arm assignment, and child age, both the cumulative DDS (β [95% CI]: 1.92 [0.4, 3.5]) and the cumulative consumption of animal source foods (2.46 [0.3, 4.7]) were significantly associated with total child development (Table 4). In both models, maternal education, home environment, and child age were also strongly associated with child development scores.

4 | DISCUSSION

In the longitudinal sample (*N* = 269) of children in rural Nepal followed over 4 years, developmental assessments at endline underlined the important contributions of diverse diet, ASF consumption, maternal education, household wealth, and home environmental quality to child

TABLE 2 Relation of endline (Round 6) household characteristics and child diet to ASQ score results, cross-sectional sample, N = 629, descriptive statistics and multivariable logistic regression

	Descriptive statistics			Multivariable regression		
	ASQ Results					
	Top three quartiles	Bottom quartile	*p*	Adjusted OR of ASQ score in bottom quartile	[95% CI]	*p*
Household characteristics						
Group assignment, % of children in			NS			
Control group	78	22		REF		
Full package intervention	75	25		0.87	[0.50–1.52]	NS
Partial package intervention	73	27		0.84	[0.51–1.38]	NS
Household wealth score[a] (mean [95% CI])	0.14 [0.05–0.23]	−0.33 [0.48–0.18]	<0.0001*	0.71	[0.56–0.89]	0.003
Home environmental quality[b] (mean [95% CI])	4.48 [4.27–4.68]	3.32 [3.08–3.56]	<0.0001*	0.79	[0.7–0.88]	<0.0001
Maternal education[c], % of children whose mothers had			0.0003^			
None or minimal education	68	32		REF		
Some or completed primary school	82	18		0.58	[0.38–0.89]	<0.01
Some or completed secondary school	93	7		0.41	[0.09–1.96]	NS
Child diet						
Dietary diversity score[d] (mean [95% CI])	4.79 [4.69–4.89]	4.36 [4.19–4.54]	<.0001*	NA[g]		
ASF sum[e] (mean [95% CI])	0.89 [0.89–0.97]	0.61 [0.48–0.71]	<.0001*	NA[g]		
Seven-day recall[f]						
# of times items in each category were consumed (mean [95% CI])						
Dairy	2.93 [2.49–3.36]	1.64 [1.06–2.22]	0.002	0.95	[0.9–1.00]	0.05
Meat	1.47 [1.36–1.58]	1.29 [1.10–1.48]	NS	0.99	[0.83–1.17]	NS
Eggs	0.84 [0.72–0.96]	0.43 [0.30–0.57]	0.0005	0.80	[0.64–0.99]	0.04
Grains	19.86 [19.58–20.18]	20.68 [20.19–21.18]	.01	1.09	[1.01–1.17]	0.02
Vitamin A-rich fruits and vegetables (including green leafy vegetables)	1.70 [1.51–1.90]	1.26 [0.99–1.52]	0.019	1.00	[0.97–1.03]	NS
Legumes, nuts, and seeds	13.25 [12.67–13.83]	13.28 [12.16–14.39]	NS	0.93	[0.83–1.04]	NS
Other vegetables	8.28 [7.75–8.81]	8.21 [7.23–9.20]	NS	1.00	[0.96–1.04]	NS
Oil	10.12 [9.71–10.52]	10.10 [9.31–10.89]	NS	1.02	[0.96–1.07]	NS

Note. Household characteristics and diet (n = 629) compared for children scoring in the top three quartiles versus the bottom quartile on ASQ scores. Continuous variables were assessed using t-tests (indicated by *); categorical variables were assessed using X^2 (indicated by ^). Regression analyses adjusted for household wealth, home environmental quality, and maternal education, as well as either diet intake of specific food items in prior 24 hr or number of items of each food category consumed in prior 7-days.

[a]Household wealth score was defined by principal components analysis of household possessions and quality of housing using DHS-methods.

[b]Home environmental quality was assessed using components of the Multiple Indicator Cluster Survey (Nepal Central Bureau of Statistics and UNICEF Nepal, 2015).

[c]Maternal education was categorized as none or informal only, some or completed primary school, or some or completed secondary school.

[d]Dietary diversity score = sum of the individual food groups consumed in the prior 24 hr, range 0–8.

[e]ASF sum = number of ASF groups (meat, fish, offal, eggs, milk, and other dairy products), range 0–6, consumed in the previous 24 hr.

[f]Seven-day recall of the number of times items in each of the eight food categories were consumed.

