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Determinants of minimum dietary diversity attainment among infants aged 6–11 months in rural China: a COM-B model-based Bayesian network analysis

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ABSTRACT

Achieving minimum dietary diversity (MDD), a crucial indicator of infant and young child diet quality, remains a challenge in rural China, especially for infants aged 6–11 months. This study examined the rate of MDD attainment in rural China, identified its determinants using the Capability, Opportunity, Motivation, and Behavior (COM-B) model and Bayesian network analysis, and estimated the potential impact of improving each modifiable determinant. A multi-stage sampling design selected 1328 caregivers of infants aged 6–11 months across 77 rural townships in China. Data were collected through a cross-sectional survey via in-person household interviews. Bayesian network analysis identified key factors influencing MDD attainment and their interrelationships, while Bayesian inference estimated MDD attainment probabilities. Results showed that only 22.2 % of the sample infants attained MDD. Bayesian network analysis revealed that caregiver knowledge (a proxy of capability), self-efficacy and habits (proxies of motivation), and infant age directly influenced MDD attainment. Social support (a proxy of opportunity) indirectly promoted MDD attainment by boosting self-efficacy and habit. Notably, simultaneous improvements in knowledge, self-efficacy, and habit could increase MDD attainment by 17.6 %, underscoring the potential effectiveness of interventions focused on enhancing caregiver capability and motivation. The critically low MDD attainment rate among rural Chinese infants highlights the urgent need for targeted interventions. Strategies should prioritize enhancing caregiver feeding knowledge, self-efficacy, and habit formation to improve infant dietary diversity. Addressing these key factors could substantially boost MDD attainment in rural China.

1. Introduction

Diverse diets are essential for meeting the nutritional demands, promoting good growth, and fostering development in infants and young children (WHO Guideline for Complementary Feeding of Infants and Young Children 6-23 Months of Age, 2023). Inadequate dietary diversity remains a significant obstacle to healthy early childhoods and poverty reduction in many emerging economies, as it can lead to undernutrition, weakened immunity, poor growth, and a higher risk of chronic diseases like cancer and diabetes later in life (Keno et al., 2021). To address this, the World Health Organization (WHO) introduced Minimum Dietary Diversity (MDD) as a core indicator for Infant and Young Child Feeding practices (IYCF). MDD sets a minimal standard for adequate nutrition by encouraging the consumption of foods from at least five out of eight food groups, including breast milk, grains, roots and tubers, legumes and nuts, dairy products, flesh meats, fish, eggs, and

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fruits and vegetables (Indicators for Assessing Infant and Young Child Feeding Practices, n.d.).

However, MDD attainment remains suboptimal in rural China, particularly among infants aged 6–11 months. The 2018 Nutrition Improvement Project on Children in Poor Areas (CNIPCPA) reported that only 58.5 % of the breastfed children aged 6–23 months in China's rural regions met the criteria for MDD, with the lowest rates observed among infants aged 6–8 months (34.8 %) and 9–11 months (54.4 %) (Liu et al., 2021). Subsequently, a 2021 cross-sectional survey conducted in six rural counties with low average income showed that merely 17.1 % of infants aged 6–11 months met the MDD criteria (Zhao et al., 2021a), further underscoring the prevalence of inadequate dietary diversity among children with lower socioeconomic status in rural China.

The extant international research on strategies for promoting dietary diversity among infants and young children have identified several determinants of MDD attainment but largely overlooked their interactions and synergistic effects. For example, studies from Ethiopia (Solomon et al., 2017) and Ghana (Opoku Agyemang et al., 2023) show that caregivers with better feeding knowledge are more likely to help infants achieve MDD. The social support available to caregivers and their self-efficacy—their confidence in their ability to perform caregiving tasks—are also key factors (Dougherty & Dadi, 2024; Ickes et al., 2017). Nevertheless, recent correlational research conducted in rural China suggests that these factors interact with each other rather than independently influence MDD attainment, as social support could enhance caregivers' feeding self-efficacy (Li et al., 2022a), and nutrition knowledge was also associated with perceived family support and self-efficacy (Nie et al., 2023). These findings suggest that the extant approach of focusing on the individual effects of each determinant may overlook the direct and indirect effects between knowledge, social support, and self-efficacy which jointly affect MDD attainment. Similarly, the widespread use of logistic regression models in current research (Belay et al., 2022a; Kumar et al., 2024; Singh et al., 2024; Solomon et al., 2017), which assumes variable independence, may fail to account for these interactions and limit the understanding of real-world dynamics.

A more comprehensive understanding of the determinants of MDD attainment will help identify optimal pathways for improving it, facilitating the design of cost-effective interventions suited for low-resource contexts. To address the limitations of previous research, we use the Capability, Opportunity, Motivation, and Behavior (COM-B) model to explore the determinants of MDD attainment behavior. Among the various models previously proposed for identifying behavior determinants (Craig et al., 2008; Michie et al., 2008; Skivington et al., 2021), the COM-B model stands out as one of the most comprehensive (Michie et al., 2011). It proposes that behavior is driven by three core components: capability, which includes physical and psychological abilities like knowledge and skills; opportunity, which includes both material conditions like economic status and social factors like support systems; and motivation, which includes reflective processes like self-efficacy and automatic processes like habits. These components form an interconnected system, where, for instance, opportunity and capability can influence motivation. Unlike traditional health behavior theories that take a one-dimensional perspective, the COM-B adopts a holistic approach to consider a broad range of influences at individual, organizational, and societal levels. It also accounts for the crucial but often overlooked influence of automatic processes like habits. These strengths make the COM-B model particularly valuable for understanding feeding behaviors that influence MDD attainment.

Based on the interactions proposed by the COM-B, we employ a Bayesian network model to analyze the determinants of MDD attainment behavior. Compared to traditional methods like logistic regression, Bayesian networks offer a more comprehensive and intuitive representation of variable relationships while imposing fewer statistical assumptions (Heckerman, 1997; Jensen & Nielsen, 2007). Moreover, Bayesian inference enables flexible prediction of MDD attainment improvements based on known conditions.

By leveraging the strengths of the COM-B model and Bayesian networks, we seek to offer a more robust analysis of how caregivers' capability, opportunity, and motivation interact with each other to influence their infants' MDD attainment. The hypothesized roles of each determinant in MDD attainment as proposed by the COM-B model are shown in Fig. 1. Because our focus is on the determinants of MDD attainment behavior, we do not examine reverse pathways through which behavior may enhance capability, opportunity, and motivation in this study. To achieve this goal, we pursue three objectives: 1) to describe the rates of MDD attainment among infants aged 6–11 months in rural China; 2) to identify the determinants of MDD attainment behavior based on the COM-B model; 3) to predict how changes in each determinant can potentially improve MDD attainment rate.

