



Relationships between dietary diversity and early childhood developmental outcomes in rural China

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Abstract

The period from birth to 2 years of age is highly sensitive with respect to the relationship between nutrition and neurodevelopment, but data regarding the association between dietary diversity and early childhood neurodevelopment are limited. We sought to examine the association of two feeding indicators—minimum dietary diversity (MDD) and minimum meal frequency (MMF)—with the neurodevelopment of children aged 6–23 months, using data from a cross-sectional survey conducted in six rural counties in China. Data on 1,534 children were analysed using logistic regression to explore the associations between dietary diversity and early neurodevelopment, with adjustments for the age, sex and prematurity of the child; the age, sex and educational level of the caregiver; and family size, income and simulative care practices and resources. We found that 32.4% of children had suspected developmental delays based on the Chinese version of the Ages and Stages Questionnaires Version 3, whereas 77.0% and 39.2% failed to meet the MDD and MMF, respectively. Meeting the MDD was associated with a 39% lower risk of developmental delays (AOR = 0.61, 95% CI [0.43, 0.86]). There was a significant association between MDD and reduced likelihood of developmental delays in gross motor, fine motor, problem-solving and personal social subscales, whereas MMF was only associated with a lower risk of developmental delays in the gross motor subscale (AOR = 0.63, 95% CI [0.42, 0.94]). We observed an inverse dose–response relationship between the number of food groups consumed and the risk of developmental delays ($P < .001$).

KEYWORDS

child development, complementary feeding, developmental delays, dietary diversity, infant and young child feeding, meal frequency, World Health Organization feeding indicators

1 | INTRODUCTION

The period between birth and 2 years of age is well recognized as a critical window for the optimal growth, development and well-being

of children. It is highly sensitive with respect to the relationship between nutrition and cognition, motor development, language development and future educational performance (Black, Perez-Escamilla, & Rao, 2015; Black et al., 2017). As a result of multiple adversities in

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early life, an estimated 249 million children under the age of 5 have failed to reach their developmental potential in developing countries; approximately 17 million of these are in China (Lu, Black, & Richter, 2016).

Despite national decreases in stunting from 41.4% in 1990 to 8.1% in 2013, and in the prevalence of anaemia from 19.3% in 2005 to 12.6% in 2010 (Chang, He, & Chen, 2006; Yu et al., 2016), impoverished regions in rural China exhibit higher levels of poor early development. A cross-sectional study of 1,422 children aged 18–30 months in poor areas of rural China indicated that 42.0% had delayed cognitive development, and 10.2% exhibited delayed motor development (Yue et al., 2019). Early developmental deficits may lead to poorer school performance, lower earnings in adulthood and higher risk of chronic diseases in later life (Black et al., 2017; Black et al., 2013).

Data from low- and middle-income countries (LMICs) have demonstrated a significant association between nutrition and early childhood development. Previous studies have found that stunted growth, weight insufficiencies, iron deficiency-induced anaemia and iodine deficiencies are all associated with compromised developmental outcomes in young children (Ahun, Aboud, Aryeetey, Colecraft, & Marquis, 2018; Black et al., 2017; Black et al., 2013; Hamadani et al., 2014; Pivina, Semenova, Dosa, Dauletyarova, & Bjorklund, 2019). Other studies from LMICs have reported that better linear growth, as measured by a height-for-age Z-score (HAZ), is linked with better cognitive, language and motor development, albeit weakly (Ahun et al., 2018; Larson et al., 2017; Sudfeld et al., 2015). Biological, socio-economic and psychosocial factors comprising prematurity at birth, family income, maternal education, early stimulation and home learning resources are also related to child developmental outcomes (Aboud, Singla, Nahil, & Borisova, 2013; Fernald, Kariger, Hidrobo, & Gertler, 2012; Fernald, Weber, Galasso, & Ratsifandrihamanana, 2011; Lu et al., 2016; Pierrat et al., 2017; Schady et al., 2015; Vazir et al., 2013; Yousafzai, Rasheed, Rizvi, Armstrong, & Bhutta, 2014; Yue et al., 2019). However, most studies use outcome level indicators (e.g., HAZ, weight-for-age Z score or anaemia rates) to explore the relationship between nutritional factors and early child development. By contrast, complementary feeding practices, which constitute an important component of care and a determinant of nutrition in infants and young children, have not been adequately addressed in existing studies.

Dietary diversity, defined as access to five or more food groups, is a well-recognized indicator reflecting the quality of complementary foods (WHO & UNICEF, 2017). Although dietary diversity was reported to be 52.5% for children aged 6–23 months in China in 2013 (Duan et al., 2018), dietary diversity in poor areas of rural China remains concerning. Wang et al. (2017) reported an alarmingly low diet diversity of 26.9% for Yi ethnic minority children aged 6–11 months in poor, rural China. Other studies have reported that the complementary foods introduced were either introduced too early or too late and comprised mainly plant-based foods low in micronutrients (Geng, Ma, Liu, Zhang, & Sheng, 2018; Luo et al., 2014). Inadequate dietary diversity was found to be associated with

Key messages

- In children aged 6–23 months, meeting the minimum dietary diversity (MDD) was associated with 39% lower risk of poor development compared to children consuming fewer than five food groups.
- MDD was associated with lower risk of poor development in the gross motor, fine motor, problem-solving and personal social subscales, whereas MMF was only associated with lower risk of poor development in the gross motor subscale.
- An inverse dose–response relationship between the number of food groups consumed and the risk of developmental delays was observed.

diminished linear growth status, stunted growth and micronutrient deficiencies in infants and young children (Briaux et al., 2019; Geng et al., 2018; Meshram et al., 2019; Mohammed et al., 2019; Wang et al., 2017; Zhao et al., 2017). However, limited evidence is available about the relationship between dietary diversity and early childhood developmental outcomes, especially in resource-constrained areas of China.