[g]Diet summary measures were not included in the regression, as they were correlated with the individual food groups.

Abbreviations: ASF, animal-source foods; ASQ, Ages and Stages Questionnaire-3; CI, confidence interval; OR, odds ratio; SD, standard deviation; NS = not significant, NA = not applicable.

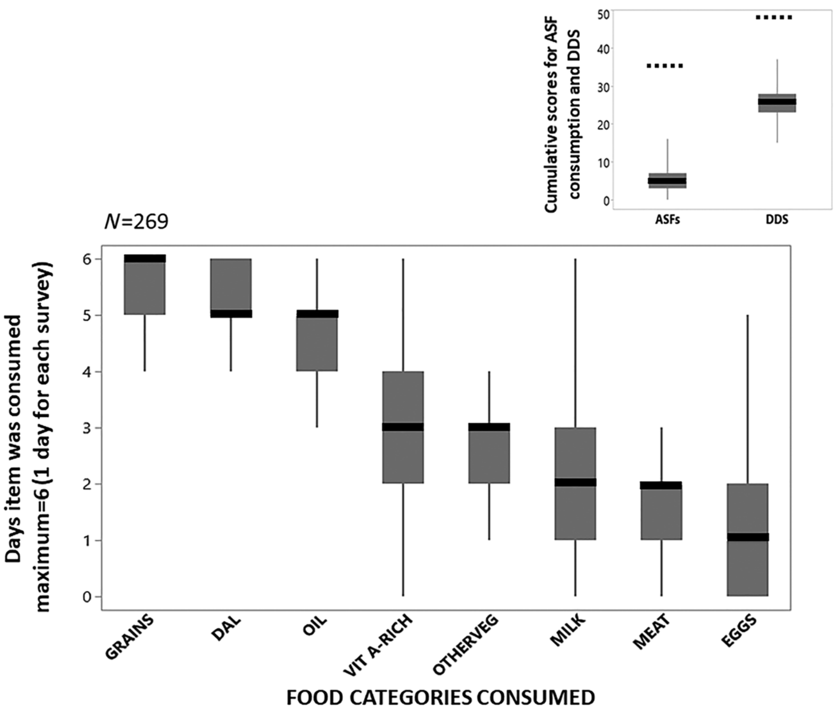

FIGURE 2 Longitudinal sample, *N* = 269 median number of days and interquartile range for which various food items were reported to have been consumed within the prior 24 hr, at each of the six household visits, for the longitudinal sample of 269 children. Median (black bar) and interquartile range (grey box) are shown for each food category. The inset shows cumulative scores for ASF consumption (maximum possible 36, indicated by the dotted line [six ASF categories × six household visits]) and DDS (maximum possible 48, indicated by the dotted line [eight food categories × six household visits]). ASF, animal-source foods; DDS, dietary diversity score

developmental performance. The general inadequacy of dietary intake among the children in the longitudinal sample was striking. Notably, in six surveys over a period of 4 years, ASFs were rarely consumed, and diet diversity was minimal for most of the children. We observed meaningful relationships between better diets over time, specifically greater diet diversity, more ASF consumption, and consumption of specific items (including milk or other dairy products, eggs, meat, vitamin A-rich fruits, and vegetables), and lower odds of being in the bottom quartile of total development. These relationships were attenuated but many remained statistically significant after adjustment for potential confounders. The evident contributions of diet to developmental status were striking: Even small changes in dietary intake were associated with impressive improvements in child developmental performance. In addition, cumulative DDS over time was strongly associated with total ASQ score, along with maternal education level and the quality of the home environment. In the larger cross-sectional sample (*N* = 629), the relationship of developmental performance to diet was confirmed when a 7-day diet recall record was used in the analysis. Consumption of eggs and dairy products were associated with reduced odds of having an ASQ score in the bottom quartile. Household wealth, maternal education, and quality of the home environment also significantly related to child developmental performance. Together, these findings underline the key contributions of long-term dietary intake on developmental outcomes and the importance of using such measures to assess these relationships. In addition, the important role of household factors to child developmental achievement was confirmed.