2. Methods

2.1. Design and setting

Data in this study were collected through a cross-sectional survey of 1328 primary caregivers of infants aged 6–11 months residing in six rural counties in Sichuan Province in southwestern China.

2.2. Participants and sampling

The research team followed a multi-stage sampling protocol to select the study sample. First, we categorized all counties in Sichuan Province into tertiles according to the per capita disposable income of their rural populations, with high representing the top third of the counties, medium the middle third, and low the bottom third. We randomly selected two counties from each tertile for inclusion in the study, resulting in a total of six counties representing populations with various income levels. Second, we included all rural townships within the sample counties, a total of 77, in the study. Finally, we obtained a list of all households with registered births in the target age range (6–11 months at the time of the survey) from health officials in each sample township and identified 1399 eligible households. The average income of the sampled counties closely aligns with the average of their corresponding tertile, supporting the representativeness of the sample (see Table A.1 in Appendix A).

We invited the primary caregivers, identified by each sample household as the family member primarily responsible for the infant's diet, to participate in the study. While we initially identified 1399 eligible primary caregivers, 71 either declined to participate or were later excluded due to reasons including schedule conflict. The final sample consisted of 1328 primary caregivers. All participants completed the full questionnaire, and no missing data were present in the dataset. This study received ethical approval from the Ethics Committee of West China Fourth Hospital and West China School of Public Health (Approval Number: Gwll2022101). Infant caregivers provided written informed consent for their own participation and that of their infants in this study.

2.3. Measures

Trained enumerators administered a survey to all sample caregivers through one-to-one, in-person interviews. The survey was structured to collect three blocks of data: a) the dietary diversity of the infant; b) the caregiver's capability, opportunity, and motivation related to MDD; and c) the sociodemographic characteristics of the caregiver and the infant. The questionnaires were developed through consultation with experts in nutrition and maternal and child health. They were pre-tested in two non-sample counties. Based on the feedback, the instrument was refined to ensure content validity and contextual relevance before data collection.

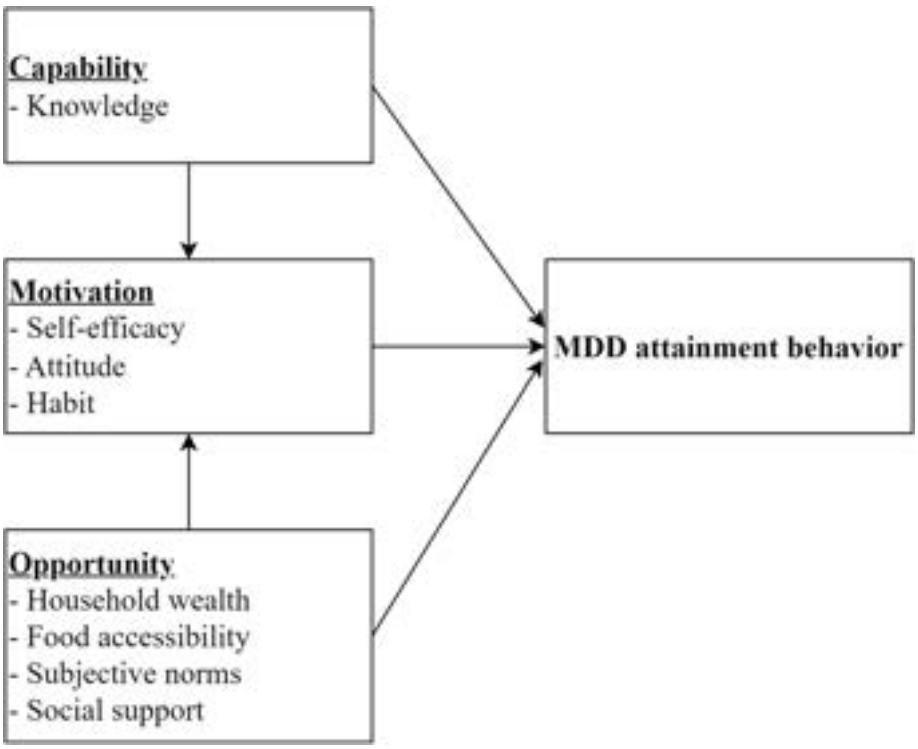

Fig. 1. Theoretical framework based on the COM-B model.

2.3.1. Dietary diversity

Dietary diversity data were collected using the 24-h recall method, where caregivers recalled all types of food provided to their infant in the 24 h preceding the survey. As one of the core indicators in the IYCF for infants aged 6–23 months, MDD is measured as the percentage of infants who consumed food in at least five out of the following eight food groups in the prior 24 h: (1) breast milk; (2) grains, roots, and tubers; (3) legumes and nuts; (4) dairy products (milk, yogurt, cheese); (5) flesh foods (meat, fish, poultry, liver or other organs); (6) eggs; (7) vitamin A-rich fruits and vegetables; and (8) other fruits and vegetables. Given that an infant's diet is predominantly determined by his or her primary caregiver, MDD attainment, in the context of this study, is defined by whether the caregiver had fed an infant a minimum of five out of the eight food types in the prior 24 h.

2.3.2. Capability, opportunity, and motivation related to MDD

The second block of the survey measured the capability, opportunity, and motivation related to MDD. As is shown in Fig. 1, we proxied the three constructs with eight variables. The detailed items for each measure are listed in Table A.2 of Appendix A.

Capability is proxied by the caregiver's knowledge about dietary diversity and complementary feeding, measured by their responses to five multiple choice items. The items were developed by the research team based on the Chinese Dietary Guidelines for children aged 7–24 months (Chinese Nutrition Society, 2022), with a focus on nutrition challenges specific to rural areas like limited dietary diversity and high rates of anemia identified in past research (Wang et al., 2018; Zhao et al., 2021a). The items were designed to evaluate knowledge related to the introduction of diverse and iron-rich foods. Example items include "When can you start giving your baby animal-based foods?" (1 = Around 3 months, 2 = Around 6 months, 3 = Around 9 months, 999 = Don't know) and "Which of the following foods is the best source of iron?" (1 = Lean meat or liver, 2 = Egg, 3 = Porridge, 4 = Sweet potato, 999 = Don't know). Each item only had one correct answer. Correct responses were assigned a score of 1, while incorrect responses a score of 0. The final knowledge score was the sum of scores from all five items. Item-level correct response rates in our sample ranged between 45.56 % and 82.91 %, indicating appropriate item difficulty and no evidence of floor or ceiling effects.