Here, we investigate relationships between dietary diversity, meal frequency and early child developmental outcomes in children aged 6–23 months in poor rural areas of China.

2 | METHODS

2.1 | Study site and sampling procedures

We conducted a community-based cross-sectional survey between July and September 2013 in six poor, rural counties in Shanxi and Guizhou Provinces, located in northern and southern China, respectively. We investigated child health, growth and developmental status, as well as related factors for the Integrated Early Childhood Development programme. Three counties in each province were selected by referring to county lists for the nationally designated poverty battlefields of Shanxi and Guizhou Provinces. In total, 83 villages from a pool of 856 were selected. Selected villages met the following criteria: (1) presence of >50 children under the age of 3; (2) presence of both a health centre and maternal and child health workers in the township in which the village is located; and (3) vehicle accessibility. All children under 3 years old in the selected villages were eligible for inclusion in the study, and a total of 4,288 children aged 0–35 months were identified based on information from local child health care systems. All children and their families were contacted by telephone and asked to participate in the survey in the village clinic or a public space close to the village clinic. Ultimately, 2,953 children (68.9% of the total) were surveyed; 1,335 did not participate owing to migration to another

county or to cities, or to difficulties in travelling from remote mountainous areas. All caregivers provided written, informed consent to participate in this study. Among the 2,953 participants, 16 children with disabilities, for example, blindness or deafness, and 81 participants who were not the primary caregivers were excluded from the analysis. A total of 1,534 children 183–730 days in age were included in the final analysis. Details of the survey have been described previously (Wei, Zhang, et al., 2015).

2.2 | Data collection

2.2.1 | Sociodemographic characteristics

Data were collected via face-to-face interviews with caregivers in a village clinic or a quiet public room. If caregivers were unable to come to the clinic, surveys were conducted via household visits. Basic sociodemographic data were collected, including the child's sex, date of birth, prematurity, caregiver's age, sex, educational status, family size and annual household income. Annual household income refers to the combined annual income of all family members who live together and share financial resources. Prematurity is defined as birth before 37 weeks of gestation. The child's date of birth and sex, as well as information on prematurity, were obtained from immunization cards or birth certificates. Data were immediately input using electronic questionnaire software installed on tablets (Lenovo, Beijing, China). Basic logic and integrity checking were programmed into the software to minimize missing values and to correct errors in a timely manner. Investigators verified and uploaded data daily. Designated survey supervisors from Peking University reviewed the data and made edits if necessary.

2.2.2 | Anthropometric measures

Postgraduate students with standardized training measured the heights/lengths of children using a standard infant length scale with an accuracy of 0.1cm, and weighed children using an electronic scale with an accuracy of 0.01kg, following standard anthropometric procedures. The recumbent length and weight of children were measured twice, and the average value was used if the two measurements differed by <1.0 cm for length and 0.5 kg for weight. Otherwise, a third measurement was taken. Stunting, underweight and wasting were defined using the length-for-age Z-score, weight-for-age Z-score and weight-for-length Z-score of less than -2.

2.2.3 | Assessment of child functional development

The Ages and Stages Questionnaires Version 3 (ASQ-3) was used to assess early childhood development. The ASQ-3 is a parent-administered, general screening tool for early detection of developmental delays in children aged 1–66 months (Squires & Bricker, 2009), and

has been widely used in a variety of settings in the United States and other countries (Singh, Yeh, & Boone Blanchard, 2017). Cross-cultural adaptation, validation and standardization of the ASQ-3 in China were conducted in 2011 and 2012 (Wei, Bian, et al., 2015). Cronbach's alpha coefficient for the Chinese version of ASQ-3 (ASQ-C) is 0.8. Sensitivity and specificity of the ASQ-C are 87.50% and 84.48%, respectively, and the agreement between the ASQ-C and the Gesell diagnostic tool is 84.74%, indicating that the ASQ-C is a valid, reliable tool in China (Wei, Bian, et al., 2015).

The ASQ-C was administered by county child health workers who received standard training from authorized ASQ-C trainers, with quality assurance conducted by Peking University researchers and prefecture child health specialists. With support from trained interviewers, parents were asked to assess their children's development on all milestones. Responses of 'yes', 'sometimes' or 'not yet' were given scores of 10, 5 and 0 points, respectively. The total score for each subscale comprised the sum of the scores of the six constituent items. A score of 0–60 for each domain, and a maximum overall score of 300 points for ASQ-C, was assessed based on the performance of the children. Scores more than 2 standard deviations below the Chinese normative mean in any of the five subscales were considered indicative of developmental delays.

