The first 1000 days: window of opportunity for child health and development

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The first 1000 days: window of opportunity for child health and development

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Editorial: The first 1000 days: window of opportunity for child health and development

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Editorial on the Research Topic
The first 1000 days: window of opportunity for child health and development

Introduction

The first 1,000 days of a child's life, spanning from conception to their second birthday, represent a pivotal period that shapes their future health, cognitive abilities, and overall wellbeing. This critical window is a time of extraordinary growth and development, particularly for the brain, which undergoes rapid formation of neural connections that lay the foundation for lifelong learning and health (1). During this phase, a child's body grows at a remarkable pace, and their immune system begins to mature, making proper nutrition, healthcare, and socio-emotional support indispensable. Research underscores that interventions during this period can have profound, long-lasting effects, while neglect or adverse conditions can lead to irreversible consequences, such as stunted growth, cognitive deficits, and compromised immunity (2, 3). In this Research Topic, we invited researchers, public health practitioners, and policy experts to share their work related to nutrition, caregiving, social protection programs, and early child development within the first 1,000 days. The published articles offer a comprehensive view of the multifactorial influences and interventions that shape early childhood outcomes.

The importance of the first 1,000 days

The concept of the first 1,000 days as a "window of opportunity" is grounded in extensive scientific evidence demonstrating that early interventions can yield significant dividends for individuals and societies. Proper nutrition during this period is paramount. Breastfeeding, for instance, provides essential nutrients and antibodies that bolster a child's immune system and cognitive development (4). A diverse, nutrient-rich diet further supports physical growth and prevents deficiencies that could impair development (5). Access to clean water, sanitation, and healthcare services—such as vaccinations and regular check-ups—ensures that children are protected from preventable diseases and developmental setbacks. Beyond physical health, the socio-emotional environment plays a critical role. Responsive caregiving, a safe living environment, and opportunities for stimulation foster emotional security and cognitive growth, setting the stage for resilience and adaptability in later life.

The consequences of failing to provide adequate support during this period are severe. Malnutrition, for example, can lead to stunting, which affects not only physical growth but also cognitive capacity and economic productivity in adulthood (6). Similarly, lack of healthcare access can result in untreated illnesses that hinder development, while exposure to environmental toxins or inadequate caregiving can impair brain development and emotional wellbeing. Investing in the first 1,000 days is thus not only a moral imperative but also an economic one, as healthier children grow into more productive adults, contributing to stronger communities and equitable societies.

Challenges to optimizing child health and development

Despite the clear importance of the first 1,000 days, numerous challenges hinder efforts to ensure that all children receive the necessary support. Malnutrition remains a pervasive issue, particularly in low- and middle-income countries, where millions of children lack access to adequate nutrition (7). This leads to conditions such as wasting, stunting, and underweight, which have long-term consequences for health and development. Limited access to healthcare services, especially in remote or low-income areas, exacerbates these issues, as families struggle to obtain vaccinations, prenatal care, or treatment for illnesses. Poverty compounds these challenges, restricting access to nutritious food, clean water, and safe living environments. Additionally, a lack of education and awareness among parents and caregivers about the importance of the first 1,000 days can result in missed opportunities for intervention (8). Environmental factors, such as exposure to pollutants or inadequate sanitation, further threaten child health, particularly in resource-constrained settings.

Addressing these challenges requires coordinated, evidence-based policies and programs that prioritize early childhood development. Governments, NGOs, and communities must work together to improve access to nutrition, healthcare, and education while addressing systemic issues like poverty and environmental degradation.

Insights from the Research Topic

The Research Topic, comprising 19 chapters, offers a multifaceted examination of the first 1,000 days, drawing on empirical research from diverse global contexts. Each chapter contributes to a deeper understanding of the factors influencing child health and development and proposes strategies to address the associated challenges. Below, we highlight key themes and findings from select chapters, illustrating the breadth and depth of this critical research.

Nutrition and feeding practices

Nutrition is a cornerstone of child development during the first 1,000 days, and several chapters in the topic address this Research Topic. For instance, S. Calgaro et al. evaluates feeding practices in the first 12 months of life in Beira, Mozambique, highlighting the link between suboptimal feeding practices (inadequate breastfeeding during complementary feeding) and poor nutritional outcomes in low-resource urban settings (Calgaro et al.). Similarly, Hailemariam Mamo Hassen examines trends in exclusive and predominant breastfeeding practices in Ethiopia over two decades, underscoring the importance of sustained efforts to promote breastfeeding as a cost-effective intervention for child health (Hassen). Rohini Saran et al. explores the role of fortification and breastfeeding in improving nutrition outcomes, emphasizing the need for scalable interventions to combat malnutrition (Saran et al.).

Maternal nutrition also plays a critical role, as evidenced by Teshale Fikadu et al., which investigates the nexus between maternal nutritional status and food consumption patterns in pregnant women in South Ethiopia (Fikadu T. et al.). The study reveals how maternal diets influence fetal development, highlighting the need for targeted nutritional support for pregnant women. Additionally, Li et al. examines how dietary preferences, such as a preference for mala-flavored foods in Chongqing, China, can lead to excessive gestational weight gain, mediated by high-carbohydrate diets, which may affect both maternal and child health (Li et al.).

Healthcare and supplementation

Access to healthcare and appropriate supplementation is another critical focus of the Research Topic. Lian et al. investigates the effects of folic acid supplementation before conception on the immune function and anti-HBs levels of offspring born to HBsAg-positive mothers, demonstrating the protective role of preconception interventions (Lian et al.). Similarly, Yin et al. explores the necessity of gestational vitamin D supplementation, noting its dependence on ambient temperature and its implications for infant vitamin D status (Yin et al.). Baker et al. advocates for omega-3 long-chain polyunsaturated fatty acid (LC-PUFA) consumption during pregnancy to reduce the risk of preterm birth, emphasizing sustainable implementation strategies (Baker et al.). These findings highlight the importance of tailored healthcare interventions to address specific nutritional deficiencies and health risks during pregnancy and early childhood.

Socio-emotional and environmental factors

The socio-emotional environment and caregiving practices are equally vital for child development. Alabdullah et al. uses a qualitative approach to explore factors influencing breastfeeding knowledge and practices among Saudi mothers, revealing the role of cultural barriers and the importance of education (Alabdullah et al.). Randhawa et al. examines the knowledge, attitudes, and practices of mothers and frontline health workers in Assam, India, emphasizing the need for community-based education to improve infant and young child feeding (Randhawa et al.).

Benjamin et al. focuses on transforming hospital organizational culture to promote parent-child relationships, demonstrating how institutional changes can foster supportive environments for early childhood development (Benjamin et al.).

Environmental factors also receive attention. Song et al. investigates the relationship between maternal vitamin D status during pregnancy and infant gut microbiota, highlighting the interplay between maternal health and environmental influences on child development (Song et al.). Alamneh et al. explores recovery times from severe acute malnutrition among cholera-exposed and unexposed children in Ethiopia, underscoring the impact of environmental health crises on nutritional outcomes (Alamneh et al.).

Policy and systemic interventions

Several studies address the role of policy and systemic interventions in improving outcomes during the first 1,000 days. Jagannath and Chakravarthy evaluates the impact of India's Pradhan Mantri Matru Vandana Yojna scheme, which improves access to maternal and child health services, leading to better health and nutritional outcomes (Jagannath and Chakravarthy). Fikadu et al. examines intra-household decision-making on child feeding in rural South Ethiopia, highlighting the social determinants that influence nutritional practices. These studies emphasize the need for policies that address both individual and systemic barriers to child health (Fikadu K. et al.).

Addressing malnutrition and health disparities

The Research Topic also tackles the persistent challenge of malnutrition and health disparities. Tamir et al. uses spatial and multilevel analyses of the 2023 Senegal Demographic and Health Survey to map the prevalence and determinants of wasting among children under five, providing critical data for targeted interventions (Tamir et al.). Dassie et al. conducts a systematic review of factors influencing concurrent wasting, stunting, and underweight in low- and middle-income countries, offering insights into the complex interplay of nutritional deficiencies (Dassie et al.). De Rose et al. provides a practical overview of improving growth in preterm infants through nutrition, addressing a vulnerable population with unique needs (De Rose et al.).

Moving forward: a call to action

The first 1,000 days represent a unique opportunity to shape the trajectory of a child's life, but realizing this potential requires overcoming significant challenges. The Research Topic provides a roadmap for action, highlighting the need for integrated approaches that combine nutrition, healthcare, education, and environmental interventions. Policymakers must prioritize investments in maternal and child health programs, ensuring access to nutritious food, clean water, and healthcare services, particularly in low-resource settings. Community-based education campaigns can empower parents and caregivers with the knowledge and tools to support their children's development. Additionally, addressing systemic issues like poverty and environmental degradation is essential to creating equitable opportunities for all children.

The research presented under the Research Topic underscores the global nature of these challenges and the need for context-specific solutions. From urban Mozambique to rural Ethiopia, from Saudi Arabia to China, the studies highlight the diverse factors influencing child health and development. By synthesizing these insights, the Research Topic calls for a collaborative effort among governments, NGOs, healthcare providers, and communities to ensure that every child has the opportunity to thrive during the first 1,000 days.

In conclusion, the first 1,000 days are a window of opportunity that we cannot afford to miss. By investing in nutrition, healthcare, and supportive environments during this period, we can lay the foundation for healthier, more productive, and equitable societies. The Research Topic serves as both a call to action and a blueprint for change, urging stakeholders to prioritize the health and wellbeing of children in their earliest years. Together, we can transform the promise of the first 1,000 days into a reality for all children, ensuring a brighter future for generations to come.

Author contributions

SS: Conceptualization, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. GV: Writing – review & editing. SR: Writing – review & editing.

Conflict of interest

SR was employed by TVS Motor Company.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Maternal vitamin D status during pregnancy and infant's gut microbiota: a prospective cohort study

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Objectives: To prospectively explore the association of maternal serum 25(OH)D levels with the infant's gut microbiota in Chinese populations, and to evaluate its potential influence on the dynamic change patterns of offspring's gut microbiota from 1 to 6 months old.

Methods: Eighty-seven mother-infant dyads (vitamin D insufficient group vs. normal group = 59 vs. 28) were included in this longitudinal study. Two fecal samples were collected for the included infant at home by the parents at 1 month of age ("M1 phase") and 6 months of age ("M6 phase"). Gut microbiota were profiled by 16S rRNA gene sequencing. We performed mixed effects models on alpha diversity metrics, PERMANOVA tests on beta diversity distances, and linear discriminant analysis (LDA) to identify differently abundant taxa.

Results: We observed significantly lower Pielou's evenness and Shannon diversity in the vitamin D insufficient group in the M6 phase (p = 0.049 and 0.015, respectively), but not in the M1 phase ($p > 0.05$), and the dynamic changes in alpha diversity from 1 to 6 months old were significantly different according to maternal vitamin D status ($p < 0.05$). There were also significant differences in gut microbiota composition between the vitamin D insufficient group and normal group, both in the M1 and M6 phases (LDA score > 2.0, $p < 0.05$). Moreover, among the predicted metagenome functions, pathways related to amino acid biosynthesis, starch degradation, and purine nucleotides biosynthesis were enriched in the vitamin D insufficient group.

Conclusion: Our findings highlight that maternal vitamin D status plays a pivotal role in shaping the early-life gut microbiota of the next generation.

KEYWORDS

serum 25(OH)D level, maternal, pregnancy, gut microbiota, dynamic change, infant

1 Introduction

A growing body of evidence suggests that vitamin D during pregnancy is essential for optimal maternal and offspring health (1–3). Maternal vitamin D deficiency or insufficiency was considered as a significant risk factor for adverse maternal-fetal outcomes, including preeclampsia, gestational diabetes mellitus, low birth weight, and preterm births (2).

It is well acknowledged that early life gut microbiota is influenced by various factors during pregnancy, such as maternal antibiotic and probiotic uses, dietary intake, and diseases of pregnancy (4–6). In recent years, the role of vitamin D during pregnancy in the infant's gut microbiota has been of increasing interest. In vitamin D receptor knockout mice, there were significant communal and functional changes in the gut microbiota compared with wild type mice, the mechanism of which may be related to reduced inflammation, upregulation of innate immunity, etc. (7–9). The latest systematic review research has summarized associations between maternal vitamin D supplementation during pregnancy and infant's gut microbiota, and revealed that maternal supplementation with vitamin D could impact the gut microbiota composition of offspring (10). However, this systematic review included only eight articles (two animal studies, three randomized clinical trials, and three cohort studies), and the large heterogeneity of the results prevented them from drawing a reliable conclusion.