Opportunity was proxied by four variables: household wealth, food accessibility, subjective norms, and social support. Household wealth was measured by an index created via polychoric principal component analysis (PCA) based on whether the household owned or had access to seven household items, including a water heater, a washing machine, a computer, broadband, a refrigerator, an air conditioner, and/or a car. This approach is supported by previous research demonstrating the association between asset-based indices and overall socioeconomic status (Kolenikov & Angeles, 2009). The items were selected from questionnaires used in previous rural surveys for their relevance and usefulness in distinguishing between different household living standards (Li et al., 2022b; Ye et al., 2022). Although ownership of some items was high in our sample (e.g., over 90 % of households owned refrigerators), these items were retained to reflect basic infrastructure ownership, and their inclusion did not compromise the performance of the index due to the multivariate nature of the PCA. The first principal component explained 55.8 % of the total variance, indicating a strong underlying structure. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.68, suggesting that the data were suitable for factor analysis. Households were subsequently categorized into tertiles representing low, medium, and high wealth based on their index scores.

Food accessibility was measured by the self-reported ease of purchasing the following seven types of foods: (1) tubers and coarse grains, (2) vegetables, (3) fruits, (4) eggs, (5) meat and meat products, (6) dairy and dairy products, and (7) nuts and legumes. These categories were selected based on the core food groups included in the WHO-recommended MDD indicator for infants and young children. Given that MDD was a primary outcome in this study, the food accessibility items were designed to represent the major food groups young children are recommended to consume. Caregivers indicated the ease of purchasing each food type on a four-point Likert scale ranging from "1 = very inconvenient" to "4 = very convenient." To generate an overall food accessibility score, we calculated the sum of the scores across the

seven food items. Cronbach's alpha was 0.93 in our sample, indicating excellent internal consistency of the scale.

Subjective norms refer to the social pressure that an individual perceives regarding whether to adopt a specific behavior, usually determined normative beliefs and the motivation to comply (Ajzen, 1991). In this study, normative beliefs were measured by the caregiver's reports of how much up to three key referents in their social environment (selected from family members, friends, neighbors, and doctors) agreed with the importance of feeding infants with diverse foods. Caregivers indicated their response on a five-point Likert scale ranging from "−2 = strongly disagree" to "2 = strongly agree." Motivation to comply was measured by the caregiver's self-reports of whether they complied with the approval or disapproval of the selected individual. Caregivers selected one of the following three options: "0 = do not comply," "1 = relatively comply," and "2 = fully comply." A subjective norms score was calculated as the sum of the products of each normative belief and the corresponding motivation to comply. This measurement approach reflects the Theory of Planned Behavior's formulation of subjective norms as a weighted sum of normative beliefs and motivations to comply with key referents (Ajzen, 1991). Since referents varied across respondents in both number and identity, conventional reliability metrics such as Cronbach's alpha were not applicable. To ensure measurement quality, content validity was established through expert consultation and pilot testing.

Social support was assessed through six items measuring caregivers' perceived support for complementary feeding from others. On a four-point Likert scale ranging from "1 = strongly disagree" to "4 = strongly agree," caregivers responded to six-items assessing whether they perceived instrumental support (e.g., whether family members helped prepare complementary foods for the baby, such as preparing ingredients and making complementary foods), emotional support (e.g., whether they were complimented for engaging in complementary feeding), and informational support (e.g., whether they could obtain information about complementary feeding from doctors, neighbors, and friends). The items were developed based on established conceptualizations of social support in health behavior research (Langford et al., 1997; Mukuria et al., 2016a) and adapted to the rural caregiving context through expert consultation and pilot testing. To generate an overall social support score, we calculated the sum of the six item scores. Cronbach's alpha for the social support scale was 0.70 in our sample, indicating acceptable internal consistency.

Motivation was measured by three variables: self-efficacy, attitude, and habit. Self-efficacy refers to the caregivers' confidence in their ability to conduct complementary feeding successfully. In this study, self-efficacy was measured using seven items adapted from the breastfeeding self-efficacy scale (Dennis, 2003), adapted to reflect key aspects of complementary feeding. The adapted items were refined through expert consultation and pilot testing to ensure contextual relevance and content validity. Caregivers rated their confidence on a four-point Likert scale ranging from "1 = not at all confident" to "4 = very confident." Example items include "I can always prepare a variety of foods—vegetables, fruits, staple foods, protein—for my baby, instead of feeding them a single type of food." To generate an overall self-efficacy score, we calculated the sum of the seven item scores. Cronbach's alpha for the self-efficacy scale was 0.74 in our sample, indicating acceptable internal consistency.

The caregiver's attitude towards dietary diversity for infants was measured by their response to one item: "Do you agree or disagree with the statement: As many types of food as possible should be prepared for infants." Responses were recorded on a five-point Likert scale ranging from "1 = strongly disagree" to "5 = strongly agree." To facilitate Bayesian network analysis, responses of 1, 2, and 3 were categorized as "neutral/disagree," while responses of 4 and 5 were categorized as "agree." The item was adapted from attitude measures commonly used in Theory of Planned Behavior (Ajzen, 1991) and was designed to capture general evaluative orientation toward dietary diversity in a concise form. We adapted the wording and format based on prior feeding behavior studies (Assefa et al., 2021; Mora et al., 1999), and the scale underwent expert consultation and pilot testing to ensure clarity and contextual relevance.

Habit was assessed using a single item adapted from the Self-Report Behavioral Automaticity Index (Gardner et al., 2012). Caregivers reported whether they provided their infants with diverse foods—such as a combination of rice porridge, vegetables, fruits, and meats—without consciously thinking about it. Responses were recorded on a four-point Likert scale, ranging from "1 = completely disagree" to "4 = completely agree." To facilitate Bayesian network analysis, responses of 1 and 2 were categorized as "no habit," while responses of 3 and 4 were categorized as "habit present." This item was designed to capture the automaticity of habitual behavior, which is central to contemporary habit theory (Verplanken et al., 1997). The item wording was refined through expert consultation and pilot testing to ensure accurate reflection of the automaticity construct.

2.3.3. Sociodemographic characteristics

The third block of the survey collected the sociodemographic characteristics of the caregivers and the infants. Caregivers reported their age, sex, education level, and their relationship to the infant (usually parent or grandparent in our sample). They also reported the sex and age (in months) of the infant.