Limited resource environments present many potential hazards to growing children, including poor nutrition, lack of medical care, increased exposure to infections, physical and emotional neglect, stress, and lack of stimulation for cognitive development (Johnson et al., 2016; Walker et al., 2007; Walker et al., 2011). Children may also experience possible adverse prenatal exposures (drugs, alcohol, and tobacco), perinatal complications (especially prematurity and low birth weight), and environmental toxins (McCoy et al., 2016; Miller, 2005; Nyaradi et al., 2013; Prado & Dewey, 2014; Walker et al., 2011). Lower educational levels of the parents (particularly the mother) are one of many additional risk factors in impoverished households. Together and separately, these conditions contribute to child developmental delays. We found that child developmental scores were significantly associated with household wealth, maternal education, and the home environmental quality, as well as cumulative DDS and ASF consumption over 4 years (Tables 3 and 4).

Poor nutrition is one of the key influences on child development (Winick, 1969; Cravioto & Delicardie, 1970; Alvarez et al., 1991; Colombo, de la Parra, & Lopez, 1992; Grantham-McGregor, 1993; Allen, 1995; Galler & Ross, 1993; Drewett, Corbett, & Wright, 1999; Ivanovic et al., 2000; Galler & Barnett, 2001; Ivanovic, Leiva, et al., 2004; Nyaradi et al., 2013; Ihab et al., 2014; Black et al., 2017; Kvestad et al., 2017). Nutrition is critical to brain development, via its influence directly on structure and function and indirectly via its effect on children's behaviour and experience (Muhoozi, Atukunda, Mwadime, Iversen, & Westerberg, 2016). Nutritional deficiencies may start in fetal life, continue into infancy when the child may not receive appropriate complementary foods, and beyond, into early childhood. Specific nutrients needed by growing children, including protein, vitamin B12, folate, retinoic acid, omega-3 fatty acids, zinc, and iron, may be limited. Local customs, financial constraints, or realities of the time needed to prepare foods may result in inappropriate food offerings (Pries et al., 2016). The hippocampus, prefrontal cortex, amygdala, and HPA axis may be specifically vulnerable to early life insults (Staff et al.,

TABLE 3 Measures of diet quality over 48 months related to odds of having ASQ score in the bottom quartile (longitudinal sample, *N* = 269)

# of surveys (out of six) that item was consumed	Unadjusted OR (95% CI)	*p*	Adjusted OR (95% CI)	*p*
Vitamin A-rich fruits and vegetables	0.72 (0.56, 0.94)	.01	0.79 (0.59, 1.07)	.12
Eggs	0.60 (0.43, 0.83)	.002	0.59 (0.41, 0.84)	.003
Milk	0.81 (0.66, 0.99)	.041	0.82 (0.65, 1.04)	.11
Meat	0.97 (0.77, 1.22)	.8	1.14 (0.87, 1.49)	.33
Grain	0.52 (0.32, 0.83)	.007	0.61 (0.28, 1.33)	.21
Legumes, nuts, and seeds	0.68 (0.46, 0.99)	.049	0.95 (0.59, 1.54)	.84
Oils and fats	0.82 (0.61, 1.10)	.18	0.97 (0.59, 1.58)	.89
Other vegetables	0.89 (0.67, 1.19)	.44	1.03 (0.74, 1.43)	.87
Any ASF	0.78 (0.63, 0.95)	.013	0.86 (0.69, 1.08)	.20
Cumulative consumption over six surveys				
Cumulative ASF score	0.83 (0.72, 0.94)	.005	0.86 (0.73, 0.99)	.047
Cumulative DDS	0.86 (0.80, 0.93)	.001	0.89 (0.80, 0.99)	.036

Note. Logistic regression showing the unadjusted and adjusted odds ratios for an ASQ score in the bottom quartile, related to the number of surveys out of six that each item was consumed (upper section) and for cumulative DDS (sum of food groups consumed over six survey rounds) and ASF score (sum of ASFs consumed over six survey rounds; lower section). Adjustment was made for study arm assignment, maternal education, child age, wealth quartile, and home environment.
Abbreviations: ASF, animal-source foods; ASQ, Ages and Stages Questionnaire-3; CI, confidence interval; DDS, dietary diversity score; OR, odds ratio.