In addition to vitamin D supplementation, only a few studies focused on vitamin D levels in the blood. In the KOALA birth cohort, Talsness et al. (11) found that maternal plasma vitamin D levels, which were determined at approximately the 36th week of pregnancy, were associated with counts of several limited bacterial taxa of infants at 1 month of age. Cord blood vitamin D was associated with increased *Lachnobacterium* and decreased *Lactococcus* in the Vitamin D Antenatal Asthma Reduction Trial (12). Another recent study reported that higher prenatal plasma and cord 25(OH)D levels were significantly associated with lower richness and diversity of the gut microbiota of their offspring at 1 month of age (13). These findings suggest maternal vitamin D levels might influence the infant's gut microbiota composition and structure. However, questions remain and there are no clear conclusions. Moreover, most of previous studies were conducted in European and American populations, studies on Chinese populations were limited. Due to possible racial differences, studies conducted in Chinese populations are needed.

Therefore, in the present study, we aimed to explore the association of maternal vitamin D levels during pregnancy with the infant gut microbiota in a prospective cohort study in Shenzhen, China. In addition, we would evaluate the potential influence of maternal vitamin D status on the dynamic change patterns of offspring's gut microbiota from 1 to 6 months old for the first time.

2 Methods

2.1 Participants

The present study was conducted at the Shenzhen Baoan Women's and Children's Hospital from November 2020 to December 2021, and was approved by the Ethical Committees of Shenzhen Baoan Women's and Children's Hospital (approval number: LLSC 2020-09-02-KS). All participants provided their written informed consents, and all methods were carried out in accordance with relevant guidelines.

Women enrolled in this study were between 20 and 45 years old, in their second trimester, with serum 25(OH)D measured, and living in Shenzhen. Those who would not possibly give birth at the Shenzhen Baoan Women's and Children's Hospital were excluded. A total of 87 mother-infant dyads were included in the present study, with all infants born of a singleton pregnancy with full-term (≥37 weeks and <42 weeks of gestation) and normal birth weight (≥2,500 g and ≤4,000 g). Newborns with any obvious congenital abnormality, neurological dysfunction, fetal chromosomal abnormality, or metabolic diseases were excluded. None of the infants received antibiotics or probiotics before the 6-month visit.

Information on maternal and infant characteristics, including maternal age at delivery, pre-pregnancy body mass index (BMI), gestational weight gain, gestational age, delivery mode, gestational diabetes mellitus (GDM), hypertensive disorders of pregnancy (HDP), infant's sex, birth weight and length were derived from the electronic medical records of the hospital information system. In addition, information on feeding practices (breastfeeding, formula, or mixed), weight, length, and head circumference at 1 month and 6 months of age were also collected from the medical records.

2.2 Maternal serum vitamin D measurement

Maternal 25(OH)D levels were measured in serum samples from the second trimester of pregnancy (median = 17 weeks, range: 15 ~ 19 weeks) in the laboratory of Shenzhen Baoan Women's and Children's Hospital using chemiluminescence immunoassay (CLIA) technology. There is no consensus on optimal vitamin D levels during pregnancy. In the present study, 25(OH)D < 30 ng/mL is considered to be vitamin D insufficiency, whereas 25(OH)D ≥ 30 ng/mL is considered normal levels (3, 14).

2.3 Collection of fecal samples

Two fecal samples were collected for the included infants at home by the parents at 1 month of age (median = 30 days, range: 26 ~ 42 days, henceforward referred to as "M1 phase") and again at 6 months of age (median = 184 days, range: 170 ~ 258 days, henceforward referred to as "M6 phase"). All infants had no fever, diarrhea, or other symptoms during the week prior to sampling. All fecal samples were collected using sterile tubes and temporarily placed in ice boxes and then carried or mailed to the hospital, and finally stored in a −80°C freezer within 24 h until DNA extraction.

2.4 Sequencing and sequence processing

Genomic DNA was extracted from fecal samples using the MoBio PowerSoil DNA isolation kit (MoBio, Carlsbad, CA) according to the manufacturer's instructions. The concentration and quality were assessed using Qubit (Invitrogen) and verified by agarose gel electrophoresis. The 16S rRNA gene was amplified using 338F/806R primer pair (forward primer: 5′-ACTCCTACGGGAGGCAGCAG-3′, and reverse primers: 5′-GGACTACHVGGGTWTCTAAT-3′), targeting the V3-V4 hypervariable regions. All quantified amplicons were equally pooled and sequenced on the Illumina MiSeq system (Illumina Inc., CA, United States) with the paired-end mode. The raw sequencing data were deposited into the China National GeneBank DataBase (CNGBdb Project ID: CNP0005435).

The 16S rRNA gene sequences were analyzed using QIIME2 software (version 2020.11) with the following steps (15). Firstly, the raw sequencing reads were demultiplexed with a custom Perl script, and then the paired-end sequencing reads were imported into a QIIME2 artifact with the command "qiime tool import." Secondly, quality filtering was followed, including the removal of Phix and the processing of chimeric sequences with the command "qiime dada2 denoise-paired." Thirdly, run the command "qiime2 feature-classifier classify-sklearn" against the Greengenes (13_8 revision) database to finish the taxonomic assignment (16). Finally, the indexes of alpha and beta diversity were generated with the command "qiime phylogeny align-to-tree-mafft-fasttree" and "qiime diversity core-metrics-phylogenetic," respectively, at a sample depth of 10,000 according to the tutorials of QIIME2 (15).

2.5 Statistical analysis

Statistical analysis was performed using R software (version 3.6.1). A p-value < 0.05 was considered statistically significant for all tests.

2.5.1 General characteristics comparison

To compare the differences in general characteristics between the vitamin D insufficient group and normal group, continuous characteristics were analyzed using unpaired t-tests and reported as means ± standard deviation (SD), while categorical data were studied with the chi-square test or Fisher's exact tests and presented as numbers and percentages.

2.5.2 Alpha and beta diversity

Alpha diversity metrics refer to the diversity within a particular area or ecosystem, summarizing the structure of an ecological community concerning its richness (number of taxonomic groups, e.g., observed feature value), evenness (distribution of abundances of the groups, e.g., Pielou's evenness index), or both (e.g., Shannon diversity index) (17). Wilcoxon rank sum tests were applied to compare the above mentioned three alpha diversity metrics between the vitamin D insufficient group and normal group. Linear mixed effects models were performed to evaluate the changes in alpha diversity from the M1 to M6 phase, adjusted for maternal pre-pregnancy BMI, gestational weight gain, gestational age, delivery mode, infant's sex, and feeding practices, with a random effect of subjects.

Beta diversity quantifies differences in the overall taxonomic composition between two samples or ecosystems, commonly using the "distance" to capture the dissimilarity (18). In the present study, Bray-Curtis distance was applied to determine multivariate sample distances and visualized by principal coordinates analysis (PCoA). Permutational Multivariate Analysis of Variance (PERMANOVA) was used to compute the cross-sectional difference of beta diversity between the vitamin D insufficient group and normal group in the M1 and M6 phases. To test for the differential change in beta diversity from the M1 to M6 phase in offspring born to mothers with and without vitamin D insufficiency, a PERMANOVA model was fitted with a two-way interaction between vitamin D status and time. All analyses were adjusted for maternal pre-pregnancy BMI, gestational weight gain, gestational age, delivery mode, infant's sex, and feeding practices.

2.5.3 Relative abundance analyses

At various taxonomic levels (from phylum to genus level), linear discriminant analysis (LDA) was performed, and the LDA Effect Size (LEfSe) with the logarithmic LDA score threshold set at 2.0 was applied to identify taxonomic biomarkers that characterize the differences between the vitamin D insufficient group and normal group (19).

2.5.4 Abundant pathways and ecological association networks analyses

In addition, pathway analysis for metabolomics data was conducted to predict enriched pathway of differential metabolites. PICRUSt2.0 (Phylogenetic Investigation of Communities by Reconstruction of Unobserved States) in QIIME2 was used to predict microbiome function based on the Greengenes 16S rRNA database and KEGG orthologs (20). The different metabolic functional pathways between the vitamin D insufficient group and normal group were generated using the STAMP (v2.1.3) program (21), followed by Benjamini-Hochberg correction.

What's more, regarding that gut bacteria usually do not exist independently, but interact with each other and form a dynamic network that may significantly impact human health, determining networks of microbial interactions is important for the functional characterization of a microbial community. Therefore, SPIEC-EASI (SParse InversE Covariance Estimation for Ecological ASsociation Inference), a statistical method for the inference of microbial ecological networks from amplicon sequencing datasets, was used to analyze the microbial ecological network (22).

3 Results

3.1 Cohort characteristics

Eighty-seven infants (vitamin D insufficient group vs. normal group = 59 vs. 28) were included in the present study, with two visits at 1 and 6 months of age, respectively. In general, maternal age at delivery was around 31 years old, and gestational age was around 39.3 weeks, with an average pre-pregnancy BMI of 21 kg/m^2 and gestational weight gain of 14.5 kg. About 40 percent of the mothers were diagnosed with GDM, 35 percent of the infants were born by cesarean section, and about 70 percent were breastfed. Table 1 shows the maternal and infant characteristics comparison between the vitamin D insufficient group and normal group. Except for maternal serum vitamin D level, which was significantly lower in the vitamin D insufficient group (22.1 ± 4.5 vs. 33.2 ± 1.5 ng/mL, p < 0.001), there were no significant differences between the two groups, signifying comparable general characteristics.

TABLE 1 Maternal and infant characteristics comparison between the vitamin D insufficient group and normal group ($N = 87$).

	Vitamin D status		*p* value
	Insufficient group ($N = 59$)	Normal group ($N = 28$)	
Maternal characteristics			
Age at delivery, year	31.6 ± 3.5	31.2 ± 4.1	0.679
Pre-pregnancy BMI, kg/m^2	21.1 ± 3.0	21.4 ± 4.0	0.724
Gestational weight gain, kg	14.4 ± 4.3	14.6 ± 3.7	0.844
Gestational age, week	39.3 ± 1.1	39.3 ± 0.8	0.713
Serum vitamin D level, ng/mL	22.1 ± 4.5	33.2 ± 1.5	<0.001
Seasonal distribution of vitamin D measurement			0.920
Spring (March–May)	1 (1.69)	0	
Summer season (June–August)	30 (50.85)	13 (46.43)	
Autumn (September–November)	23 (38.98)	13 (46.43)	
Winter season (December–January)	5 (8.47)	2 (7.14)	
Delivery mode			0.991
Vaginal	38 (64.41)	18 (64.29)	
Cesarean	21 (35.59)	10 (35.71)	
GDM	24 (40.68)	11 (39.29)	0.902
HDP	6 (10.17)	1 (3.57)	0.421
Infant characteristics			
Sex, male/female	32/27	15/13	0.954
Birth weight, kg	3.2 ± 0.4	3.2 ± 0.5	0.939
Birth length, cm	49.9 ± 1.3	50.0 ± 1.9	0.969
Feeding practices			0.104
Breastfeeding	40 (67.80)	20 (71.43)	
Mixed	18 (30.51)	5 (17.86)	
Formula	1 (1.69)	3 (10.71)	
Days at collection of gut sample at 1 month	30.3 ± 2.9	31.1 ± 2.9	0.263
Weight at 1 month, kg	4.3 ± 0.5	4.4 ± 0.7	0.590
Length at 1 month, cm	54.9 ± 1.9	55.0 ± 2.2	0.899
Head circumference at 1 month, cm	36.8 ± 1.0	37.1 ± 1.3	0.316
Days at collection of gut sample at 6 months	186 ± 12.3	192 ± 12.2	0.063
Weight at 6 months, kg	8.0 ± 0.7	8.0 ± 1.0	0.991
Length at 6 months, cm	68.4 ± 2.3	68.4 ± 2.1	0.974
Head circumference at 6 months, cm	43.2 ± 1.2	43.4 ± 1.0	0.408

Data are shown as means (SD) or *n*(%). Significant differences in maternal and infant characteristics between the two groups are highlighted in bold. BMI, body mass index; GDM, gestational diabetes mellitus; HDP, hypertensive disorders of pregnancy.

3.2 Alpha and beta diversity

In the M1 phase, the differences in alpha diversity indexes between the vitamin D insufficient group and normal group were not significant (all $p > 0.05$, Figures 1A–C); while in the M6 phase, compared to the normal group, the observed feature value was marginally lower ($p = 0.081$, Figure 1A), and the Pielou's evenness and Shannon diversity were significantly lower in the insufficient group ($p = 0.049$ and $p = 0.015$, respectively, Figures 1B,C).

The mixed effect model analyses showed that the changes in observed feature value and Shannon diversity from the M1 to M6 phase were significantly different between the vitamin D insufficient group and normal group ($p = 0.015$ and $p = 0.029$, respectively).