2.4. Data analysis

2.4.1. Descriptive analysis

We first described MDD attainment status, sociodemographic characteristics, and the distribution of COM-B variables in the sample. Nominal variables were summarized using frequency counts and percentages, while continuous variables (e.g., knowledge, food accessibility, subjective norms, social support, and self-efficacy) were reported as medians with interquartile ranges (IQRs). To facilitate Bayesian analysis, continuous variables were dichotomized into high and low levels based on the median, ensuring standardization across variables. All data processing and descriptive analyses were conducted in Stata 18.0 (Stata Corporation, College Station, TX, USA), while the radar chart was generated using the "fmsb" package in R version 4.3.2 (R Core Team).

2.4.2. Bayesian network construction

To identify determinants of MDD attainment behavior and depict interrelationships between variables, we incorporated all proxies of capability, opportunity, and motivation, as well as sociodemographic characteristics, into a Bayesian network model. Bayesian networks represent dependencies among variables using conditional independence assumptions. Their structure, a directed acyclic graph (DAG), consists of nodes representing variables and directed edges indicating probabilistic or causal relationships. Each node's conditional probability table quantifies the strength of these associations (Jensen & Nielsen, 2007).

Bayesian network modeling consists of structure learning and parameter learning. We first conducted structure learning using the Tabu algorithm to select the best-fitting structure via the Bayesian Information Criterion (BIC) while restricting age and sex from having parent nodes to ensure causal interpretability. We selected Tabu search because it uses adaptive memory to avoid local optima and achieve global optimization (Glover, 1997), and outperforms traditional algorithms in handling complex dependencies (Gámez et al., 2011). Then, we conducted parameter learning using maximum likelihood estimation to determine node conditional probabilities based on the known network structure. To evaluate the goodness-of-fit and complexity of the final Bayesian network model, we computed the Bayesian Information Criterion (BIC), Akaike Information Criterion (AIC), and log-likelihood based on the maximum likelihood estimates. Structural stability was

assessed using average arc strength obtained from bootstrapped networks. Predictive accuracy was also evaluated based on classification agreement between predicted and observed outcomes. The Bayesian network modelling was operated using the "bnlearn" package in R version 4.3.2 (R Core Team).

2.4.3. Bayesian network inference

To estimate how changes in the modifiable determinants can improve MDD attainment, we conducted Bayesian network inference. After completing Bayesian structure and parameter learning, backward reasoning enables probability updates across nodes based on given values, allowing dynamic Bayesian inference (Jensen & Nielsen, 2007). Based on the Bayesian network model, we applied maximum likelihood estimation to infer outcomes from modifiable parent nodes using the conditional probability table. The Bayesian network graph and Bayesian network inference model were constructed using Netica (Norsys Software Corp, Vancouver, BC, Canada).

3. Results

3.1. Socio-demographic characteristics and COM-B variables

Table 1 shows the sociodemographic characteristics of the respondents in rural China. Among the total of 1328 sample primary caregivers, the 16-to-30-year-old age group accounted for the largest proportion (41.0 %). Most (98.0 %) of the caregivers were female. Three-fourths (75.7 %) of the caregivers were parents of the infants. Less than half (37.2 %) of the caregivers had completed senior high school or above. Around half (49.4 %) of the infants were between 6 and 8 months old, and 47.4 % of the infants were female.

Regarding the COM-B variables, in the capability dimension, 57.8 % of caregivers had low feeding knowledge, defined as answering three or fewer of the five knowledge questions correctly. The median knowledge score was 3 (IQR: 2). In the opportunity dimension, nearly half (48.0 %) of caregivers had low household wealth. The median food accessibility score was 26 (IQR: 7), the median subjective norms score was 1(IQR: 3), and the median social support score was 17 (IQR: 4). In the motivation dimension, the median self-efficacy score was 21 (IQR: 4). A majority (85.5 %) of caregivers held a neutral or negative attitude toward feeding infants diverse foods. Additionally, 58.5 % of caregivers reported that when preparing complementary foods for infants, they would instinctively prepare a diverse range of food types. The descriptive results of the COM-B variables are presented in Table A.3 of Appendix A.

Table 1
Descriptive statistics of socio-demographic characteristics.

	Variable	Level	*N* (%)
Caregiver characteristics	Age of caregiver (years)	16–30	545 (41.0 %)
		30–39	436 (32.8 %)
		40–49	67 (5.0 %)
		≥50	280 (21.1 %)
	Sex of caregiver	Female	1301 (98.0 %)
		Male	27 (2.0 %)
	Education of caregiver	Lower than junior high school	316 (23.8 %)
		Junior high school	518 (39.0 %)
		Senior high school	143 (10.8 %)
		College/university or higher	351 (26.4 %)
	Relationship to the infant	Parents	1005 (75.7 %)
		Grandparents	323 (24.3 %)
Infant characteristics	Infant age (months)	6–8	656 (49.4 %)
		9–11	672 (50.6 %)
	Infant sex	Female	630 (47.4 %)
		Male	698 (52.6 %)

3.2. MDD attainment

The attainment rate of MDD among the sample infants was 22.2 %. Based on dietary recall, the sample infants consumed an average of 3.4 food groups ($SD = 1.3$) in the prior 24 h, with a median of 3 food groups. Fig. 2 offers a visual depiction of the percentage disparities in the consumption of eight food groups. A majority of caregivers reported providing infants with two types of food in the prior 24 h: grains, roots and tubers (83.4 %) and dairy products (72.3 %). In contrast, reported consumption of beans and nuts (2.9 %), eggs (23.6 %), and meat products (28.8 %) were considerably lower in the sample (Appendix A: Table A.4 and Fig. 2).

Values represent the percentage of caregivers who reported feeding the corresponding food group to the infant in the prior 24 h.

3.3. Bayesian network model of MDD attainment behavior

Fig. 3 presents the probabilistic model of MDD attainment behavior established through Bayesian networks. As illustrated, there are four parent nodes that directly impact MDD attainment: the infant's age, the caregiver's knowledge, self-efficacy, and habit. Further, the caregiver's age could indirectly influence MDD attainment through affecting their knowledge and self-efficacy. Social support may be associated with self-efficacy and habit, thus indirectly affecting the MDD attainment behavior.

We found no direct or indirect associations between MDD attainment and the following variables, which were excluded from the final model: household wealth, food accessibility, subjective norms, caregiver's sex, caregiver–infant relationship, and infant sex.