2.2.4 | Infant feeding practices

Data on feeding practices were examined based on World Health Organization (WHO) guidelines for measurement of infant and young child feeding (WHO, 2010; WHO & UNICEF, 2017). Dietary intake information was collected based on a 24-h dietary recall using the adapted questionnaire from the standard module in UNICEF's 4th Multiple Indicator Cluster Survey (MICS4; UNICEF, 2013). The eight food groups are (1) breast milk, (2) grains, roots, and tubers, (3) legumes and nuts, (4) dairy products (milk, yogurt, cheese), (5) flesh foods, including fish, poultry, and liver/organ meats, (6) eggs, (7) vitamin A-rich fruits and vegetables and (8) other fruits and vegetables (WHO & UNICEF, 2017). MDD refers to the proportion of children age 6–23 months who received foods from five or more of these groups during the previous day. Minimum meal frequency (MMF) is defined as consumption of solid, semi-solid or soft foods ≥ 2 times/day for breastfed infants aged 6–8 months, ≥ 3 times/day for breastfed children aged 9–23 months and 4 times/day for nonbreastfed children aged 6–23 months. The minimum acceptable diet is defined as the proportion of children 6–23 months of age who receive a minimum acceptable diet (apart from breast milk). The numerator was the number of breastfed children 6–23 months old receiving the MMF and four or more food groups excluding breast milk, or the number of nonbreastfed children receiving the MMF and at least two milk feedings plus four or more food groups during the previous day. The denominator was the number of children 6–23 months old included in the survey. Children who were breastfed in the 24-h period prior to the survey were considered breastfed. Introduction of solid, semi-solid or solid food referred to

children aged 6–8 months who consumed any type of semi-solid, solid or soft foods during the previous day.

2.2.5 | Other care practices

Other care variables related to early childhood developmental outcomes, including early stimulation, availability of children's books and availability of playthings, were included (Yousafzai et al., 2014; Yue et al., 2019). Data on early stimulation were collected using the standard module from the MICS4. Early stimulation refers to the percentage of children engaged in four or more play or communication activities, and responsive care in the last 3 days by any adult household member aged 15 or over. Such activities include taking the child outside the home, playing with the child, sharing pictures or books, storytelling, singing, and naming, counting, or drawing things for or with the child. The availability of children's books is defined as the percentage of children who have three or more children's books. The availability of playthings refers to the percentage of children who play with two or more types of playthings.

2.3 | Data processing and statistical analyses

Data were checked, coded and entered into SPSS for Windows (version 22.0; SPSS, Inc., Chicago, IL, USA) for analysis. Total ASQ scores, converted to a dichotomous variable ('Delayed' and 'Not delayed') based on normative Chinese data, were used to explore the association between dietary diversity and overall ASQ performance as well as performance in each of the five subscales. Descriptive statistics are presented using the median and range for continuous variables and frequency (percentage) for categorical variables. Reliability analysis was conducted to assess the internal consistency of ASQ scale domains. Cronbach's alpha coefficient was 0.861.

We performed binary logistic regression to assess the association between dietary variables (MMF, dietary diversity as measured by MDD, and the number of food types consumed in the preceding 24 h) and ASQ performance, with odds ratios (ORs) and 95% confidence intervals (CIs) calculated for unadjusted and multivariable-adjusted logistic models. Stratified analyses by age group (6–11 months, 12–17 months and 18–23 months) were also conducted to further investigate diet–development relationships. Tests for trend were performed by entering categorical variables (the number of food groups consumed in the preceding day) as continuous variables in the model. We considered the following variables to be controlled in the logistic regression analysis: age, sex and prematurity of the child; age, sex and education level of the caregiver; family size, annual household income, early stimulation and the availability of children's books and playthings. Model fit was assessed using the Hosmer–Lemeshow goodness of fit test. Collinearity statistics were used to examine collinearity among all variables. Results with a two-tailed *P* value of <0.05 were considered statistically significant.

2.4 | Ethical considerations

The study protocol was reviewed and approved by the Institutional Review Board of Peking University (Approval number IRB00001052-16034). Peking University's Biomedical Ethics Committee approved this study (Approval number IRB00001052–16034).

3 | RESULTS

3.1 | Sociodemographic characteristics

Of the 1,534 study participants, more than half (57.0%) were male, and 3.3% were born prematurely. Most caregivers were female (86.8%), under 40 years old (89.7%), and had completed at least middle school education (67.5%). Approximately two thirds of households comprised 2–4 people (64.0%) and over half had an annual income of more than 8000CNY, equivalent to USD1,143 (Table 1).

3.2 | Anthropometric and developmental outcomes

Among the 1,534 children included in the survey, 15.6% were stunted, 4.3% were wasted and 7.9% were underweight. Approximately one third (32.4%) of participants had suspected developmental delays as assessed by the ASQ-C. Fine motor delays were the most common type of delay (17.3%), whereas gross motor delays were the least common (11.3%; Table 1). Children with caregivers who were female, less than 40 years old, and with higher education and annual income had fewer developmental delays. The proportion of suspected delays was also lower among children with access to early stimulation, children's books, and playthings.