We also tested if maternal vitamin D status during pregnancy was associated with the overall community structure and found no difference in Bray-Curtis distances between the two groups in both M1 and M6 phases ($R^2 = 0.015$; $p = 0.132$, and $R^2 = 0.012$; $p = 0.713$, respectively, Figures 1D,E). A significant temporal change in beta diversity was observed from the M1 to M6 phase (time: $p = 0.032$, Figure 1F); however, we found no differential change in beta diversity from the M1 to M6 phase according to maternal vitamin D status (time × maternal vitamin D status interaction: $p = 0.768$, Figure 1F).

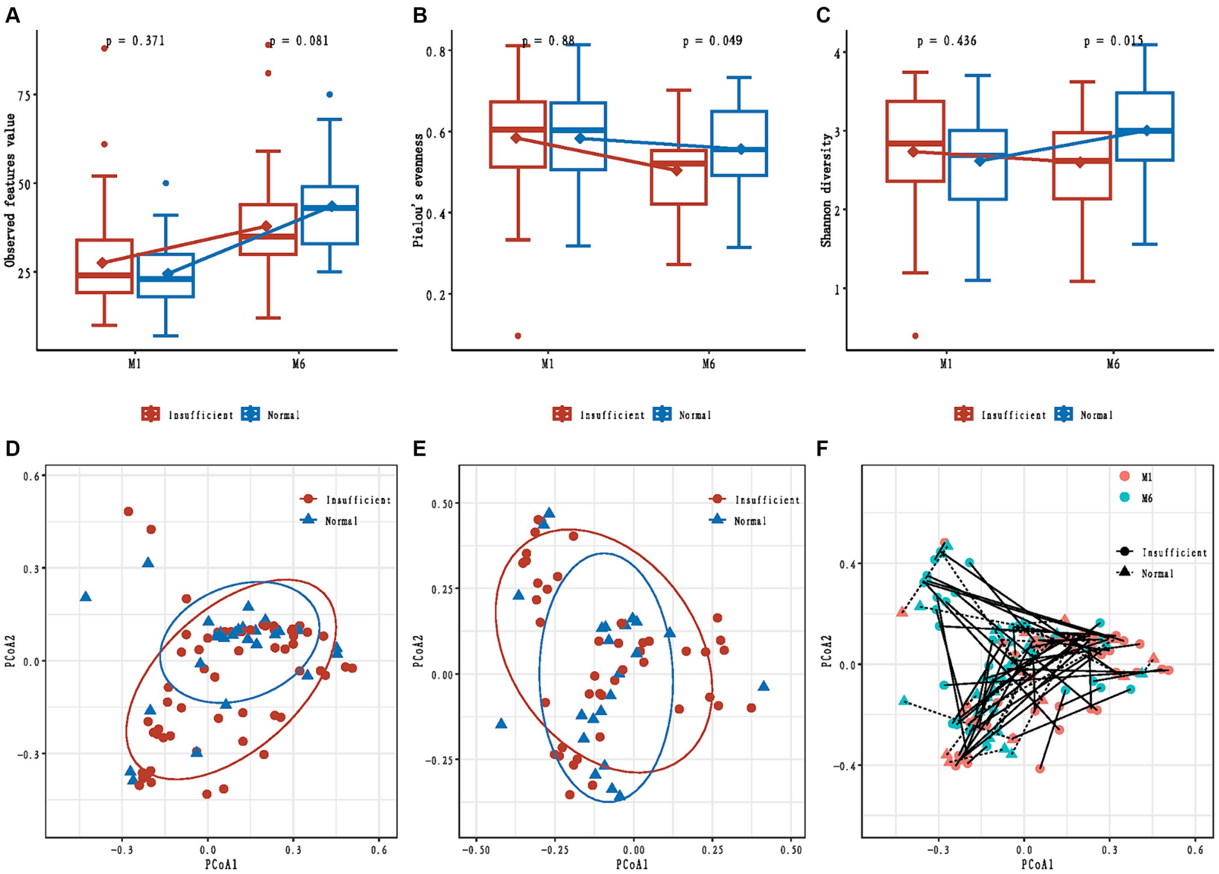

FIGURE 1
Alpha and beta diversity of infants' gut microbiota in maternal vitamin D insufficient and normal group. **(A)** Comparisons of observed feature value; **(B)** Comparisons of Pielou's evenness; **(C)** Comparisons of Shannon diversity; **(D)** Principal coordinates analysis based on Bray-Curtis distances in the M1 phase; **(E)** Principal coordinates analysis based on Bray-Curtis distances in the M6 phase; **(F)** Change in principal coordinates analysis based on Bray-Curtis distances from M1 to M6 phase.

3.3 Relative abundance

Compositionally, the gut microbiota was dominated by members of the three major bacterial phyla *Proteobacteria*, *Firmicutes*, and *Actinobacteria*, accounting for approximately 95% in both the vitamin D insufficient and normal groups (Figure 2A). From the M1 to M6 phase, the relative abundance of phyla *Proteobacteria* and *Firmicutes* declined, while the phylum *Actinobacteria* rose. At the genus level, *Bifidobacterium*, *Clostridium*, *Streptococcus*, and one unclassified genus belonging to the family *Enterobacteriaceae* were the predominant genus, with genus *Bifidobacterium* rising and the other three genera declining in the M6 phase (Figure 2B). In addition, it is noteworthy that the relative abundance of the genus *Lactobacillus*, *Ruminococcus*, and *Blautia* also exhibited an upward trend from the M1 to M6 phase.

Using LDA, we identified the genus *Campylobacter* and all parent taxa within class *Epsilonproteobacteria* (i.e., family *Campylobacteraceae*, and order *Campylobacterales*), class *Anaerolineae* and its parent phylum *Chloroflexi* were depleted in the vitamin D insufficient group, while genus *Bacteroides* and its parent family *Bacteroidaceae* were enriched in the vitamin D insufficient group in the M1 phase (Figure 2C). In the M6 phase, we found genus *Clostridium* and *Morganella* were enriched, while genus *Epulopiscium* and *Proteus* were depleted in the vitamin D insufficient group (Figure 2D).

3.4 Abundant pathways

As shown in Figure 3, more pathways were significantly abundant in the vitamin D insufficient group, including PWY-6749 (CMP-legionaminate biosynthesis I), COLANSYN-PWY (colanic acid building blocks biosynthesis), PWY-6572 [chondroitin sulfate degradation I (bacterial)], PWY-6562 (norspermidine biosynthesis), PWY-6263 (superpathway of menaquinol-8 biosynthesis II), and PWY-7323 (superpathway of GDP-mannose-derived O-antigen building blocks biosynthesis) in the M1 phase, and quite a few pathways related to amino acid biosynthesis (HISTSYN-PWY, PWY-3001, BRANCHED-CHAIN-AA-SYN-PWY, TRPSYN-PWY, VALSYN-PWY, ILEUSYN-PWY, PWY-5103, GLUTORN-PWY), PWY-6737 (starch degradation V), and PWY-6123 (inosine-5′-phosphate biosynthesis I) in the M6 phase. In the normal group, we found that 1CMET2-PWY [folate transformations III (*E. coli*)] was enriched in the M1 phase, while 2-methylcitrate cycle I and II (PWY0-42 and PWY-5747) were enriched in the M6 phase.

3.5 Ecological association network

Figure 4 shows the ecological association networks at the genus level in the vitamin D insufficient group and normal group in the M1

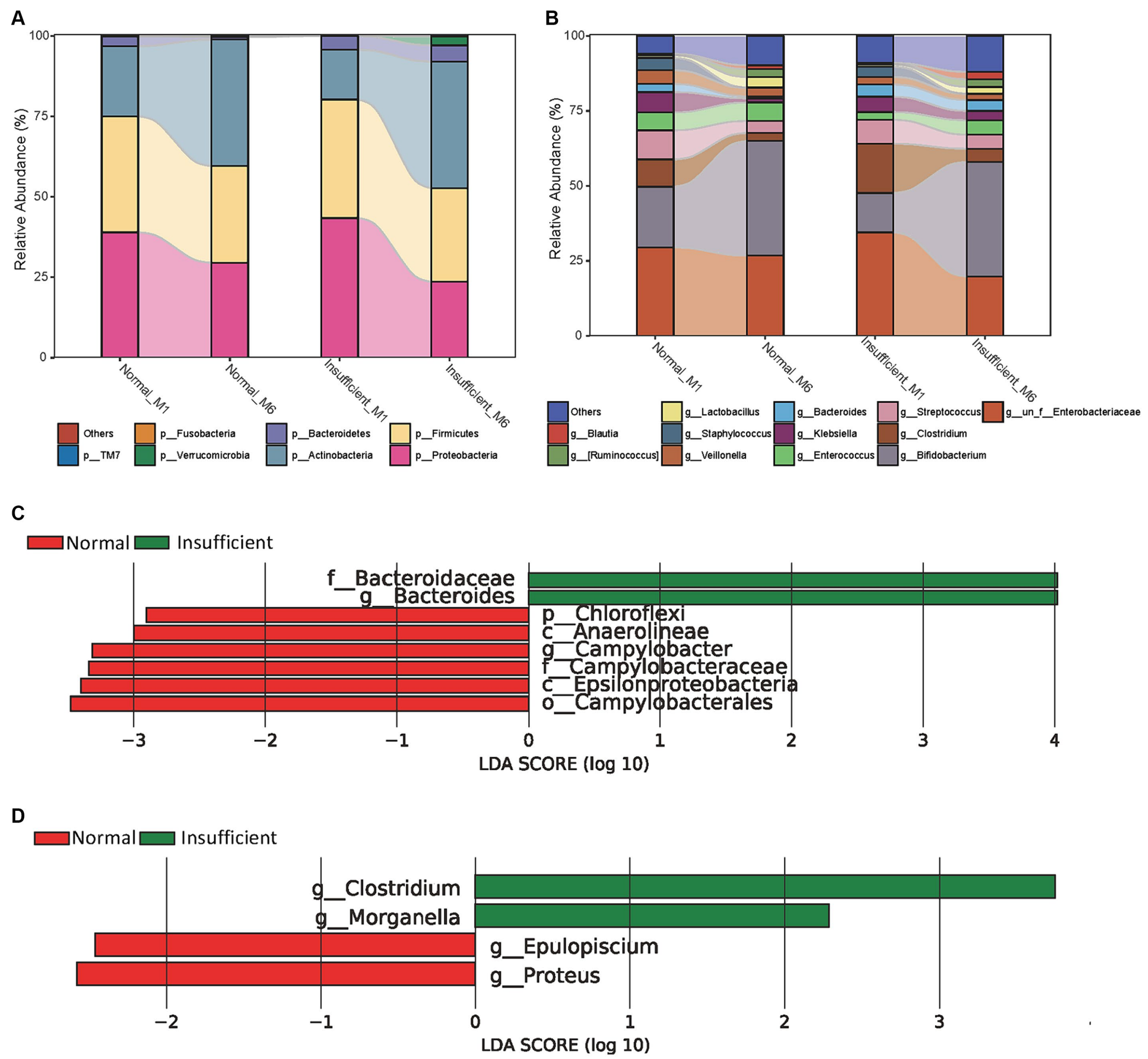

FIGURE 2
Relative proportions of abundant microbes and their differences between the vitamin D insufficient group and normal group. **(A)** Relative proportions of abundant microbes at the phylum level; **(B)** Relative proportions of abundant microbes at the genus level; **(C)** Histogram of LEfSe analysis in the M1 phase; **(D)** Histogram of LEfSe analysis in the M6 phase. The prefixes "p," "c," "o," "f," "g" represent the annotated level of phylum, class, order, family and genus.

and M6 phases, respectively. In the M1 phase, the number of nodes and edges in the insufficient and normal groups looked similar (Figures 4A,B). However, in the M6 phase, the number of edges decreased dramatically, especially in the vitamin D insufficient group, indicating fewer microbial correlations in the vitamin D insufficient group.

4 Discussion

In the current study, we prospectively examined the influence of maternal vitamin D levels on the gut microbiota of the offspring during 1–6 months of life. We observed significantly lower Pielou's evenness and Shannon diversity in the vitamin D insufficient group in the M6 phase, and the dynamic changes in alpha diversity from 1 to 6 months old were significantly different according to maternal vitamin D status. In terms of gut microbiota composition, there were significant differences between the vitamin D insufficient group and the normal group at both 1 and 6 months of age of infants. Moreover, among the predicted metagenome functions, pathways related to amino acid biosynthesis, starch degradation, and purine nucleotides biosynthesis were enriched in the vitamin D insufficient group. In addition, ecological network analysis showed an apparent decrease in microbial correlations from M1 to M6 phase, especially in the vitamin D insufficient group.