As shown in Table A.5 (Appendix A), the final model yielded a BIC of −8857.34, an AIC of −8717.17, and a log-likelihood of −8663.17, suggesting a strong fit between the model and the observed data with reasonable complexity. Bootstrap analysis indicated that arc strengths ranged from 0.986 to 1.0, demonstrating that the network had high

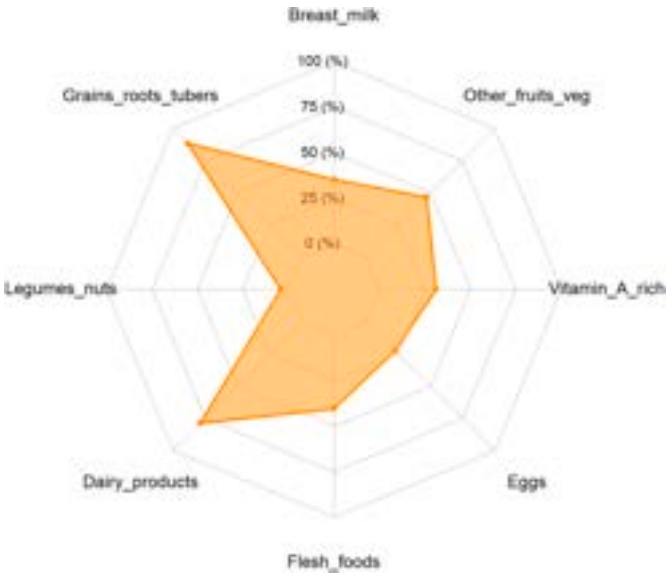

Fig. 2. Radar chart of caregivers feeding eight food groups in 24 h.

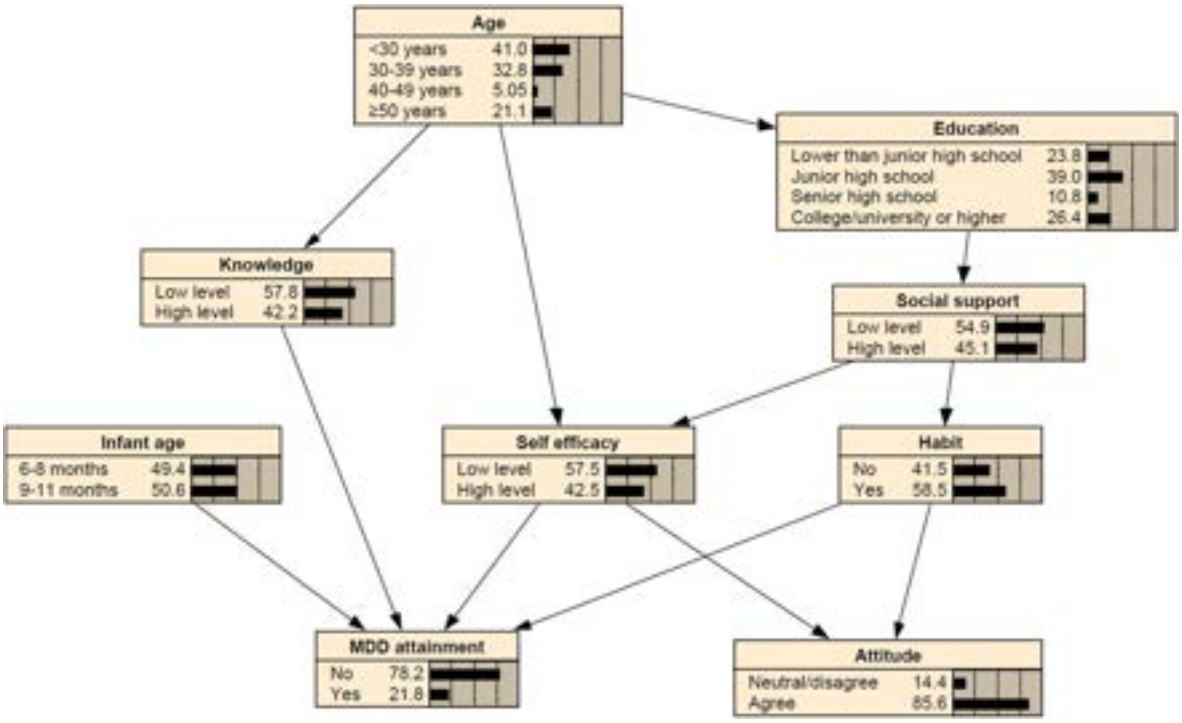

Fig. 3. Bayesian network model of MDD attainment behavior.

structural stability. The model achieved an overall prediction accuracy of 79.13 %, reflecting reliable predictive performance.

The nine nodes each represent one variable, while the 12 arcs signify the probabilistic dependencies between them. For each node, a bar graph presents all levels of the variable, in which the rectangular bars depict the prior probabilities of each level in our data. For instance, 21.8 % of the sample infants attained MDD whereas 78.2 % did not.

3.4. Bayesian inference for MDD attainment behavior

Among the four parent nodes that directly influence MDD attainment, the caregiver's knowledge, self-efficacy, and habit were factors modifiable through interventions. To assess the effects of potential interventions on these factors, we deduced the conditional probabilities of the MDD attainment based on the diverse states of these nodes.