3.3 | Dietary characteristics

Approximately three fifths of participants achieved MMF (60.8%) and one fourth met the recommended dietary diversity (23.0%), resulting in an exceptionally low proportion (17.6%) of children attaining the minimum acceptable diet. More than half had been breastfed in the preceding day. Of the children in the 6–8 months age group, 68.7% had been introduced to semi-solid, solid, or soft foods. With respect to specific food items, grains, roots and tubers were most commonly consumed (80.1%), whereas egg consumption was uncommon (22.3%). More than half of the participants (58.7%) had consumed meat during the previous 24 h, and more than two thirds consumed some type of fruits and vegetables (69.2%). Only one quarter had consumed legumes and nuts (Table 2).

Dietary diversity in relation to participant characteristics is presented in Table 3. Compared to their older peers, the youngest group (6–11 months) had the lowest consumption of the recommended food diversity (17.1%), the lowest meal frequency (58.7%) and were least likely to achieve the minimum acceptable diet (13.7%). Breastfed children were more poorly fed with respect to appropriate food frequency, but the percentage meeting the

TABLE 1 Basic characteristics of children aged 6 to <24 mo in six poor rural counties, China, 2013, $n = 1,534$

Characteristics	N(%)
Child gender-male	874(57.0)
Child age (months)	
6–11	519(33.8)
12–17	470(30.6)
18–23	545(35.5)
Preterm birth	51(3.3)
Caregivers' age (year)	
<40	1,365(89.7)
≥40	156(10.3)
Caregiver gender-female	1,332(86.8)
Caregiver education	
Illiterate and primary School	498(32.5)
Middle school and above	1,036(67.5)
Household size (person)	
2–4	974(64.0)
≥5	548(36.0)
Household annual income (CNY) ^a	
<8,000	515(42.5)
≥8,000	698(57.5)
Early stimulation (times) in the past 3days	
≤3	248(16.2)
≥4	1,286(83.8)
Availability of children's books	
<3	1,097(74.9)
≥3	368(25.1)
Availability of playthings	
<2	625(45.7)
≥2	920(60.2)
Stunted	229(15.6)
Wasted	63(4.3)
Underweight	118(7.9)
SDD ^b	530(32.4)
Communication	237(14.4)
Gross motor	185(11.3)
Fine motor	280(17.3)
Problem solving	217(13.1)
Personal-social	187(11.5)

^a8000CNY equivalent to USD\$1143 at an exchange rate of 7.

^bSDD refers to suspected developmental delay measured by the Ages and Stages Questionnaire-3 version.

MDD and minimum acceptable diet was higher than that of non-breastfed children ($P < 0.01$). Children with caregivers with high levels of education and/or income, and with more picture books, playthings, and early stimulation activities, exhibited higher MMF and MDD ($P < 0.05$; Table 3).

TABLE 2 Dietary characteristics in the previous 24 h among children 6 to <24 mo in six poor rural counties, China, 2013, $n = 1,534$

Indicator	N(%)
Minimum meal frequency	929(60.8)
Minimum dietary diversity	351(23.0)
Minimum acceptable diet	268(17.6)
Currently breastfeeding	743(54.4)
Introduction of semi-solid or solid food at 6–8 months	182(68.7)
Consumption of grains, roots & tubes	1,227(80.1)
Consumption of animal source foods	1,206(79.0)
Dairy products	718(47.2)
Eggs	342(22.3)
Flesh foods	900(58.7)
Consumption of legumes and nuts	378(24.7)
Consumption of fruits and vegetables	1,060(69.2)
Vitamin-A rich fruits and vegetables	950(62.0)
Other fruits and vegetables	624(40.7)

Note. Animal source food including any type of dairy products, eggs and flesh foods; vegetables and fruits consumption including any type of vitamin-A rich fruits and vegetables, and other types of fruits and vegetables; minimum meal frequency defined as solid, semi-solid and soft foods ≥2 times/day for breastfed infant aged 6–8 months, ≥3 times/day for breastfed children aged 9–23 months, and 4 times/day for nonbreastfed children aged 6–23 months. Minimum dietary diversity referring to children receiving foods from at least 5 of 8 food groups including breast milk. Minimum acceptable diet referring to children receiving a minimum acceptable diet (apart from breast milk) considering both minimum dietary frequency and diversity.

3.4 | Relationships between dietary diversity and ASQ performance

Consumption of five or more food groups in the previous day was associated with a 39% lower probability of developing suspected developmental delays (AOR = 0.61, 95% CI [0.43, 0.86]) in a regression model adjusted for the age, sex and prematurity of the child; the age, sex and education level of the caregiver; and family size, annual income and care practices including early stimulation activities, and resources.