The role of vitamin D during pregnancy in the infant's gut microbiota has been of increasing interest recently. Talsness et al. (11) found that maternal plasma vitamin D levels were negatively associated with counts of *Bifidobacterium* species and positively associated with *B. fragilis* counts in infants at 1 month of age. On the

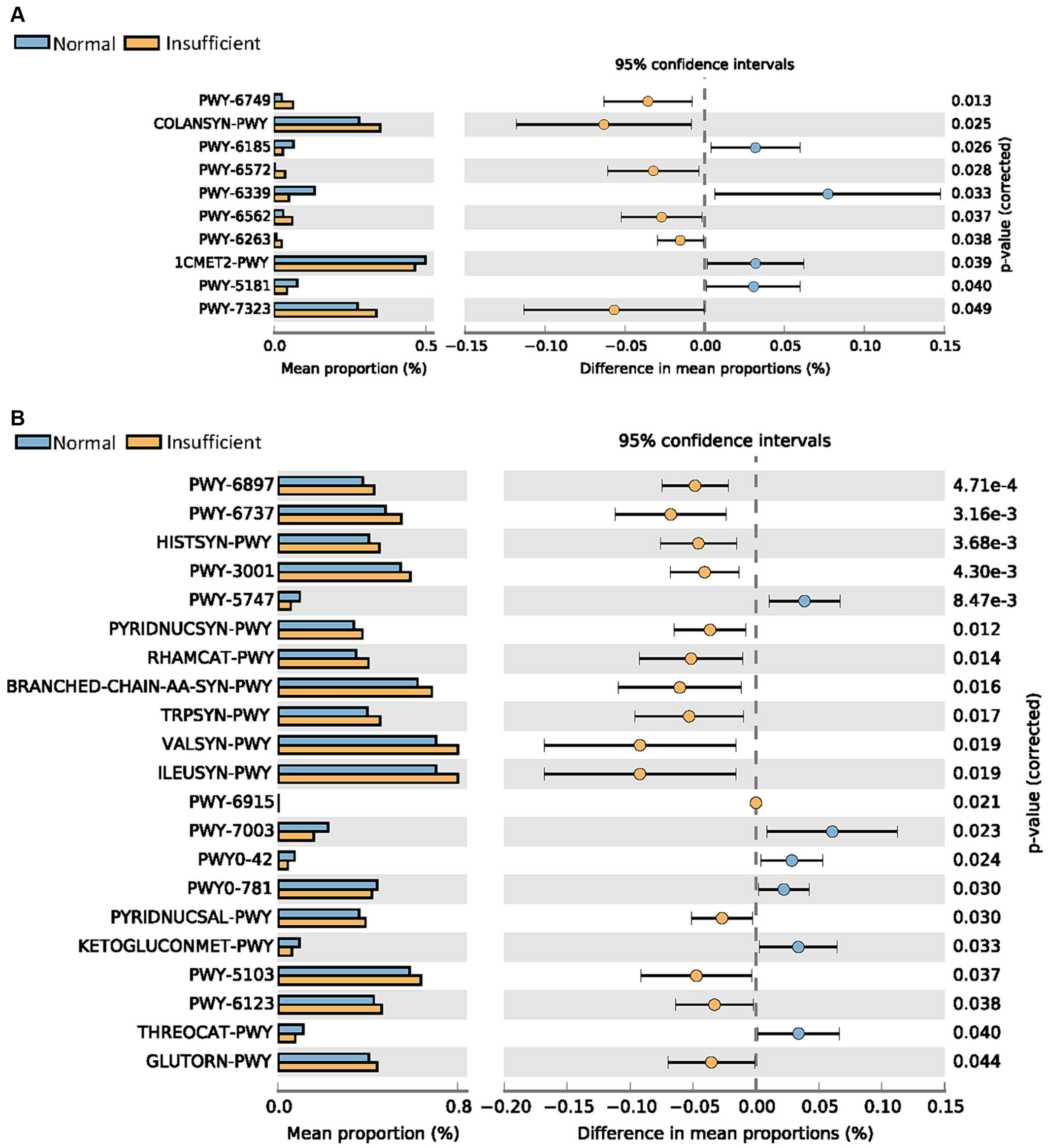

FIGURE 3
Comparisons of metabolic pathways between the vitamin D insufficient group and normal group in the M1 **(A)** and M6 **(B)** phases, respectively.

contrary, in our study, we found that the relative abundance of *Bifidobacterium* was lower and *Bacteroides* was higher in the vitamin D insufficient group in the M1 phase. Inconsistent results might be due to the different timing of vitamin D detection [i.e., the third (around 36 weeks) vs. second (15 ~ 19 weeks) trimester in the study of Talsness et al. (11) and our study, respectively] or racial differences (Dutch vs. Chinese). *Bifidobacterium*, also known as probiotics, is a natural part of the bacterial community in the human body and there is a symbiotic bacteria-host relationship with humans. *Bacteroides*, commonly found in the human gut, assist in breaking down food and producing valuable nutrients and energy that the body needs. Our study indicated that vitamin D insufficient during pregnancy may reduce the beneficial effect of *Bifidobacterium* on infants, but has an auspicious influence on the *Bacteroides* with a beneficial role.

In addition, we also found that the relative abundance of the genus *Bifidobacterium,* as well as *Lactobacillus*, *Ruminococcus*, and *Blautia,* exhibited an upward trend from M1 to M6 phase. *Lactobacillus* metabolizes carbohydrates to produce lactic acid, and there is strong evidence associating various *Lactobacillus* probiotics with several health benefits (23, 24). *Ruminococcus* obtains nutrients by breaking down cellulose that passes through the host's digestive system. *Blautia* is a new functional genus with potential probiotic properties, such as biological transformation, regulating host health, and alleviating metabolic syndrome (25). From 1 month to 6 months old of infants, all these bacteria mentioned above were rising, suggesting that the gut microbiota in infants was developing toward a ever-risingly mature and beneficial direction over time.

Linear discriminant analyses showed that genus *Campylobacter* and its all parent taxa within class *Epsilonproteobacteria* were significantly depleted in the vitamin D insufficient group in the M1 phase. Such association was not observed in the M6 phase.

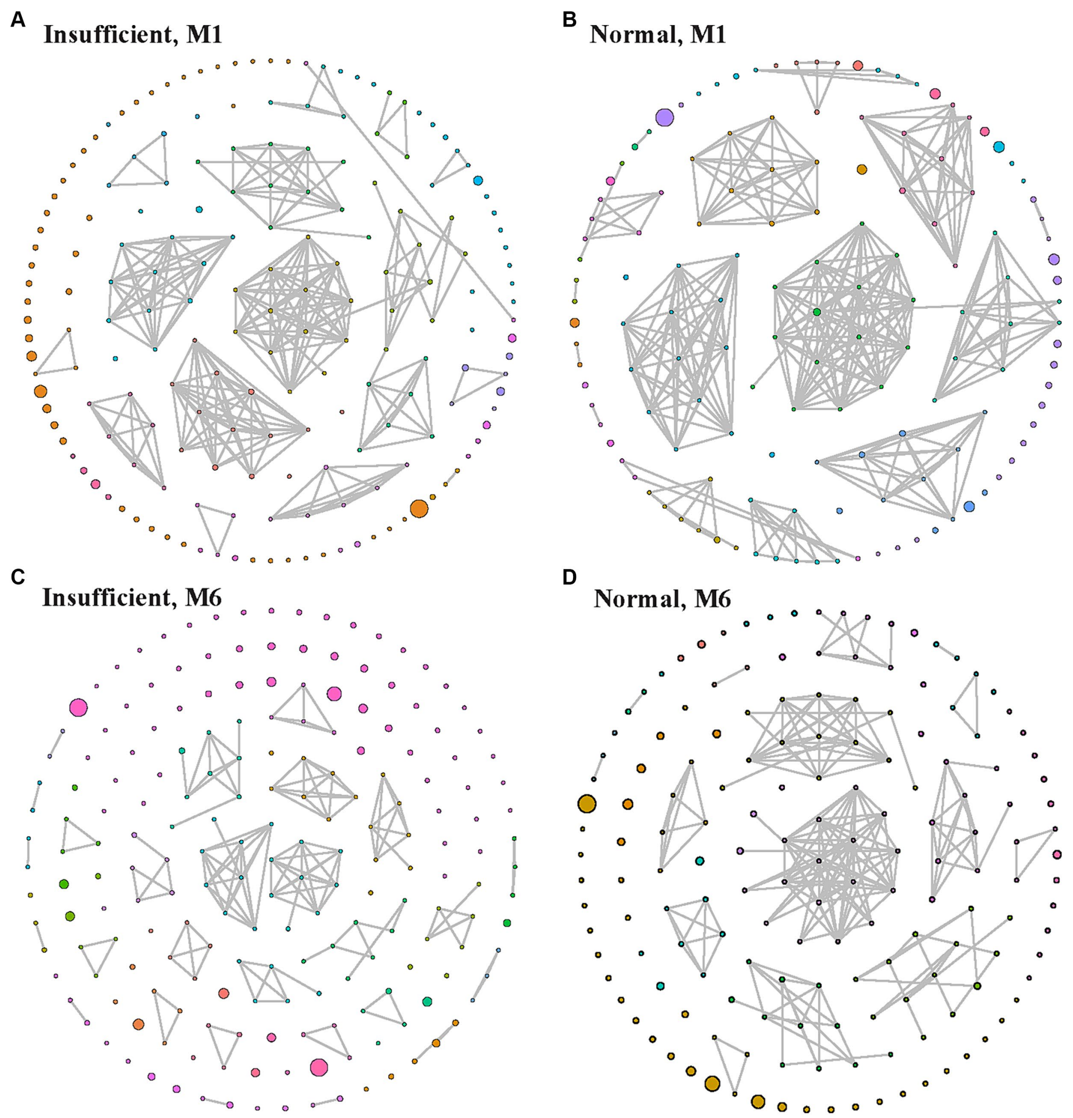

FIGURE 4
Ecological association network in the vitamin D insufficient group **(A,C)** and normal group **(B,D)** groups in the M1 **(A,B)** and M6 **(C,D)** phases, respectively. Each node indicates a genus, with larger node indicating higher relative abundance, and edges between nodes represent their predicted interactions. Different colors indicate different modularity classes.

Campylobacter, considered to be the most common bacterium that leads to human gastroenteritis, is one of the major causes of diarrhoeal diseases in the world, and it can be fatal among very young children (26). Our finding indicated that maternal vitamin D insufficiency during pregnancy might be a protective factor for infants at 1 month old. However, genus *Campylobacter* was only detected in a very small number of samples in the present study; therefore, the association between maternal vitamin D status and genus *Campylobacter* might be spurious. More researches are awaited in the future to confirm our findings.

In the M6 phase, genus *Clostridium* and *Morganella* were enriched, while genus *Epulopiscium* and *Proteus* were depleted in the vitamin D insufficient group. The identified association between the maternal vitamin D status and the relative abundance of genus *Clostridium* in offspring is in agreement with a previous finding that *Clostridium* was enriched in vitamin D receptor knockout mice (7). Besides, Chan et al. (27) found that vitamin D protected against *Clostridioides difficile* infection in mice by restoring macrophage lysosome acidification. *Clostridium* can be found in the human gastrointestinal tract, and its pathogenic species produce exotoxins that cause tissue and nerve necrosis, resulting in lesions. Previous studies have shown that colonization by *Clostridium* in the infant gut in early life was associated with increased risks of wheeze, eczema, and atopic dermatitis (28, 29). These findings suggested that maternal vitamin D insufficiency might be associated with higher levels of *Clostridium* in the gut of infants, which was linked to an increased risk of allergic diseases. Both *Morganella* and *Proteus* are opportunistic pathogens capable of causing major infectious disease problems (30). *Epulopiscium* is not usually found in the human gastrointestinal tract (31). Since the latter three were detected in only a few samples in our study, we would like not to discuss them here. More studies are needed in the future.

Through functional and pathway analysis, we found a large number of pathways enriched in the vitamin D insufficient group in the M6 phase, including multiple amino acid biosynthesis, starch degradation, and purine nucleotides biosynthesis pathways. Amino acids are the building blocks of proteins, which are of primary importance to the continuing functioning of life. Starch degradation is involved in energy metabolism, and nucleotides biosynthesis plays an essential role in DNA replication and transcription (32). These pathways enriched in the vitamin D insufficient group indicated that this group had more active microbial biosynthesis and more abundant microbial community metabolism. However, we do not know what kind of flora these abundant metabolic activities come from and whether it has a positive or negative impact on infant gut health.