TABLE 4 Diet, maternal education, and home environment related to total ASQ scores (longitudinal sample, *N* = 269)

	Cumulative dietary diversity score			Cumulative ASF score		
	β	Pr >|t|	95% CI	β	Pr >|t|	95% CI
Intercept	65.9	<0.01	(19.8, 112.0)	81.5	<0.001	(37.8, 125.3)
Cumulative DDS or ASF (continuous)	1.92	0.01	(0.4, 3.5)	2.46	0.03	(0.3, 4.7)
Mother's educational achievement						
No or minimal education	Reference			Reference		
Some or completed primary education	13.8	0.04	(0.4, 27.1)	14.8	0.03	(1.47, 28.1)
Some or completed secondary education	33.7	0.01	(7.5, 60.0)	34.1	0.01	(7.7, 60.4)
Household wealth quartile						
Lowest wealth quartile 1	Reference			Reference		
Wealth quartile 2	4.09	0.55	(−9.7, 17.8)	4.92	0.48	(−8.8, 18.6)
Wealth quartile 3	0.39	0.96	(−13.7, 14.5)	1.07	0.88	(−13.0, 15.2)
Highest wealth quartile 4	5.83	0.47	(−10.1, 21.8)	6.01	0.46	(−10.2, 22.2)
Home environmental quality	4.97	<0.001	(2.7, 7.2)	5.2	<0.001	(3.0, 7.5)
Control group	Reference			Reference		
Full package intervention	6.00	0.34	(−6.4, 18.4)	3.64	0.56	(−8.7, 16.0)
Partial package intervention	4.89	0.42	(−7.0, 16.7)	1.49	0.80	(−10.1, 13.0)
Age at endline (continuous)	1.00	0.02	(0.2, 1.8)	1.42	<0.001	(0.68, 2.16)

Note. Full model assessing the impact of dietary diversity, maternal education, and home environmental quality, wealth score, study arm assignment and child age on total ASQ scores. Cumulative DDS (sum of food groups consumed over six survey rounds), cumulative ASF score (Sum of ASFs consumed over six survey rounds).
Abbreviations: ASF, animal-source foods; ASQ, Ages and Stages Questionnaire-3; CI, confidence interval; DDS, dietary diversity score.

2012; Johnson et al., 2016). We previously found that ASF consumption related to brain size in young Nepali children (Miller et al., 2016).

Some of these structural and functional changes in the brain may be permanent, even if other factors (food intake, health, and other environmental influences) later improve. For example, low SES in childhood was associated with reduced hippocampal volume more than 50 years later, even after adjusting for adult education and SES (Staff et al., 2012). In an impoverished environment, the effect of dietary deficiencies may be magnified by the presence of additional risk factors and the lack of protective resources (Johnson et al., 2016;

Muhoozi et al., 2016). For example, chronic stress, illness, and low levels of maternal education (Sania et al., 2019) are closely linked to child developmental delays. Additionally, a lack of adult supervision, opportunities to play, and nurturing social interactions limit the ability of children to develop needed skills (Kariger et al., 2012).

We found that maternal education was strongly and independently associated with child developmental performance. Multiple studies in both developed and developing countries have reported a positive relationship between a mother's level of education and her child's behaviour and school performance (Carneiro, Meghir, & Parey, 2013; Grantham-McGregor et al., 2007; Walker et al., 2007; Walker et al., 2011). Furthermore, an analysis of survey data from five countries in South Asia recently demonstrated that lack of maternal education was among the strongest correlates of poor child nutritional status (Kim, Shin, & White-Traut, 2003); we have previously confirmed this finding in rural Nepal (Miller et al., 2017).

Maternal education may be considered a proxy marker for household wealth status, but it may also independently denote genetic potential transmitted from the mother to the child. Generally, it is estimated that about 50% of intelligence as measured by IQ is attributable to genetics. However, the validity of this statistic has been questioned in low-resource environments, as genes explain more of the variance in cognition and brain structure in high-SES individuals than in low-SES individuals (Johnson et al., 2016). Thus, environmental factors, such as lack of opportunity to receive an education, rather than genes, are likely to be more influential in this context.

One of the key environmental factors is the degree of nurturing and stimulating interactions available to the child. Animal and human studies clearly demonstrate that maternal caregiving relates to the regulation of stress responses via the number of glucocorticoid receptors in the hippocampus—and better cognitive performance (reviewed in Johnson et al., 2016). The quality of caregiving by the parent is central (Bann et al., 2016; Dreyer, 2016; Hamadani et al., 2014; Racine, 2014). Correspondingly, we found that developmental status was associated strongly with home environment, emphasizing the importance of parent–child engagement, interactions, and play to child outcomes (Shrestha et al., 2019). Some evidence suggests that the nutritional status of the child directly influences parent engagement. Undernourished children are often less active and more irritable. These behaviours may not reinforce parent engagement, thus creating a cycle of hypo-responsive children and more detached parents (Graves, 1978). Likewise, parental stress is likely to negatively influence the child's development (Johnson et al., 2016; Walker et al., 2011); some research has suggested that parents in economically marginal households in low- and middle-income countries are more likely to experience stress (Petterson & Albers, 2001; Black et al., 2017). Children whose mothers are disengaged due to stress or depression tend to have higher cortisol levels and lower levels of development; their home environments are less nurturing and stimulating (Black, Baqui, Zaman, El Arifeen, & Black, 2009; Johnson et al., 2016).