MDD was found to be associated with reduced delays, with a 47% lower risk in the gross motor subscale, 50% in the fine motor subscale, 46% in the personal social subscale and 67% in the problem-solving subscale ($P < 0.05$). By contrast, MMF was only associated with reduced likelihood suspected developmental delays in the gross motor subscale (AOR = 0.63, 95% CI [0.42, 0.94]). No significant associations were detected between MMF, MDD and suspected delays in communication skills after adjusting for potential confounding variables ($P > 0.05$).

Stratified analyses by age group indicated that MDD was associated with a reduced likelihood of developmental delays in the 18–23-month age group (AOR = 0.41, 95% CI [0.22, 0.78]), but not in the 6- to 11-month or 12- to 17-month age groups ($P > 0.05$). Among subscales, MDD was observed to correlate with the problem-solving subscale for the 12–17 months group, and the gross motor subscale

TABLE 3 Dietary diversity across child and household characteristics among children aged 6 to <24 mo in six poor rural counties, China, 2013, $n = 1,534$

Characteristics	% Minimum meal frequency	% Minimum dietary diversity	% Minimum acceptable diet
Child gender	n.s.	n.s.	n.s.
Male	61.4	24.0	17.7
Female	60.0	21.8	17.5
Child age (months)	n.s.	***	**
6–11	58.7	17.1	13.7
12–17	61.6	27.7	21.7
18–23	62.1	24.6	17.7
Preterm birth	n.s.	n.s.	n.s.
Yes	70.6	23.5	15.7
No	60.4	23.0	17.7
Caregivers' age (year)	n.s.	*	*
<40	60.2	23.6	18.1
≥40	64.5	15.6	11.6
Caregiver' gender	n.s.	n.s.	n.s.
Female	60.5	23.1	17.5
Male	62.5	22.3	18.5
Caregiver's education	**	***	***
Illiterate and Primary School	55.6	18.1	12.3
Middle school and above	63.3	25.4	20.1
Household size (person)	n.s.	n.s.	n.s.
2–4	61.2	23.7	18.0
≥5	60.0	21.4	16.7
Household annual income (CNY)	n.s.	***	***
<8,000	58.1	18.2	13.5
≥8,000	63.1	27.6	22.0
Early stimulation	*	*	**
≤3	54.3	17.7	11.4
≥4	62.0	24.0	18.8
Availability of children's books	*	***	***
<3	58.9	20.5	15.4
≥3	66.8	31.6	25.3
Availability of playthings	*	***	***
<2	57.1	14.3	11.1
≥2	63.3	28.8	21.9
Currently breastfeeding	**	**	***
Yes	54.4	26.1	20.4
No	62.2	19.5	13.1

Note. n.s. refers to no statistically significant difference.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

for the 18–23 months group ($P < 0.05$). We observed a relationship between MMF and developmental delays in the gross motor subscale for the 6–11 months group, and in the personal–social subscale for the 12–17-month age group; however, no relationships were detected for the 18- to 23-month age group ($P > 0.05$; Table 4).

We further examined the association between dietary diversity and the probability of developmental delays by the number of food groups consumed in the previous day, as shown in Table 5 and Figure 1. An inverse dose–response relationship was observed between the number of food groups and the probability of

TABLE 4 The association between dietary diversity and child developmental performance in ASQ scale using logistic regression analysis for children aged 6 to <24 mo in six poor rural counties by age group, China, 2013, $n = 1,534$

Variable	6–11 months		12–17 months		18–23 months		Total	
	MMF	MDD	MMF	MDD	MMF	MDD	MMF	MDD
ASQ-SDD								
Crude OR ^a	0.72(0.50,1.05)	0.51(0.30,0.87)*	0.72(0.49,1.08)	0.57(0.36,0.90)*	0.67(0.46,0.97)*	0.47(0.29,0.76)**	0.70(0.56, 0.87)**	0.51(0.39, 0.68)***
Adjusted OR ^a	0.81(0.51, 1.28)	0.57(0.30,1.10)	0.77(0.47,1.28)	0.76(0.43,1.36)	0.85(0.52,1.37)	0.41(0.22,0.78)**	0.81(0.61,1.06)	0.61(0.43,0.86)**
Communication								
Crude OR ^a	0.67(0.43,1.04)	0.50(0.25,1.02)	0.87(0.52,1.47)	0.70(0.38,1.30)	0.71(0.41,1.25)	0.42(0.19,0.95)*	0.73(0.55, .97)*	0.53(0.36,0.79)**
Adjusted OR ^a	0.92(0.52,1.62)	0.64(0.28,1.47)	0.98(0.52,1.87)	0.91(0.44,1.92)	0.85(0.44,1.65)	0.34(0.11, 1.02)	0.89(0.63, 1.27)	0.65(0.40,1.04)
Gross motor								
Crude OR ^a	0.32(0.16,0.62)**	0.35(0.11,1.15)	0.76(0.41,1.41)	0.54(0.24,1.18)	0.56(0.35,0.89)*	0.36(0.18,0.72)**	0.54(0.39,0.75)***	0.43(0.27,0.69)***
Adjusted OR ^a	0.28(0.11,0.70)**	0.57(0.12,2.68)	0.85(0.37,1.92)	0.64(0.22,1.89)	0.74(0.41,1.33)	0.43(0.19,0.99)*	0.63(0.42,0.94)*	0.53(0.29,0.95)*
Fine motor								
Crude OR ^a	0.62(0.40,0.95)*	0.35(0.16,0.75)**	0.62(0.37,1.00)	0.42(0.22,0.79)**	0.83(0.51,1.37)	0.42(0.21,0.84)*	0.67(0.51,0.88)**	0.39(0.26,0.58)***
Adjusted OR ^a	0.65(0.37,1.15)	0.43(0.17,1.12)	0.62(0.33,1.17)	0.50(0.21,1.18)	1.24(0.64,2.42)	0.57(0.23,1.42)	0.80(0.57,1.13)	0.50(0.31,0.83)**
Problemsolving								
Crude OR ^a	0.49(0.28,0.86)*	0.16(0.04,0.67)*	0.61(0.37,1.00)*	0.29(0.14,0.60)**	0.62(0.37,1.05)	0.46(0.22,0.96)*	0.58(0.43,0.79)***	0.34(0.21,0.54)***
Adjusted OR ^a	0.53(0.25,1.12)	0.35(0.08,1.58)	0.72(0.38,1.36)	0.26(0.10,0.72)**	0.80(0.40,1.63)	0.47(0.15,1.44)	0.72(0.49,1.06)	0.33(0.16,0.63)***
Personal-social								
Crude OR ^a	0.68(0.38,1.23)	0.52(0.20,1.35)	0.47(0.28,0.78)**	0.34(0.16,0.70)**	0.83(0.47,1.47)	0.42(0.19,0.96)*	0.63(0.46,0.87)**	0.42(0.26,0.68)***
Adjusted OR ^a	0.53(0.24,1.17)	0.82(0.26,2.61)	0.50(0.26,0.95)*	0.40(0.16,1.03)	1.07(0.52,2.22)	0.55(0.21,1.47)	0.73(0.49,1.08)	0.54(0.30,0.96)*