Maternal vitamin D may potentially impact infant gut microbiome structure and composition via the following mechanisms. Ooi et al. (8) demonstrated that 1,25(OH)2D3 (i.e., active form of vitamin D) deficiency and vitamin D receptor knockout can affect the gut microbiome by increasing inflammation, and more gut inflammation provides a conducive environment for pathogens to proliferate at the expense of beneficial bacterial species. Vitamin D may also affect the gut microbiome by upregulating innate immunity, producing antimicrobial peptides through macrophages, maintaining the gut barrier function, and altering calcium and phosphate absorption (9). Since an infant's gut microbiota inherited from the mother's to some extent (33), therefore, we supposed that maternal vitamin D influenced maternal gut microbiota, and then be provisioned to fetuses *in utero*, which decided the first microbial colonizers of the infant's gut. However, mechanistic links between maternal vitamin D status and gut microbiome in offspring remain to be elucidated.

The Developmental Origins of Health and Disease (DOHaD) theory believes that many diseases may originate from exposures *in utero* or during childhood. As a result, maternal vitamin D levels during pregnancy, as a modifiable factor, is of great public health significance in the prevention of many diseases, such as allergic diseases, by influencing the maintenance of gut microbiota homeostasis (10). Therefore, vitamin D supplementation is strongly recommended in clinic practice. However, due to the chronicity of vitamin D deficiency and the potential for physiologic adaptations to this condition, a longer supplementation period might be necessary, possibly even commencing prior to pregnancy (34).

Our study, to the best of our knowledge, was the first one to assess the influence of maternal vitamin D status during pregnancy on the gut microbiota in infants in a Chinese population, and newly reported that the dynamic changes of alpha diversity in infant's gut microbiota from 1 to 6 months old were significantly different according to maternal vitamin D status using a prospective study design. Another advantage of this study was that the basic characteristics of the subjects in the vitamin D insufficient group and the control group were similar and comparable, which reduced the confounding of related factors.

One limitation of this study was the small sample size. However, given the sample size, standard deviation and difference in the present study, we would therefore calculated a statistical power of more than 85%, with a level of statistical significance of 5%; moreover, the basic characteristics were comparable in the two groups, strengthening the statistical power. Future studies require larger sample sizes, longer follow-up periods, and assessment of prenatal vitamin D at multiple time points. Secondly, the associations between maternal vitamin D supplementation during pregnancy and the infant's gut microbiota were not studied in our research, since the vast majority of the included women were prescribed to receive a routine vitamin D supplementation of 125 IU per day, combined with calcium supplementation. In addition, unmeasured confounding factors such as maternal dietary habits, hygiene practices, and medication use may also affect infant gut microbiota structure and composition.

5 Conclusion

In brief, this study found evidence of an association between maternal vitamin D status with the gut microbiota structure and composition of infants in Shenzhen, China, notably a lower Pielou's evenness and Shannon diversity, and a higher abundance of *Clostridium*, which might be linked to an increased risk of allergic diseases. Furthermore, function prediction showed that at 6 months of age, infants born to mothers with vitamin D insufficiency had more active biosynthesis and metabolism. These findings highlight that maternal vitamin D status played a pivotal role in shaping the early-life gut microbiota of the next generation. Therefore, it is of great significance to prevent vitamin D insufficiency in women, and policies or recommendations, such as routine vitamin D supplementation of 400 IU or more per day, and more outdoor activities to get adequate sun exposure during pregnancy, for the prevention of vitamin D insufficiency in China is highly essential.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found here: https://db.cngb.org/, China National GeneBank DataBase.

Ethics statement

The studies involving humans were approved by Ethics Committee of Shenzhen Baoan Women's and Children's Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

QS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Visualization, Writing – original draft, Writing – review & editing. YL: Investigation, Validation, Writing – review & editing. TZ: Methodology, Visualization, Writing – review & editing. MX: Investigation, Validation, Writing – review & editing. BX: Formal analysis, Methodology, Visualization, Writing – review & editing. MW: Supervision, Writing – review & editing. YZ: Data curation, Funding acquisition, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Improving growth in preterm infants through nutrition: a practical overview

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The primary purpose of this practical overview is to provide a practical update on appropriate nutritional strategies to improve growth in preterm infants. Current recommendations for improving preterm growth concern both macronutrients and micronutrients, with tailored nutrition since the first days of life, particularly when fetal growth restriction has been reported. Human milk is undoubtedly the best nutrition for all newborns, but, in some populations, if not adequately fortified, it does not adequately support their growth. In all preterms, growth should be correctly monitored weekly to intercept a negative trend of growth and implement nutritional strategies to avoid growth restriction. Similarly, growth should be accurately supported and monitored after discharge to improve long-term health consequences.

KEYWORDS

extra-uterine growth restriction, parenteral nutrition, human milk, prematurity, fortification, fetal growth restriction

1 Introduction

Preterm infants have postnatal growth windows that are neurodevelopmentally sensitive both before and after the infant reaches term (1): increased energy and lipid intake in the early postnatal weeks has been linked to better neurodevelopmental outcomes, including a lower incidence of brain injury in magnetic resonance imaging (MRI) and a decreased level of brain dysmaturation at term equivalent age (with a more pronounced association for the gray matter) (2), and better developmental quotient scores (3). Better language developmental scores have been demonstrated in infants who received more proteins (4), but an excessive load of proteins may be harmful to neonatal metabolism and later neurodisability and has few short-term benefits for growth (5).

Indeed, an overly fast weight increase in term newborns is linked to a heightened risk of metabolic syndrome, a condition that is common in ex-preterm infants in later life (6).

The large observational EPICure study suggested that the key growth phase for metabolic health occurs much later in childhood (in preschool age) (7). Therefore, it can be hypothesized that promoting growth in early infancy could potentially eliminate the need for later catch-up growth, leading to improved neurodevelopmental outcomes without compromising future metabolic health (8).

The primary purpose of this practical overview is to provide an update on appropriate nutritional strategies to improve growth in preterm infants. We also provided some details about the tailored nutrition that some categories require, such as for the case of fetal growth restriction.

2 Methods

In order to create this narrative review, the terms "nutrition" and "neonate" were matched with "growth" in the PubMed database. All English-language papers that were recovered and released from 1990 to 30 June 2024 were analyzed without imposing restrictions on date, country, study design, outcomes, or inclusion/exclusion criteria. The reference lists of the identified papers were further checked, and each author identified additional references for this review based on their expertise in the relevant topic.

3 Macronutrients in the early postnatal phase (parenteral nutrition)

3.1 Glucose

Glucose is the primary energy source for the central nervous system and, thus, for its development. Preterm neonates have smaller hepatic glycogen stores at birth, and the proportion of glycogen concentration only rises after 36 weeks of gestation, making them more susceptible to developing hypoglycemia. Different thresholds for hypoglycemia have been proposed, but little is known about which one produces worse short-and long-term impacts (9, 10).

On the other hand, preterm infants are also often prone to hyperglycemia, which is associated with increased mortality and morbidity early in life due to the consequences of higher glucose levels in different organs (11).

The glucose infusion rate in preterm nutrition is most relevant in the critical early postnatal phase and in prescribing adequate parenteral nutrition. Once exclusive enteral nutrition is established, glucose intakes are generally more easily controlled by the infant's own metabolic response provided there are no comorbidities.

Continuous glucose monitoring (CGM) offers a quantifiable measure of neonatal stress that reflects increased glucose variability during newborn care procedures (12). Utilizing CGM devices, combined with protocols for adjusting glucose infusion, might assist in keeping blood glucose levels within proposed ranges and decrease the frequency of blood sampling (13, 14).

The amount of glucose to be provided in preterm infants should start with 5.8–11.5 g/kg/day, considering the phase of illness and the supply of glucose and other macronutrients via parenteral and enteral nutrition. From day 2 onwards, glucose intake should gradually increase over 2–3 days up to 11.5–14.4 g/kg/day (15).

Excessive glucose intake should be avoided as it can lead to hyperglycemia (>180 mg/dL), which has been linked to increased morbidity and mortality (16).

3.2 Lipids

Lipids are a crucial energy source for premature infants and are vital for the intricate processes essential for normal central nervous system development (17).

A 25–50% lipid intake of non-protein calories is often advised in completely parenterally fed patients. Essential fatty acids (EFAs) are provided by lipids, which also aid in the transport of the lipid-soluble vitamins A, D, E, and K. Parenteral lipid intake in preterm newborns should not go beyond 4 g/kg/day. Intravenous lipid emulsions can be begun at the time of parenteral nutrition (PN) commencement and no later than day two following birth (18).

The delay in parenteral lipid introduction has been negatively related to weight gain up to day 28 of life and up to 36 weeks of postmenstrual age, independently from gestational age at birth, sex, and being small for gestational age (19).

Furthermore, early cumulative lipid intake in the first month of life has been associated with significantly greater cerebellar volume in a cohort of VLBW (Very Low Birth Weight, born weighing less than 1,500 g) infants on MRI obtained at term-equivalent age (20).

Newer multicomponent lipid emulsions (MLEs) in the last years, containing olive oil, fish oil and medium-chain triacylglycerols oil in addition to standard soybean oil, should be preferred to avoid administrating high levels of ω-6, which can increase proinflammatory eicosanoids biosynthesis leading to increased oxidative stress, and low levels of ω-3 as contained in pure soybean-based lipid emulsions (21, 22).

Indeed, higher ω-3 fatty acids docosahexaenoic acid (DHA) levels seemed to be associated with larger deep gray matter, cerebellar, and brainstem volumes at MRI studies performed at near-term age in a cohort of preterm neonates born <32 weeks GA. Kamino et al. reported that higher ω-3 and lower ω-6 fatty acid levels correlated with larger volumes: larger cortical and deep gray matter, cerebellar, and brainstem volumes by term age were associated with improved language scores and larger cerebellar and brainstem volumes with improved motor scores in pre-scholar age (30–36 months corrected age) (23).

MLEs might improve growth and neurological outcomes, delivering fats for brain growth that the traditional soybean-based lipid emulsions (SLEs) fail to provide. Vlaardingerbroek et al. demonstrated in VLBW infants that an MLE was well tolerated and associated with improved growth during the first 28 days of life compared to the pure SLE (24).

Then Costa et al. confirmed evidence from a randomized controlled trial that an MLE is associated with improved head circumference growth compared to a pure SLE from birth to 36 weeks PMA or at discharge (25).

3.3 Proteins

There is still debate over the ideal dose of amino acids to start with and the maximum amount that should be consumed because nutritional practices must prevent toxicity brought on by providing nutrients in excess of the preterm body's ability to use them (26).

The estimated daily intake of amino acids for the fetus is 3 to 4 g per kilogram of body weight, which is considered to be sufficient for fetal growth and brain development (27).

Conversely, it is unknown how many proteins ELBW (Extremely Low Birth Weight, born weighing less than 1,000 g) infants should receive to support their growth and development, particularly in the first few days of life (28).

The amino acid supply should start on the first postnatal day with at least 1.5 g/kg/day to achieve an anabolic state, and then from postnatal day 2 forward, the parenteral amino acid intake should range from 2.5 g/kg/day to 3.5 g/kg/day and should be combined with non-protein intakes greater than 65 kcal/kg/day and sufficient vitamin intakes (29).

Indeed, almost 3.5 g/kg/body weight of amino acid is needed to retain 350 mg of nitrogen, enabling 17 g/kg/day growth (30).

The resting energy expenditure (REE) should also be considered: the majority of preterm infants have a greater REE (+140%), while full-term neonates exhibit lower needs (+47%). Furthermore, it is well known that comorbidities raise energy consumption, with consequent increased metabolic need, such as in the case of increased oxygen consumption of injured lungs (31).

Beyond observational studies reporting the association between higher levels of protein intake and better growth and neurodevelopment (32, 33), a double-blind, placebo-controlled trial (Protein Intravenous Nutrition on Development – ProVIDe trial) randomized neonates with birth weight lower than 1,000 grams to receive either amino acids at a dose of 1 gram per day (intervention group) or placebo in addition to usual nutrition for the first 5 days of life. The number of infants who survived without neurodevelopmental impairment at 2 years of life did not increase when additional parenteral amino acids were administered, but a higher relative risk of patent ductus arteriosus (RR 1.65; 95% CI 1.11–2.46) and refeeding syndrome (RR 1.64; 95% CI 1.09–2.47) were observed in this group (34).

4 Micronutrients in the early postnatal phase (parenteral nutrition)

4.1 Electrolyte supplementation

Electrolyte imbalances should be avoided since they may cause neurological morbidities and are related to growth failure (35, 36).