As illustrated in Fig. 4, the probability of attaining MDD is 0.262 if

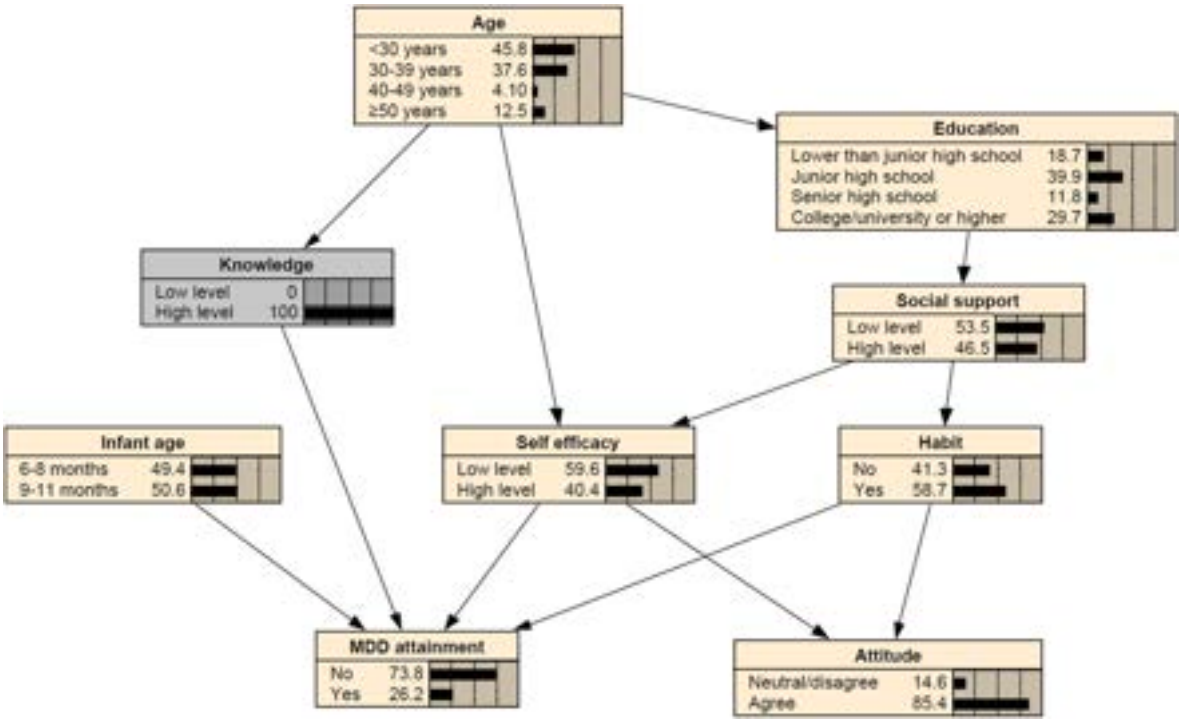

Fig. 4. Bayesian inference for MDD attainment with high caregiver knowledge.

the caregiver had high levels of feeding knowledge; Mathematically, P (attaining MDD | high-level knowledge) = 0.262. The probability of attaining MDD rose to 0.328 if that caregiver additionally had high self-efficacy (see Fig. 5); Mathematically, P (attaining MDD | high-level knowledge, high-level self-efficacy) = 0.328. This probability further increases to 0.394 if that caregiver also had a habit of feeding their infant diverse foods (see Fig. 6); Mathematically, P (attaining MDD | high-level knowledge, high-level self-efficacy, having habit) = 0.394. Table 2 presents the outcomes of the Bayesian network inference, which indicates that among the three modifiable variables, modifying habit alone led to the highest increase in the probability of attaining MDD (4.70 percentage points). Joint improvements in knowledge, self-efficacy, and habit can result in a 17.6 percentage point increase in the probability of attaining MDD.

In addition, we conducted a supplementary inference based on infant age, a non-modifiable variable, to further illustrate its association with MDD attainment. The results showed that infants aged 9–11 months had a higher estimated probability of meeting MDD (31.6 %) than those aged 6–8 months (11.6 %), suggesting that infant age is positively associated with MDD attainment.

3.5. *Interactions between social support, self-efficacy, and habit*

The Bayesian network also identified the interrelationships between social support, self-efficacy, and habit. Specifically, as shown in Fig. A.1 in Appendix A, social support was indirectly associated with MDD attainment through its positive associations with self-efficacy and habit. The probability of having high self-efficacy is higher among caregivers with high social support (49.5 %) than those with low social support (42.5 %). Concurrently, the probability of having a habit of feeding infants diverse foods was also 6.3 percentage points higher among caregivers with high social support (65.1 %, compared to 58.8 % among caregivers with low social support).

4. Discussion

This study described Minimum Dietary Diversity (MDD) attainment among infants aged 6–11 months in rural China. We then used a Bayesian network approach to explore the determinants of MDD attainment based on the Capability-Opportunity-Motivation (COM-B) model, their interrelationships, and the probability of improving MDD attainment through modifying them. To our best knowledge, although prior research has investigated the determinants of MDD attainment behavior individually, ours is the first study to integrate a behavioral model that accounts for interactions between determinants with Bayesian network analysis which estimates their effects.

Our findings suggest that in rural China, only 22.2 % of the caregivers fed their 6-to-11-month-old infants five or more of the eight types of foods identified in the IYCF in the prior 24 h, implying that nearly 80 % of infants failed to meet the MDD requirement for their age. The observed MDD attainment in our sample is lower than that reported in a national survey conducted in Uganda (MDD: 26 %) (Scarpa et al., 2022), yet higher than those documented in other studies in sub-Saharan African countries (MDD: 18.57 %) (Belay et al., 2022b) and in India (MDD: 9.7 %) (Beckerman-Hsu et al., 2020). The observed discrepancy could be attributed to factors including differences in geographical location, population growth rates, and socioeconomic differences across these countries (Lutter et al., 2011). Governmental initiatives to implement nutrition assistance programs centered around appropriate complementary feeding practices might also play a pivotal role (Ahoya et al., 2019). Additionally, the MDD attainment rate in our sample is substantially lower than the MDD attainment rates of infants of the same age in urban China (48.3 %) published in a national survey (Wu et al., 2024), which illustrates that the dietary diversity of infants in economically less developed areas requires increased monitoring and intervention from health practitioners. Low dietary diversity in this critical developmental stage heightens the risk of stunted growth and micronutrient deficiencies, which have been associated with compromised developmental outcomes in young children, less schooling and poor test performance, and lower earnings in adulthood (Black et al., 2015; Zhao et al., 2021b). As such, our findings underscore the urgency of promoting MDD attainment behavior among caregivers of infants aged 6–11 months in rural China.