Abbreviations: SDD, suspected developmental delay; MMF, minimum meal frequency; MDD, minimum diet diversity.

^aAdjusted for age, sex, and prematurity of the child, caregiver's age, sex, education, family size, annual household income, early stimulation, availability of children's books, availability of playthings; Hosmer and Lemeshow Test $P > 0.05$. Collinearity variance inflation factor <1.5 and tolerance >0.8 for regression model.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

TABLE 5 The association between number of food groups consumed in the previous 24 h and child developmental performance in ASQ scale using logistic regression analysis for children aged 6 to <24 mo in six poor rural counties, China, 2013, $n = 1,534$

Variable	No. of food groups consumed in the previous 24 h				
	0-1	2	3	4	≥5
ASQ-SDD					
Crude OR	3.05(2.07,4.49)***	2.28(1.64,3.19)***	1.60(1.14, 2.25)**	1.48(1.04, 2.11)*	Reference
Adjusted OR ^a	2.71(1.63,4.52)***	2.00(1.32,3.02)**	1.39(0.91,2.10)	1.38(0.90,2.11)	Reference
Communication					
Crude OR	4.04(2.49,6.55)***	2.10(1.33,3.32)**	1.19(0.72, 1.96)	1.40(0.85, 2.32)	Reference
Adjusted OR ^a	3.99(2.15, 7.44)***	1.76(1.01, 3.06)*	0.99(0.55, 1.80)	1.33(0.75, 2.37)	Reference
Gross motor					
Crude OR	4.38(2.50,7.70)***	2.27(1.32,3.91)**	2.12(1.23,3.67)**	1.56(0.86,2.82)	Reference
Adjusted OR ^a	3.80(1.79,8.07)***	2.03(1.02,4.04)*	1.84(0.93,3.63)	1.32(0.64,2.71)	Reference
Fine motor					
Crude OR	4.04(2.47,6.60)***	2.87(1.83,4.51)***	2.11(1.33,3.36)**	1.94(1.19,3.14)**	Reference
Adjusted OR ^a	3.03(1.56,5.87)**	2.19(1.23,3.91)**	1.75(0.98,3.14)	1.73(0.96,3.12)	Reference
Problemsolving					
Crude OR	5.46(3.11,9.59)***	3.46(2.04,5.90)***	2.21(1.26,3.86)**	2.09(1.17,3.72)*	Reference
Adjusted OR ^a	6.07(2.74,13.44)***	4.14(2.02,8.50)***	2.35(1.12,4.96)*	2.08(0.97,4.49)	Reference
Personal-social					
Crude OR	5.35(3.08,9.32)***	2.27(1.32,3.91)**	2.00(1.15,3.48)*	1.38(0.75,2.54)	Reference
Adjusted OR ^a	4.37(2.11,9.06)***	2.26(1.17,4.35)*	1.64(0.84,3.20)	1.13(0.55,2.32)	Reference