Refeeding syndrome (RS), which has been associated with high intravenous amino acid consumption in the setting of inadequate electrolyte supply (especially potassium and phosphorus), is widespread in ELBW infants, particularly in those who are small for gestational age (SGA), defined as a birth weight of less than the 10th percentile for gestational age (37–40). In this population, severe hypophosphatemia has been correlated to an elevated risk of intraventricular hemorrhage, and RS has been linked to a three-fold increase in death. Phosphate and calcium optimization in intravenous solutions may lessen RS and its effects (40). The incidence of hypophosphatemia in different cohorts of preterm infants ranges from 7 to 56%: it is difficult to compare the incidence across the different thresholds (<4.96 mg/dL, <4.65 mg/dL, <4.5 mg/dL, <4.3 mg/dL, or < 4 mg/dL) (41).

The balance of calcium and phosphorus requires simultaneous control of calcium and phosphorus intake (42). Lower calcium (Ca), phosphorus (P), and magnesium (Mg) intakes are advised for preterm newborns on early PN during their first few days of life than for developing stable preterm infants. Early PN should contain a molar Ca:P ratio below 1 (0.8–1.0) to lower the prevalence of early postnatal hypercalcemia and hypophosphatemia while protein and energy intakes are progressively increased (43).

Concerning sodium (Na), primary sodium depletion is common in preterm children born before 34 weeks GA due to insufficient proximal and distal tubule sodium reabsorption, which is worsened by pharmacological side effects from substances like diuretics (44).

The major sources of salt for the preterm neonate include the prescribed PN, blood product transfusions, flush solutions, and saline infusions. Supplementing parenteral feeding with sodium glycerophosphate since the first day of birth considerably reduced the incidence of hypophosphatemia, according to Bustos Lozano's findings, who compared a prospective cohort study of infants ≤1,250 g receiving sodium glycerophosphate from the first day of life and a previous subcohort supplied with phosphate after 48 h (45, 46).

Hyponatremia (<135 mEq/L) is not as benign as previously thought since sodium is an essential ingredient found in bone, cartilage, and connective tissue; it is also required for the correct development of the central nervous system (47). Sodium supplementation could have a positive impact on weight gain (36, 48).

The amount of 1–3 mmol of sodium and 1–3 mmol of potassium required per intake of 100 kcal for newborns and children beyond the neonatal stage is mostly based on empirical findings (44). In addition to the risks of metabolic acidosis and hyperchloremia, supplementing sodium losses only with sodium chloride solutions could expose patients to excessive cumulative chloride consumption (35).

Sodium lactate or sodium acetate-based solutions, rather than sodium chloride solutions, could prevent these undesirable metabolic effects (49).

Moreover, potassium (K) intake should coincide with the delivery of amino acids to prevent refeeding syndrome. As a result, enough K intake is also necessary when supplying early high amino acids and energy with early PN (44).

On the other hand, it can be crucial that sizeable quantities of sodium and potassium be provided with medications (such as antibiotics) and minerals that are prepared as Na or K salts (e.g., phosphates) (44).

Considering SGA infants, potassium and phosphorus intakes should be set at sufficient levels from birth onwards because they have a high risk of early hypokalemia and hypophosphatemia (38).

4.2 Vitamins

A sufficient vitamin intake is essential for correct growth and development. Among fat-soluble vitamins, vitamin A plays an essential role in growth: preterm infants on PN should receive 700–1500 IU/kg/day of vitamin A, and VLBW neonates often suffer from vitamin A deficiency. Considering that there are significant losses of vitamin A when administered with a water-soluble solution, parenteral lipid-soluble vitamins should always be administered with a lipid emulsion when possible (50).

Furthermore, vitamin A deficiency has been related to a higher risk for bronchopulmonary dysplasia (BPD) and retinopathy of prematurity (ROP) (51, 52).

Vitamin D has a role in growth because it increases intestinal absorption of calcium and phosphorus and enhances bone mineralization. The available research, as well as most guidelines, recommend an intake of 400 IU daily of vitamin D as adequate for bone health in preterm and full-term infants (53), whereas in Europe, according to the European Society for Pediatric Gastroenterology, Hepatology, and Nutrition (ESPGHAN) guidelines, the authors suggest a higher supplementation of vitamin D for preterm infants, reaching up to 800–1,000 IU/day, to rapidly correct the fetal low plasma levels of vitamin D (54). Enteral vitamin D supplementation in preterm or LBW infants allows an increase in weight-for-age z-scores and height-for-age z-scores at 6 months, according to a recent meta-analysis about infants who received vitamin D (200 IU to 800 IU per day). However, there were no effects on neurodevelopmental outcomes in the vitamin D supplementation groups (55).

Among water-soluble vitamins, folic acid (FA, also known as vitamin B9) has a crucial role in promoting fast cell division and proliferation, which is crucial for the growth and development of the fetus and, accordingly, of the preterm neonate. Preterm infants should receive 56 mcg/kg/day of folic acid (50).

Indeed, in the first two to three months of life, preterm neonates have low blood FA levels: rapid growth, an increase in erythropoiesis, the use of antibiotics or anticonvulsants, and intestinal immaturity with malabsorption are some of the factors that may have an impact on the hepatic FA reserves, potentially resulting in insufficiency (56, 57).

Maternal supplementation during pregnancy and smoking are the two most significant variables affecting blood FA levels during the first month of life, considering that smoking exposure during pregnancy is generally associated with lower folate levels (58, 59). Women who smoked cigarettes during pregnancy and took higher-dose folic acid supplements delivered infants with better fetal growth than smokers who took standard-dose folic acid (60).

4.3 Minerals: zinc and iron

Zinc (Zn) is a mineral essential for growth due to the increased enzyme activity and synthesis of proteins for tissues: clinical manifestations of its deficiency are growth failure, increased infection rate, and a characteristic skin rash (61).

Zinc should be provided with PN at a 450–500 mcg/kg/day dose in preterm infants to match *in-utero* growth rate. Standard trace element preparations do not supply this amount, and additional Zn has to be added to PN fluid in the preterm infant or those patients with high Zn losses (e.g., from diarrhea, stoma losses, or severe skin disease) (62, 63).

Furthermore, zinc supplementation for more than 2 weeks seems to improve head circumference growth (64), and this preliminary result has also been confirmed by a positive correlation between zinc levels at 28 days of life and next motor scores at 12 months of life (65).

Any preterm infant who is not developing normally despite receiving an apparently adequate amount of energy and macronutrients, who has not consistently consumed zinc-fortified human milk or formula made specifically for preterm infants, who underwent any gastrointestinal resection or injury, or who is receiving diuretic therapy, should be investigated for zinc deficiency (66).

LBW infants are also at high risk of iron deficiency due to low iron stores at birth and higher iron requirements due to rapid growth (67). Enteral iron supplementation in these infants increases linear growth (length) but has little effect on weight, head circumference, or cognitive development, according to a meta-analysis including eight trials. However, the anthropometric tools used in the different papers vary greatly: thus, it is important to proceed with care when evaluating these results (68).

5 Enteral nutrition

Early enteral feeding can prevent villous atrophy, reduce intestinal permeability, and improve the microbiota (69–71). Observational studies showed that standardizing enteral feeding practices in the Neonatal Intensive Care Unit (NICU) improves preterm infants' ability to receive adequate enteral feedings. Unit recommendations allow for short PN duration and hospital stays to lower the incidence of necrotizing enterocolitis (NEC) and maybe improve neurological development (72).

Recent research indicates that enteral feedings can be pushed by up to 20–30 mL/kg/day (where clinically acceptable) in the days following delivery (72–74). Early removal of peripheral and central catheters reduces discomfort, infection risk, and PN-related problems in newborns (75, 76).

6 Human milk, fortification, and growth

Human milk is recommended as the natural feeding for preterm infants and as a cost-efficacy strategy for lowering morbidity and economic burdens. Although related to a slower weight gain than formula feeding, human milk is associated with better recovery of body composition through fat-free mass deposition, which may eventually result in superior metabolic and neurodevelopmental outcomes (77, 78).

To optimize growth with human milk in general (and donor milk specifically), an adequate fortification of human milk is recommended to avoid negative trends in weight Z-scores in VLBW infants (79). Unfortified human milk at usual feeding volumes (160 mL/kg/day) does not meet the recommended energy provision (110–130 kcal/kg/day) or enteral protein intake of 3.5–4.5 g/kg/day for VLBW infants (80).

Furthermore, pasteurization and milk banking processes can reduce donor milk's fat and protein content (81).

Fortification is generally meant using multi-nutrient fortifiers rather than single-nutrient fortifiers. When adopting individualized strategies of fortification, single-nutrient fortifiers are useful for adjusting the amount of protein, carbohydrates, lipids, and calories (82).

TABLE 1 A possible method to adjust the fortification of HM according to blood urea nitrogen (BUN) values is to assess it at least once weekly.

	Level of fortification according to BUN levels	
BUN level	Multi-nutrient fortifier	Only-protein fortifier
<10 mg/dL	4%	0.4% (If low BUN levels persist, increase up to 0.8% and then up to 1.2%)
10–25 mg/dL	4%	–
>25 mg/dL	2% (If high BUN levels persist, reduce to 1%)	–

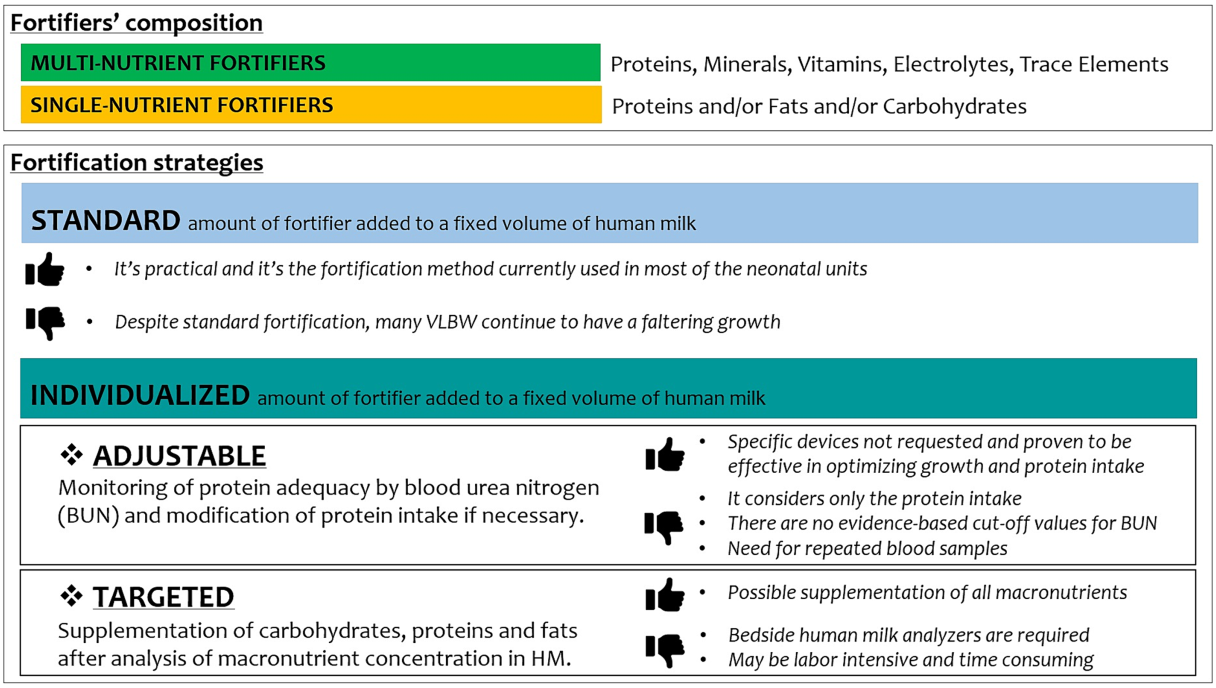

FIGURE 1
Fortifiers' composition and human milk fortification strategies.

An example of how to use a combination of multi-nutrient and single-nutrient fortifiers in a regimen of adjustable fortification is reported in Table 1.

Then, different types of fortifiers are available: bovine or donkey milk-based fortifiers or human milk-derived fortifiers with powder or liquid formulations, but there is still no consensus about the best option (80, 83).

A recent randomized controlled trial demonstrated no clinically relevant differences in body composition (adipose tissue and non-adipose tissue mass) at whole-body magnetic resonance imaging at term age in preterm babies <30 weeks GA who received a macronutrient-equivalent exclusive human milk diet (human milk formula in case of lack of own mother's milk and human milk derived fortifier) compared with a diet containing cow milk products (preterm formula in case of lack of own mother's milk and cow milk-based fortifier) (84).

However, a recent meta-analysis suggests that an exclusive human milk diet could possibly be associated with decreased mortality with no association with major complications (NEC, BPD, sepsis, and ROP) (85).