Based on the caregivers' recollection of feeding behaviors, most

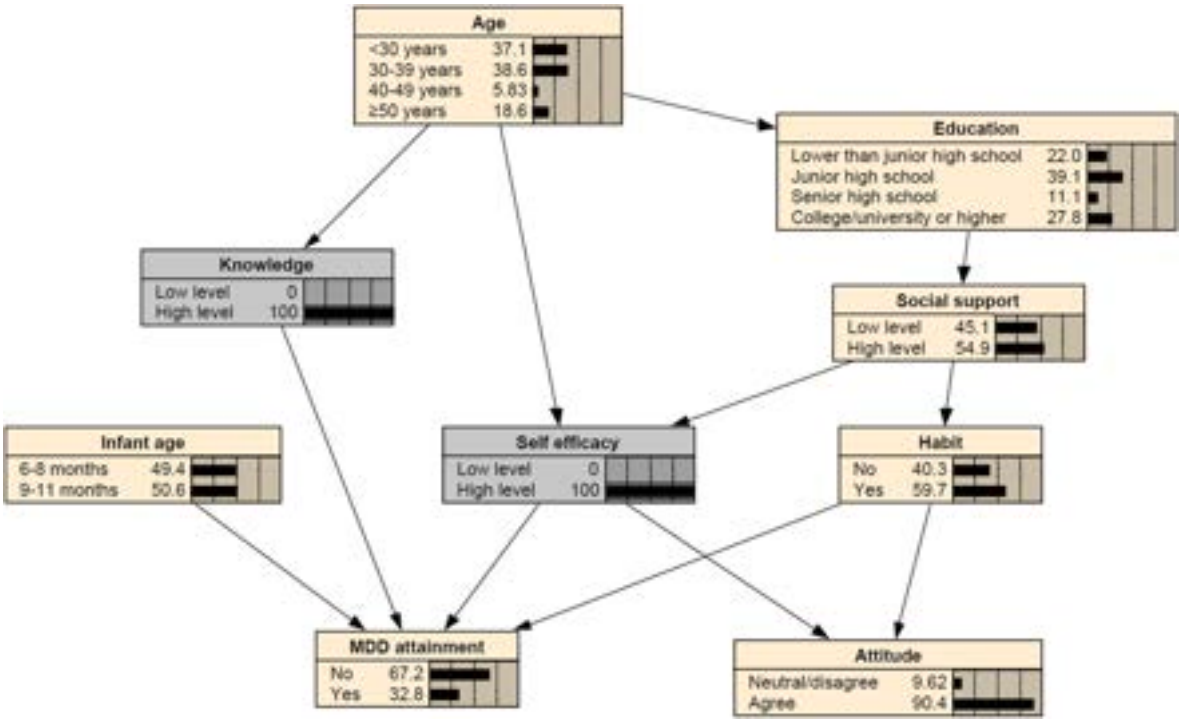

Fig. 5. Bayesian inference for MDD attainment with high caregiver knowledge and self-efficacy.

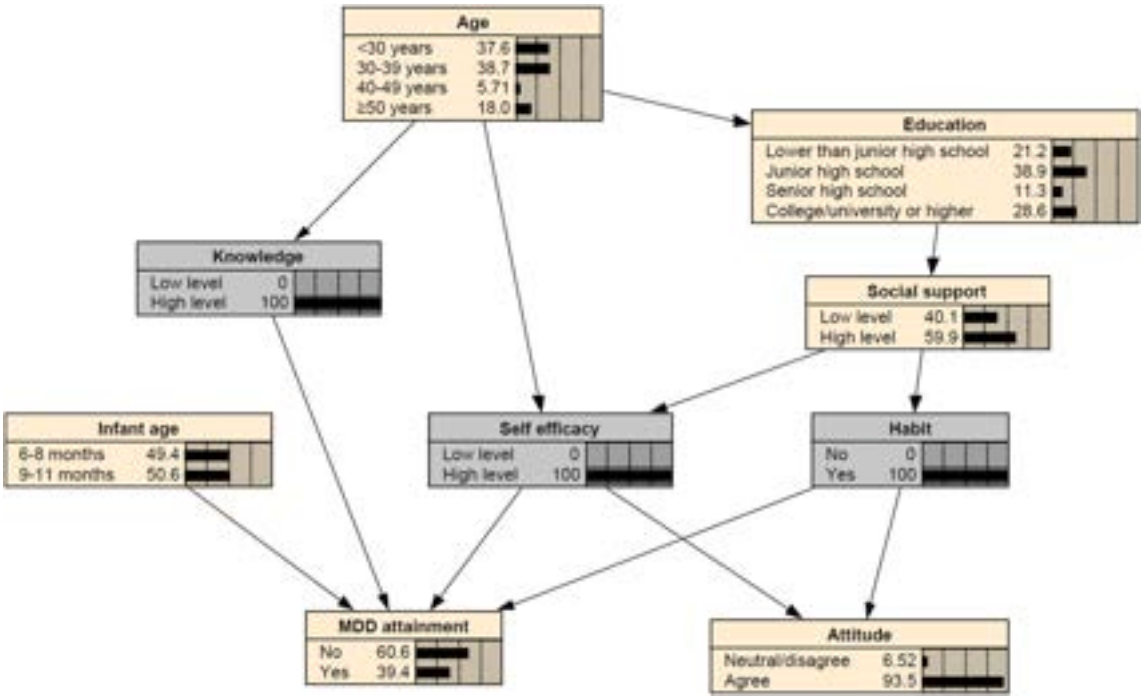

Fig. 6. Bayesian inference for MDD attainment with high caregiver knowledge, self-efficacy, and having habit.

Table 2
Results of Bayesian inference for MDD attainment.

	Rate of MDD attainment	Growth
No change	21.80 %	
Only change knowledge ("high-level")	26.20 %	4.40 %
Only change self-efficacy ("high-level")	26.30 %	4.50 %
Only change habit ("have habit")	26.50 %	4.70 %
Change self-efficacy and habit	30.10 %	8.30 %
Change knowledge and habit	32.10 %	10.30 %
Change knowledge and self-efficacy	32.80 %	11.00 %
Change knowledge, self-efficacy and habit	39.40 %	17.60 %

caregivers provided infants with grains, roots and tubers (83.4 %), and dairy products (72.3 %), whereas consumption of legumes and nuts (2.9 %) was much rarer. Similar rates were previously reported in a previous survey of child and infant nutrition in 19 low-income provinces in China (Liu et al., 2021). Our study also found that only 23.6 % of the infants were fed eggs in the previous day, similar to the rate of consumption reported in a previous study of 6-to-23-month-old infants in six low-income counties in rural China (22.3 %) (Zhao et al., 2021c). The potential reasons for not feeding legumes, nuts, or eggs to infants include a belief that infants have difficulty swallowing/digesting these foods, a lack of knowledge on how to prepare them, and a prevailing fear of choking (Bazzano et al., 2017). Therefore, future efforts should focus on knowledge dissemination related to food categories like legumes, nuts and eggs. Effective information education for caregivers should combine cultivating their skills for preparing these foods for infants with reducing their misperceptions and ungrounded concerns about feeding these foods.

Our Bayesian network analysis found that knowledge (capability), self-efficacy (motivation), habit (motivation), and infant age could directly influence MDD attainment behavior. Furthermore, social support (opportunity) could indirectly affect MDD attainment through enhancing self-efficacy and habit. Among the three modifiable factors examined, cultivating a habit of preparing diverse foods would lead to the largest increase in the probability of MDD attainment. While prior research has reported associations between habitual action, adult diet, and physical activity (Gardner et al., 2011), our study is among the first to highlight the role of habit in complementary feeding behaviors. As one of the important variables in automated motivation, habits guide action rapidly and efficiently (Verplanken et al., 1997). In familiar and unvarying contexts, behavior tends to be regulated more by habit than conscious intentions (Gardner et al., 2011). Given that infant feeding is a daily and repetitive behavior, establishing a habit of preparing diverse foods could effectively shape caregivers' automatic behaviors and reduce the need for constant deliberation. A previous study focusing on habit-based interventions provided additional support for the critical role of habits in effecting changes in dietary behavior (Gardner et al., 2014), adding to the importance of interventions targeting habit formation for increasing MDD attainment behaviors in rural areas.