Our study focused on dietary relationships to child development. As others have reported, consumption of a diverse diet and ASFs was associated with better developmental performance. We also noted that consumption of vitamin A-rich fruits and vegetables related to better developmental scores. Although this food category has not been previously linked to child developmental outcomes, vitamin A-rich foods are important to the prevention of cognitive decline in older adults. Various mechanisms for this relationship have been proposed, including modulation of functional properties of synaptic membranes, enhanced gap junctional communication, enriched neural circuitry in the visual system (important to visual processing speed), direct anti-inflammatory action in the brain (Johnson et al., 2013), and amelioration of iron deficiency anaemia through enhanced iron absorption (Garcia-Casal et al., 1998) or intake (via green leafy vegetables, included in the category of vitamin A-rich fruits and vegetables; Prado & Dewey, 2014; United Nations Standing Committee on Nutrition, 2006). Notably, children in the project area regularly received vitamin A supplements; the observed effects on child development may represent the bioactivity of other carotenoid compounds.

Our study had several limitations and strengths. As strengths, we were able to collect and analyse both cross-sectional and longitudinal results. The availability of complete dietary information six times over 4 years on a longitudinal subgroup of 269 children provided a detailed picture of child diet. This allowed us to examine trends in diet intake over time and relate these to child developmental performance. Moreover, even after adjusting for confounders, the relationships between elements of the diet and child developmental status persisted.

We recognize that our study had several limitations. Our study had a relatively small sample size, and the number of children who had complete dietary information over the 4 years was limited. We also acknowledge that the ASQ test is a screening test, which does not provide age equivalents of the child's developmental status but functions as an assessment tool to identify children with possible developmental delays. Although it is not considered a “gold standard” developmental test and some have reported problems with its use (Rubio-Codina, Araujo, Attanasio, Munoz, & Grantham-McGregor, 2016), others found it useful in Nepal (Kvestad et al., 2017; Strand et al., 2017; Shrestha et al., 2019), and elsewhere (Muhoozi et al., 2016), as it captures a wide range of adaptive behaviours. We found it to be informative and practical for use in the household under field conditions, administered by carefully trained and closely monitored but nonprofessional field enumerators. Additionally, we acknowledge that the measures of home environment selected, derived from the Multiple Indicator Cluster Survey, were self-reported and not validated independently, and this item was only obtained at one time point during this study. Furthermore, we recognize that the dietary and other relationships we found show associations only and are not proof of causality. Finally, many unmeasured variables could have contributed to child nutritional and developmental outcomes, for example, environmental enteropathy and other measures of hygienic conditions, adverse exposures (e.g., aflatoxin, lead, and domestic violence), out-migration of household adults, childhood illness, or quantities of nutrients consumed. We recognize that these and other unmeasured variables surely also affect child outcomes.

Nevertheless, our findings underline several important points about child development in resource-poor settings. First, even small changes in diet quality over a period of 4 years, as measured by dietary diversity and ASF consumption, positively relate to child developmental outcomes. Importantly, both of these measures are associated with child developmental outcomes. Second, multiple factors influence child development; programmes targeting this outcome must address home environmental quality as well as diet. Third, the importance of maternal education is once again underscored. Promoting female education at national and international levels will pay dividends not only for improved child growth but more importantly also for improved child development. Finally, assessment of development in young children as a part of interventions or surveys can highlight basic needs within the community. Developmentally capable children are the foundation of a healthy, well-functioning society. Achieving a normal developmental trajectory in early childhood increases the likelihood of later school success and consolidation of executive function. The ability of adults to plan, organize, and remember is an essential tool for a functional, progressive society. As recently stated by the WHO, "Early child development is a cornerstone of human development and should be central to how we judge the success of societies" (World Health Organization, 2018). Integrated programmes addressing the quantity and quality of caloric input, parental nurturing, and home environment (Racine, 2014) are urgently needed (Johnson et al., 2016; Prado & Dewey, 2014).

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

LCM, NJ, ShN, and ATL performed the research. LCM, NJ, ML, SuN, and ATL designed the research study. MS contributed essential training. LCM, SuN, and ATL analysed the data and wrote the paper. All authors have read and approved the final manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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