Along with deciding the type of fortifier to use, it may be difficult and is up for controversy in the NICUs when to add fortifier to human milk (72). Considering the limited published data on this topic, whether early introduction of fortification at an enteral feed volume of ≤40 mL versus delayed at ≥75 mL/kg/day improves growth or influences adverse feeding outcomes is still reason for debate (86).

Recent studies promote a move toward an earlier fortification (30 mL/Kg/day) to obtain a faster regain of birth weight and higher length and head circumference velocity without increasing the risk of feeding intolerance and NEC (87).

Evidence of the safety of early fortification, even when started at the first feed, is emerging (88).

Among fortification strategies, adjustable (based on BUN values) or targeted (based on human milk analysis) increased growth velocity of weight, length, and head circumference as compared to standard fortification (Figure 1) (89).

A tailored fortification of human milk could result in higher weekly weight gain and daily growth rates, rather than a standard approach, as reported by Morlacchi et al., with osmolality values after target fortification remaining within recommended limits (90).

7 Tailored nutrition and growth in different subcategories

It is well known that within the preterm population, several categories are distinctive in their needs and nutritional risk. Among them, VLBWs, and even more so ELBWs, or premature infants with a history of fetal growth restriction (FGR), are at risk of impaired growth and need tailored nutritional interventions (33). This specific consideration is critical both in the early stages of parenteral nutrition but becomes even more so in the often-difficult transition between parenteral and enteral and then in exclusive enteral nutrition.

Most guidelines on pediatric parenteral nutrition concluded that standard PN solutions should be utilized rather than individualized PN solutions in most neonates, including VLBW ones, according to current studies. An individually tailored PN solution should be used when the nutritional needs cannot be met by standard PN formulations (i.e., critically ill and metabolically unstable patients, such as those with abnormal fluid and electrolyte losses, and infants needing PN for extended periods, such as those with short bowel syndrome) (91).

Tailored nutrition should consider that the fetus exhibits sex-specific growth differences relatively early during pregnancy. Therefore, considering that boys born preterm are recognized to be at higher risk of adverse outcomes than girls born preterm (92), the nutritional needs of males and females should also be different. However, there are few available studies about sex differences in neonatal outcomes, neonatal body composition and metabolism, and nutritional interventions (93–96).

Human milk composition studies confirmed the possible sex differences in nutritional requirements: (a) higher calories, carbohydrates, and fats provided to males than females; (b) same protein levels; (c) higher glutamine, glycine, cysteine, and tyrosine levels in males; and (d) higher taurine levels in females. From this point of view, the mother's own milk (MOM) would give sex-specific development benefits, which are most likely due to the calibration of a mother's milk depending on her newborn's sex. Formula composition does not vary with baby gender, which might explain why body composition data promotes the use of OMM over formula (97).

Based on the observational outcome results following a randomized controlled trial of early aminoacid administration in preterm infants, van den Akker et al. reported that boys had a normal outcome significantly more often if aminoacids were administered from birth onward (OR 6.2, 95% CI 1.0–38.0) (93). Conversely, Alur et al. hypothesized that female ELBW infants may need higher protein and calories than male ones and failed to obtain different discharge outcomes between the two sexes despite differences in protein and calorie provision (98). Larger prospective studies of neonatal nutritional interventions are needed to focus on these aspects and should consider infant sex (96).

Furthermore, some SGA preterm newborns have a history of fetal growth restriction (FGR), a condition where the growth of the fetus during pregnancy is lower than expected based on the race, gestational age, and sex of the baby. This is thought to be the result of persistent malnutrition throughout the fetal period and is caused by placental dysfunction. Therefore, the refeeding syndrome may be to blame for the electrolyte imbalance seen in these newborns. In VLBW infants, the umbilical artery resistance index may be a helpful indicator of the potential emergence of hypophosphatemia resembling the refeeding syndrome. In these cases, a more aggressive nutritional strategy should be avoided; moreover, close monitoring of blood phosphorus and potassium levels, as well as early intervention, is mandatory (99).

8 The role of fetal growth restriction

Fetal Growth Restriction (FGR) may arise due to dysregulation or imbalance in the complex systems that regulate fetal growth (Figure 2) (100).

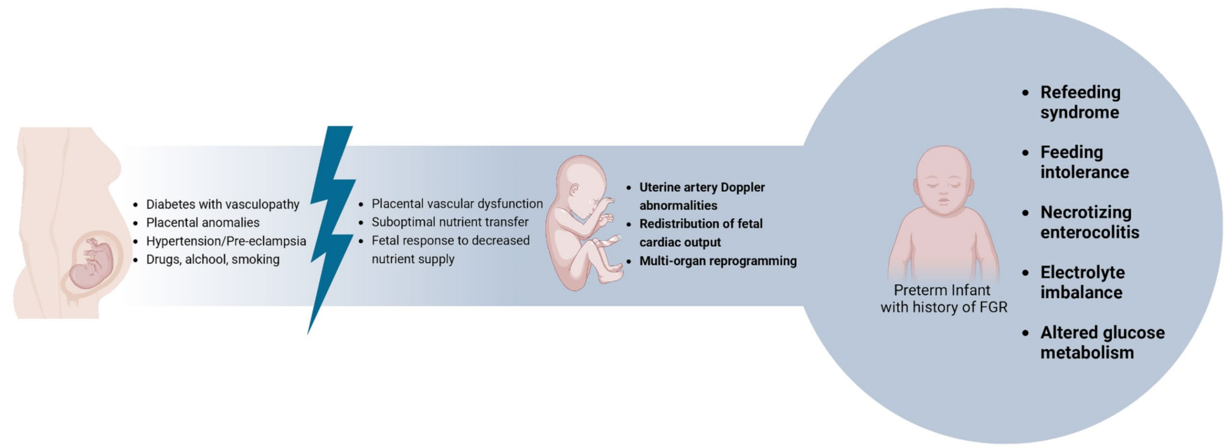

FIGURE 2
Fetal growth restriction and related risks for preterm infants.

Anthropometric measurements and functional parameters, such as Doppler abnormalities, are used to distinguish newborns with FGR from those who are constitutionally SGA. However, studies suggest that infants with birth weight below the 3rd percentile compared to reference curves are at an increased risk of adverse short-and long-term outcomes, whether there were functional abnormalities during pregnancy (100, 101).

The fetus exposed to intrauterine growth restriction undergoes multi-organ reprogramming due to low placental blood flow. This results in the redistribution of fetal cardiac output to vital organs, leading to various postnatal complications, including gastrointestinal ones (102–104).

Numerous studies have shown that newborns with FGR are at greater risk of experiencing poor food tolerance (104), necrotizing enterocolitis (105), altered glucose metabolism (106, 107), and electrolyte anomalies after birth (108). Currently, there are no established guidelines to assist us in managing the nutrition of newborns with FGR. However, given the extremely delicate nature of these infants, it is crucial to provide appropriate and timely care after birth to prevent and treat any perinatal complications using effective nutritional strategies (102).

There has been much discussion regarding the right timing for introducing enteral nutrition. Tewari et al. conducted a randomized study on a group of premature infants with gestational age below 32 weeks who showed Doppler evidence of FGR. The study concluded that newborns who were fed early (within the first 2 days after birth) achieved full enteral feeding more quickly than newborns fed later (5–6 days after birth or later). Additionally, there were no significant adverse effects such as NEC (109).

Similarly, Aradhya et al. conducted a retrospective study that showed that starting early enteral feeding within 24 h of life is safe if there are no warning signs or symptoms. This practice is also linked with achieving full enteral feeding at a median age of 9 days (110).

It is crucial to assess both the timing of the start of enteral nutrition and the speed of daily increment to achieve full enteral feeding and evaluate food tolerance. In a large randomized controlled trial conducted by Dorling et al., premature infants weighing less than 1,500 g were divided into two groups: rapid increases (30 mL/kg/day) of enteral nutrition and slow increases (18 mL/kg/day). The two groups were compared, and no significant differences were observed regarding survival, survival without neurodevelopmental disability, and incidence of NEC (111). It is crucial to highlight that 90% of the newborns enrolled in the study were fed with any human milk. Among the infants who were formula-fed, only 40% of babies in the rapid-rising group survived without neurodevelopmental disabilities, compared to 70% in the slow-rising group (111).

Interestingly, Dani et al. analyzed the effects of human milk (HM), fortified HM, and formula milk on splanchnic oxygenation in preterm infants. Mother's own milk feeding did not impair the gut tissue oxygen delivery extraction balance, and this might represent a protective mechanism against the development of hypoxic–ischemic injuries (112). Previously, Grometto et al. also studied near-infrared spectroscopy for monitoring the effects of feeding regimens on the cerebral and splanchnic regions: they found that gut oxygenation did not change during preterm formula feeding and increased after it (113).

Moreover, a research study conducted by Surmeli Onay et al. examined splanchnic oxygenation in a group of prematurely born infants affected by FGR. The aim was to determine if there were any significant differences in feeding tolerance between continuous feeding and intermittent feeding (bolus in 10 min). The study concluded that being fed by enteral route, rather than the feeding method, was the critical factor affecting splanchnic oxygenation and, therefore, feeding tolerance (114).

9 Tailored nutrition and extra-uterine growth restriction

The parenteral to enteral transition is a crucial phase for preterm infants, because up to 46% incidence of poor growth occurs during this period (115), and thus it's important to individualize nutrition based on the needs and growth trajectories of the patient (Table 2).

Extra-uterine growth restriction (EUGR) is a term commonly utilized to describe poor growth in these infants, but there is no consensus on the type of definition to use. Two types of definitions are mainly available in the literature:

1. "Cross-sectional" definitions, that identify a cut-off below which the neonate is labeled as EUGR at a specific time-point (traditionally, as weight below the 10th percentile at discharge) (116);
2. "Longitudinal" definitions that describe the growth trends, reporting the differences between two-time points, usually from birth (i.e., weight loss more than one or two standard deviations from that at birth) (117, 118).

Recently, a new approach of "true EUGR" has been proposed, considering EUGR always cross-sectionally or longitudinally, but including only infants with appropriate age weight (119).

We believe that it's crucial to have strict monitoring of preterm infants' growth during the hospital stay, calculating Z-scores in weight and head circumference from when physiological weight loss is over to identify EUGR early and improve outcomes, according to different studies (118, 120, 121).

Measurements should be plotted on a growth chart derived from a growth standard appropriate to the population in question rather than the standard birthweight-derived charts. A standardized approach to providing enteral and parenteral nutrition has been shown to improve growth (8).

10 Possible causes of inadequate growth and strategies

The cause of growth restriction in preterm infants is multifactorial, but it has been postulated that nutrition accounts for around 50% of the variation in early postnatal growth, and the real amount of milk provided and tolerated plays a key role (122).

Furthermore, we do not know well the growth target we want to reach and that the presence of other comorbidities must be taken into consideration.

TABLE 2 Current recommendations for improving preterm growth.

Macronutrients			
Glucose	Start with 5.8–11.5 g/kg/day (15)	Hyperglycaemia (>145 mg/dL) is associated with increased morbidity and mortality (16)	Continuous glucose monitoring (CGM) might assist in keeping blood glucose levels within the proposed ranges (13, 14)
Lipids	A 25–50% lipid intake of non-protein calories is often advised (18)	Parenteral lipid intake in preterm newborns should not go beyond 4 g/kg/day (18)	Newer multicomponent lipid emulsions (MLEs) should be preferred (21)
Proteins	Start with at least 1.5 g/kg/day to achieve an anabolic state (29)	From day 2, intake should range from 2.5 g/kg/day to 3.5 g/kg/day (29)	Protein intake should be combined with non-protein energy intakes greater than 65 kcal/kg/day (29)
Micronutrients			
Electrolyte supplementation	Lower Ca, P, and Mg intakes are advised during PN's first few days (43)	Primary Na depletion is common in preterm children born before 34 weeks GA (44)	SGA infants have a high risk of early hypokalaemia and hypophosphatemia (38)
Vitamins	Infants on PN should receive 700–1500 IU/kg/day of vitamin A (54)	Enteral vitamin D supplementation in preterm allows an increase in weight and height at 6 months (55)	Folic acid has a crucial role in the preterm neonate. Preterm infants should receive 56 mcg/kg/day of folic acid (50)
Minerals	Zinc should be provided with PN at a 450–500 mcg/kg/day dose in preterm infants to match the *in-utero* growth rate (62)	Zinc supplementation for more than 2 weeks seems to improve head circumference growth (64)	Enteral iron supplementation in LBW increases length but has little effect on weight, head circumference, or cognitive development (68)
Tailored nutrition			
Fetal growth restriction	In VLBW infants, a history of FGR may be linked to the emergence of hypophosphatemia (38)	Starting early enteral feeding within 24 h of life is safe if there are no warning signs or symptoms (110)	Feeding tolerance and protective effects against comorbidities were associated with mother's milk and not with formula (97)
Human milk fortification	Adequate fortification of human milk is necessary for VLBW infants (79)	Adjustable or targeted fortification strategies increase growth velocity compared to standard fortification (82)	Recent studies promote a move toward an earlier fortification (30 mL/Kg/day) to obtain an improved growth velocity (87)
Extra-uterine growth restriction	Parenteral to enteral transition is crucial: up to 46% incidence of poor growth occurs during this period (115)	Monitoring preterm infants' growth during the hospital stay is crucial to detect early EUGR (118, 120, 121)	Measurements should be plotted on a growth chart derived from a growth standard appropriate to the population in question rather than the standard birthweight-derived charts (8)

Independent risk factors of EUGR are moderate-to-severe bronchopulmonary dysplasia (BPD), gestational hypertension, cesarean section, cumulative fasting time, time required to achieve an adequate amount of enteral feeding, and hemodynamically significant patent ductus arteriosus (hsPDA) (123). In particular, infants with BPD seemed to show an unsteady pattern of growth compromise during the NICU stay (124).