Besides habit, our analysis shows that improving caregivers' self-efficacy would have the second largest positive impact on MDD attainment. The significant role of self-efficacy in MDD attainment is well documented: An integrative review found that mothers possessing higher levels of self-efficacy were inclined to provide their infants with a broader range of vegetables and introduce new foods more frequently (Bahorski et al., 2019). A similar study conducted in Niger also found a positive correlation between self-efficacy and MDD attainment (Dougherty & Dadi, 2024). Self-efficacy likely influenced MDD attainment because it increased the caregivers' belief in their ability to successfully prepare nutritional foods and help their infants achieve dietary diversity (Bandura, 1977), which are often demanding endeavors that necessitate substantial time and effort (Koh et al., 2014), especially in low-resource settings. Caregivers with higher self-efficacy in complementary feeding are more likely to overcome the difficulties associated with preparing diversified meals and feeding. Additionally, other researchers have demonstrated that self-efficacy enables caregivers to adhere to complementary feeding guidelines (Herman et al., 2023). Hence, there is a pressing need for future interventions to bolster feeding self-efficacy as an approach to improving MDD attainment.

We also found caregivers' knowledge of complementary feeding to be a significant determinant of MDD attainment. Our finding aligns with previous studies conducted in Ethiopia, which found that children whose caregivers had enhanced feeding knowledge were significantly more likely to attain MDD (Solomon et al., 2017), and studies in Ghana, which found a positive correlation between caregiver knowledge and

infant dietary diversity (Opoku Agyemang et al., 2023). A better understanding about the diverse foods and their benefits to infants' development is crucial for practicing appropriate feeding behavior (Solomon et al., 2017). However, nearly 60 % of the caregivers in our sample had a low level of complementary feeding knowledge—the foremost obstacle to complementary feeding practices, particularly those related to MDD, according to a systematic review (Manikam et al., 2017). Since information education interventions can effectively increase MDD attainment rates (Singh et al., 2018), our findings demonstrate the need to promote MDD attainment among infants in rural China through enhancing health and complementary feeding education for caregivers and the significant potential of such interventions.

Additionally, our results demonstrate that social support indirectly affected MDD attainment through influencing self-efficacy and habit. This validates the pathway proposed in the COM-B that opportunity influences behavior through motivation. Previous research has similarly demonstrated that social support increased other health behaviors through enhancing self-efficacy and establishing habits. For instance, in Type 2 diabetes patients, social support predicted higher self-efficacy and mediated the relationship between neuroticism and medication adherence (Huang et al., 2021). Family support has been found to improve dietary habits in individuals with Type 2 diabetes (Tol et al., 2014) and facilitate mothers' provision of diverse foods for infants, as shown in a quasi-experimental study in Kenya (Mukuria et al., 2016b). These findings underscore the importance of involving key social relationships, particularly family members, in encouraging caregivers to provide diverse foods for infants.

This study advances the application of the COM-B model in the research of feeding practices and MDD attainment. According to the COM-B model, capability serves as a prerequisite for behavior, opportunity acts as an external facilitator, and motivation is a critical cognitive process that drives and directs behavior (Michie et al., 2011). The model derived from our data indicates that both capability (knowledge) and motivation (self-efficacy and habits) directly influence behavior, while opportunity (social support) primarily exerts indirect effects on behavior by enhancing motivation (self-efficacy and habits). For practitioners aimed at developing effective interventions to increase infant dietary diversity, the motivation of caregivers warrants the most attention, whereas the effects of increasing opportunities may be less direct and measurable compared to the other two dimensions in the COM-B model. A U.S. study on hand hygiene behavior similarly highlighted the greater significance of motivation over opportunity (Brown et al., 2022). The application of the COM-B model provides a robust theoretical framework for understanding the factors influencing MDD attainment behavior and developing targeted interventions. By prioritizing the motivation dimension, interventions may achieve greater efficacy in shaping desired behaviors.

Several limitations also warrant mention. First, we only proxied the capability dimension in the COM-B model with knowledge. Future research could examine additional variables within this dimension, such as skills related to complementary feeding. Second, we used cross-sectional survey data to construct a Bayesian network. Further collection of longitudinal data is needed to establish temporal causality. Third, our measure of dietary diversity depended on caregivers' recall of feeding behavior in the previous 24 h. Although this measure adheres to the operational definition of MDD developed by the World Health Organization, the dependence on individual recall and self-reports could make our data susceptible to recall bias. A more accurate measure of dietary diversity could involve using ecological momentary assessment to collect feeding data over longer periods.

5. Conclusions

This study found low attainment rates of minimum dietary diversity among infants aged 6–11 months in rural China, highlighting the urgency of promoting healthy feeding behaviors to increase dietary diversity among infants under one year old. Interventions to improve feeding practices should focus on enhancing caregivers' knowledge, self-efficacy, and establishing a habit of feeding diverse foods. Addressing these critical factors could significantly enhance dietary diversity practices in rural China.

CRediT authorship contribution statement

Linhua Li: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Yanrong Dong:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Data curation. **Zhengjie Cai:** Writing – review & editing, Validation, Methodology, Investigation, Conceptualization. **Hanwen Zhang:** Writing – review & editing, Methodology. **Xiannan Xian:** Writing – review & editing, Visualization, Validation, Software, Investigation. **Yiran Tian:** Writing – original draft, Methodology, Investigation, Data curation. **Xinru Zhou:** Writing – review & editing, Software, Methodology, Investigation, Data curation. **Liang Lv:** Writing – review & editing, Validation, Methodology, Investigation. **Yuju Wu:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Huan Zhou:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Ethical statement

This study received ethical approval from the Ethics Committee of West China Fourth Hospital and West China School of Public Health (Approval Number: Gwll2022101). Infant caregivers provided written informed consent for their own participation and that of their infants in this study.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix. ASupplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2025.108144.

Abbreviations

MDD: Minimum Dietary Diversity; WHO: World Health Organization; IYCF: Infant and Young Child Feeding; CNIPCPA: Nutrition Improvement Project on Children in Poor Areas; COM-B: Capability, Opportunity, Motivation, and Behavior; Interquartile Range (IQR);

DAG: Directed Acyclic Graph; BIC: Bayesian Information Criterion.

Data availability

The datasets used during the current study are available from the corresponding author (zhouhuan@scu.edu.cn) upon reasonable request.

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