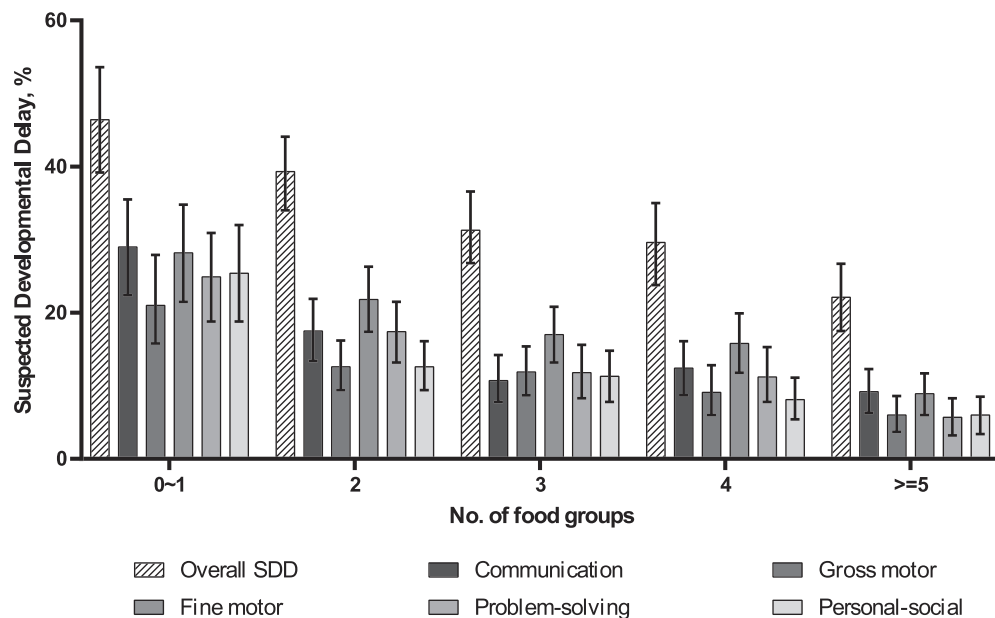
Abbreviation: SDD, suspected developmental delay.

^aAdjusted for age, sex, and prematurity of the child, caregiver's age, sex, education, family size, annual household income, early stimulation, availability of children's books, availability of playthings; Hosmer and Lemeshow Test $P > 0.05$. Collinearity variance inflation factor < 1.5 and tolerance > 0.8 for regression model.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

**FIGURE 1** Prevalence and 95% CI of developmental delays in ASQ scale by number of food groups consumed in the preceding day

developmental delays. The prevalence of developmental delays was 46.4% (84/181) in children consuming one or fewer food groups, 39.3% (133/338) in children consuming two food groups, 31.3% (106/339) in children consuming three food groups, 29.6% (87/294) in children consuming four food groups and 22.1% (77/348) in children consuming at least five food groups. Using the children who consumed five or more food groups as a reference, the adjusted odds ratio increased significantly with a decreasing number of food groups consumed in the preceding 24 h (P for trend < 0.001). Consuming one or fewer food groups in the previous day was associated with an elevated risk of developmental delays in the overall ASQ scale and in the communication, gross motor, fine motor, problem-solving and personal-social subscales (P < 0.01).

4 | DISCUSSION

Our cross-sectional study, conducted in resource-poor settings in rural China, indicates that meeting the MDD is associated with reduced risk of failing to achieve expected milestones as measured by the ASQ-3 for children aged 6–23 months. These trends were clear even after adjusting for many potential child and household confounders, as well as other care variables such as early stimulation, the availability of learning resources. The protective effect of MDD on overall ASQ performance was also found in the gross motor, fine motor, problem-solving and personal-social subscales, whereas children reaching the MMF were at lower risk of developmental delays in the ASQ gross motor subscale. Our findings highlight the importance of MDD as independent, proximate factors influencing early functional development in children aged 6–23 months, in addition to their contribution to physical growth outcomes as reported in other studies (Krasevec, An, Kumapley, Begin, & Frongillo, 2017).

The relationship between dietary diversity and early childhood development with respect to the motor skills, problem-solving and personal-social subscales was consistent with other studies from LMICs (Frongillo et al., 2017; Larson et al., 2017; Prado et al., 2017; Thorne-Lyman et al., 2019). One cohort study conducted in rural Nepal showed that each day consuming MDD counted toward a 35% reduced risk of being in the lowest category of developmental scores (Thorne-Lyman et al., 2019). Another study conducted in Ghana, Malawi and Burkina Faso reported that dietary diversity was a key predictor of early motor development (Prado et al., 2017). The relationship between dietary diversity and child developmental outcomes might be explained by several mechanisms, including increased intake of micronutrients and protein, greater amounts and variety of psychosocial stimulation and enhanced motor skills (Frongillo et al., 2017; Gould, 2017; Larson et al., 2017; Pivina et al., 2019). Another possible explanation may be that diet at the time of the survey was correlated with children's diets over the longer term and that a better diet earlier in life provided nutrients that supported early brain development. Previous studies have reported that early brain development, both structural and functional, is highly dependent on an adequate supply of protein and micronutrients, particularly iron, zinc and iodine

(Gould, 2017). Dietary diversity is an indicator of micronutrient deficiencies (Zhao et al., 2017). Children consuming a lower diversity of foods are more likely to suffer from micronutrient deficiencies. Our study found that 41.2% of children did not consume meat in survey areas; another 52.8% did not consume dairy, and egg consumption was extremely low (22.4%). Low intake of animal-based foods, which are generally high in protein, iron and zinc, might also explain the relationships we detected. By contrast, it is equally possible that children eating more diverse foods were also exposed to a greater amount and variety of psychosocial stimulation, as small children often rely on the same primary caregiver to prepare food, feed them and interact with them (Larson et al., 2017). In addition, dietary diversity might provide more nutrients to build muscles, leading to better motor skills, physical activity and social function, which may in turn enrich the child's interaction with and exploration of the environment, thus contributing to the development of problem-solving skills (Frongillo et al., 2017; Larson et al., 2017). Unquantified, residual impacts from confounding variables, including socioeconomic status measures and other environmental and cultural factors, undoubtedly affected our results.

However, we did not detect a relationship between dietary diversity and language development, which may be a result of differences in developmental assessment tools, or variables adjusted in analysis, for example, early stimulation. The role of limited verbal communication in routine care activities, such as feeding and play, cannot be ruled out as a possible predictor of language development in poor rural areas (Yue et al., 2019). The traditional practice in low-resource settings of waiting until children is old enough to talk or engage interactively might also be significant (Bornstein & Putnick, 2012; Yue et al., 2019). More research is needed into factors that hinder language development.

We also found a positive association between MMF, which is a proxy for energy intake from nonbreastmilk foods, and typical development in the gross motor subscale. Despite the reported link between MMF and weight status, few studies have empirically explored the role of MMF in early childhood development. Children in the first 2 years of life require vast amounts of energy from foods to support brain development, which is characterized during this period by intensive myelination and synaptogenesis, taking about 20% of the total energy consumed by the body (Gould, 2017). However, we found that the foods offered in early years in poor, rural areas in China were generally of low energy density. We found that thin porridge was the food item most commonly provided to children aged 6–23 months (73.9%); thin porridge provides only half to one third of the recommended energy density (World Health Organization, 2009). The number of daily feedings was thus critical to meeting energy needs; however, more than one third of the children in our study did not receive the recommended meal frequency (39.2%). This trend was more apparent among children being actively breastfed (45.6%). Failure to meet energy needs may lead to changes in metabolism in the brain and decreases in muscle strength, thus affecting the child's ability to develop normal gross motor skills (Yuniarti, Fatimah, & Nureni, 2019).

We found that only approximately one fourth of children in the study regions consumed adequately diversified foods, whereas 60.8% received optimal feeding frequency. As a result, the minimum acceptable diet was only attained by about one sixth of participants, which is alarmingly low. The MDD figure in our study areas was much lower than the national prevalence in China (53.7%), and is lower than mean values for global estimate, South Asia, East Asia and the Pacific, and Latin America and the Caribbean (Duan et al., 2018; White, Begin, Kumapley, Murray, & Krasevec, 2017). However, it is higher than that of India and Ethiopia (Aemro, Mesele, Birhanu, & Atenafu, 2013; Duan et al., 2018). Nonetheless, 31.2% of children aged 6–8 months had not received any complementary foods in the 24 h prior to the survey, and 41.2% and 52.8% had not consumed protein-rich meat or dairy products, respectively. In view of the rapid economic development in China, complementary feeding practices, and particularly the timely introduction of complementary foods and the consumption of adequately diversified foods, warrant close attention from policy makers and child health professionals.

Our study had several strengths as well as some limitations. We targeted a highly sensitive developmental period characterized by multiple vulnerabilities. In addition, we controlled for child, caregiver and household characteristics, as well as stimulation, availability of children's books and availability of playthings to minimize the influence of potential confounding effects. In spite of this, we cannot rule out the possibility that other unquantified confounding variables, such as responsive feeding, may also contribute to child development (Frances E Aboud, Shafique, & Akhter, 2009). Dietary diversity and frequency were assessed based on dietary recall over a 24-h period and may not precisely reflect typical feeding practices, creating the potential for erroneous inferences. In addition, our data collection did not account for the quantity of complementary foods provided, thus creating an information gap with respect to energy and nutrient intake that may also influence the relationship between MMF, MDD and development. Moreover, because our study was conducted in relatively populated and accessible villages, that is, those with >50 children under the age of 3 years old and with vehicle access, the results may be biased towards relatively well-off villages. Furthermore, given only 68.9% of eligible children in these villages were surveyed, the possibility of selection bias might not be ruled out. Finally, unlike directly administered assessment tools, the ASQ is a parent-reported developmental screening tool and is thus constrained by caregivers' or parents' understanding and perceptions of developmental skills, especially in poor rural areas.

Nonetheless, our study is among few studies in China to document the association between dietary diversity and early childhood developmental outcomes in rural areas. Thus, it has significant implications for future efforts to improve early childhood nutrition and development for children aged 6–23 months in China and other LMICs. More integrated approaches addressing child feeding and early stimulation practices should be explored in resource-poor settings.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

CXZ did the literature review, the methods development, the statistical analysis, interpretation of the results, wrote the paper and organized the reference. HFS and HYG contributed to the methods development. XLW and JXZ contributed to the final review.

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