Among minor factors associated with failure to thrive in preterm infants, gastroesophageal reflux (GER) is a common finding, with difficulty in differentiating between physiologic GER and GER disease (GERD) (125–127). A simple positioning approach can sometimes solve the problem, whereas there is little empirical evidence to support using feed thickeners in this age category (128, 129). Although a clear link between thickened feeds and undesirable gastrointestinal effects been not still found (130, 131), there is growing clinical concern regarding the use of thickened fluids in preterm infants and the development of NEC (132–134).

When these first measures (thickened formulas and physical approaches) are ineffective, Multichannel Intraluminal Impedance and pH Monitoring (MII/pH) with symptom correlation approaches may be necessary (125, 126). In the case of acid GER, alginates can represent a physical barrier to reducing esophageal acid exposure frequency (135, 136).

When preterm infants reach term or are beyond the full term, a cautious trial of acid suppression may be considered, carefully assessing the advantages over the potential risks (constipation, osteopenia, nausea, fatigue, abdominal pain, small intestinal bacterial overgrowth, necrotizing enterocolitis) (127, 137). Empiric treatment should not be used when arching/irritability is present, considering that extreme prematurity and neurologic impairment may more likely cause the arching/irritability (138).

Sometimes, factors associated with faltering growth are behavioral, such as poor milk drinkers, fussy eaters, and infants with oral aversion (139).

When the amount of milk administered seems to be adequate, other medical conditions should be ruled out (e.g., heart disorders, cystic fibrosis, malabsorption, or metabolic anomalies) (139). The impact of chronic conditions such as BPD and hsPDA should be weighed, considering the impact of administering large amounts of liquids to provide adequate nutrients in these infants (44, 140, 141).

If inadequate growth persists, once the term is reached, high-energy isocaloric infant formulas are widely used to provide adequate nutrients, restricting the fluids supplied and combatting poor growth. These high-energy feeds (1 kcaL/mL) are not designed specifically for formerly preterm infants, and the literature lacks clear evidence about their use in this age category. When feeding intolerance also coexists (defined as the inability to digest enteral feedings associated with increased gastric residuals, abdominal distension, vomits and/or regurgitations, abnormal feces, and associated cardiorespiratory events) (142, 143), an extensively hydrolyzed protein high-energy isocaloric infant formula could be indicated, although the lack of evidence. These formulas could be useful because they enhance energy and protein levels without mixing the milk with further products and reduce the risk of bacterial contamination and preparation errors.

11 Anthropometric follow-up of preterm infants

Early detection of post-natal growth retardation is essential in order to act promptly by fortifying human milk, adjusting the nutrient composition and caloric intake, or changing feeding methods. Anyway, preterm infants have a significant risk of metabolic disease due to their intrinsic vulnerability: they have a different body composition than their term peers, and monitoring body composition changes appears to predict long-term effects on health outcomes (117). We can intervene with our nutritional strategies, but this is not the only factor in programming long-term health outcomes. Excessive weight gain in the first months is associated with an increase in fat mass rather than in lean mass (144, 145) and this should be avoided to lower the risk of facing cardiovascular and metabolic diseases in adult life (146, 147). On the other hand, growth retardation can have significant long-term health consequences, such as an increased risk of chronic health issues (148, 149).

Therefore, surveillance of growth patterns is strongly recommended, even after NICU discharge. The most accurate and precise way to monitor infants' growth is by measuring the three main anthropometric measurements: weight, length, and head circumference. When monitoring post-natal growth, it is important to use an appropriate growth chart, like the ones indicated for preterm infants, the INTERGROWTH-21st (150).

Preterm infants, especially the ones who face IUGR, are usually born SGA. At least 85–90% of children born SGA experience catch-up growth in the first 12–24 months of life. The remaining 10–15%, who do not reach a height over-2 SDS at the age of 2 years old, have a greater risk of remaining short as an adult (151–153).

If changing feeding strategies is not enough to guarantee optimal growth, it is possible to intervene pharmacologically. Short children born SGA who fail to demonstrate catch-up growth are candidates for growth hormone (GH) treatment. The Food and Drug Administration (FDA) and the European Medicines Agency (EMA), in 2001 and 2003, respectively, approved GH treatment for infants born SGA. The FDA approves the use of GH (0,067 mg/kg/die) in all SGA infants who fail to reach catch-up growth by the age of two. The EMA approves the use of GH (0,033 mg/kg/die) in infants born SGA that at the age of four still have a height < -2 SDS or a growth velocity < 0 and there is a distance to a mid-parental height of – 1 SDS (154, 155).

GH treatment is effective and safe. Its efficacy has been reassured by different studies: long-term GH treatment in short children born SGA leads to a normalization of adult height, even with a dose of 0.033 mg/kg/die (156, 157).

Even if, over the years, there were doubts about the increased risk of cancer, mortality, and cardiovascular disease caused by GH treatment, multiple studies have confirmed that, for approved indications and at recommended doses, GH treatment is safe to use and has no long-term negative consequences on health (158, 159).

The younger the patient is at the beginning of treatment, the more favorable the response. Hence, the importance of monitoring growth in preterm infants, especially the ones born SGA (155).

12 Conclusion

The postnatal growth window is crucial to ensure adequate outcomes for extremely preterm infants. As this review has emphasized, right from parenteral nutrition, it is necessary to consider the characteristics of the single infant and provide adequate nutrients (glucose, lipids, and proteins) and micronutrients (electrolytes, vitamins, and minerals) both quantity and quality-wise. Early start of enteral feeding within 24 h of life is safe, if there are no warning signs or symptoms and can allow to reach earlier full enteral feeding, advancing meals by up to 20–30 mL/kg every day (where clinically acceptable). This is related to a lower duration of the parenteral nutrition, and an earlier removal of central venous catheter, with the reduction of related complications. With the establishment of full enteral nutrition, hopefully with human milk, adequate fortification of human milk is necessary: adjustable or targeted fortification strategies increase growth velocity compared to standard fortification. The monitoring of the trend of growth parameters (weight, length, and head circumference), assessed once a week during hospitalization, can allow for a decrease in extra-uterine growth restriction by tailoring the newborn's nutrition and leading to better outcomes. Finally, it is important not to forget the importance of adequate growth even after discharge, as poor growth is associated with long-term adverse outcomes.

Author contributions

DR: Conceptualization, Data curation, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. EM: Data curation, Investigation, Visualization, Writing – original draft. GM: Data curation, Investigation, Visualization, Writing – original draft. DM: Data curation, Investigation, Visualization, Writing – original draft. GV: Data curation, Investigation, Visualization, Writing – original draft. VT: Data curation, Investigation, Visualization, Writing – original draft. AC: Data curation, Investigation, Methodology, Visualization, Writing – review & editing. FC: Data curation, Investigation, Methodology, Visualization, Writing – review & editing. AD: Data curation, Investigation, Methodology, Visualization, Writing – review & editing. GS: Data curation, Investigation, Methodology, Supervision, Visualization, Writing – review & editing. MG: Data curation, Investigation, Methodology, Visualization, Writing – review & editing.

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The efficacy and safety of isotonic and hypotonic fluids in intravenous maintenance fluid therapy in term newborns: national multicenter observational "neofluid" study

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Objective: The objective of this study was to evaluate the efficacy and safety of isotonic and hypotonic intravenous fluids in maintenance fluid therapy for term infants.

Methods: This was a multi-centre, prospective, observational study conducted in 21 participating centres from December 30, 2020, to June 30, 2023. The study included term newborns requiring parenteral fluid therapy for maintenance (NCT04781361). The fluid treatment was divided into two groups based on the concentration of sodium in the parenteral fluid, designated as hypotonic (NaCl <130 mmol/L) and isotonic (NaCl = 130–154 mmol/L). The primary outcomes were the change in mean plasma sodium (pNa) levels per hour (ΔpNa mmol/L/h), the incidence of hyponatremia (pNa <135 mmol/L) and hypernatremia (pNa >145 mmol/L), and the occurrence of clinically significant changes in sodium levels (ΔpNa >0.5 mmol/L/h).

Results: A total of 420 patients from 21 centers were included. The ΔpNa was negative in the hypotonic fluid group and positive in the isotonic fluid group, with a significant difference between the groups [respectively −0.07 ± 0.03 (95% CI: −0.13 to −0.02); 0.04 ± 0.03 (95%CI: −0.02 to 0.09), $p = 0.04$]. There was no difference between the groups in terms of the development of hypernatremia or a clinically meaningful pNa increase. The hypotonic fluid group had a higher incidence of hyponatremia and a clinically meaningful sodium decrease compared to the isotonic fluid group [7.9% vs. 1.2% (OR:6.5, p:0.03)] and [12.2% vs.4.2% (OR:2.9, $p = 0.03$)].

Conclusion: Contrary to current understanding, this large-scale study is the first to demonstrate that the use of hypotonic fluids in maintenance fluid therapy for newborns poses a risk of hyponatremia development, whereas isotonic fluid therapy appears safe.

KEYWORDS

newborn, maintenance, fluid therapy, tonicity, isotonic, hypotonic, hyponatremia, hypernatremia

Introduction

Maintenance fluid therapy is defined as the volume of fluid required to meet daily metabolic needs, such as normal water and electrolyte losses, and maintain homeostasis (1). In children, maintenance intravenous fluid therapy aims to replace fluid and electrolyte losses under normal homeostatic conditions. The intermediate byproducts formed as a result of metabolism are heat and solutes, and these must be removed from the body for homeostasis. Heat is excreted through the skin and respiration, while solutes are excreted through urine. Therefore, maintenance fluid therapy should account for both sensible losses (urine and feces) and insensible losses (skin and lungs). For many years, fluid and electrolyte requirements in maintenance fluid therapy were calculated as suggested by Holliday and Segar. Traditionally, hypotonic fluids have been used for maintenance fluid therapy for infants, considering the daily energy needs of healthy infants and the sodium content of breast milk (2).

Recent studies have shown an increased risk of hyponatremia when hypotonic fluids are used for maintenance fluid therapy in children compared with isotonic fluids (3–6). As a result, relevant pediatric guidelines now recommend the use of isotonic fluids rather than hypotonic fluids for maintenance intravenous fluid therapy in children (7–10). In neonates, hypotonic fluids are still used for maintenance intravenous fluid therapy, and there is no consensus on the ideal fluid composition. Since there is no prospective, observational, multicenter study investigating the effectiveness and reliability of isotonic and hypotonic fluids in intravenous maintenance fluid treatment in term newborn babies, term newborn babies were included in this study.

Fluid and electrolyte needs in preterm babies vary greatly according to gestational age and postnatal age, and in addition to physiological maturity, nutritional needs and environmental factors also play an important role in maintenance fluid therapy. Since individualized maintenance fluid therapy would be a more appropriate approach for these babies, these babies were excluded from the study.

In 2015, the National Institute for Health and Clinical Excellence (NICE) published the "Intravenous Fluid and Electrolyte Treatment Guideline for Newborns and Children," which recommended the use of isotonic fluids for the maintenance fluid therapy in newborns after the postnatal renal adaptation period (8). The 2020 version of this guideline emphasized the postnatal day and recommended isotonic maintenance fluids (5–10% glucose and 131–154 mmol/liter NaCl) for term neonates after the 8th postnatal day. For term neonates up to 7 days of age, it is suggested that professional judgment be used, taking into account individual circumstances highlighting the possibility of higher sodium content and lower glucose content in these fluids. It is important to note that NICE recommendations on fluid therapy in newborns were based on expert opinion rather than evidence, as there were few trials available on this topic (9). Since this guideline is not based on strong evidence, it has not yet made a significant change in clinical practice regarding the maintenance fluid therapy of newborn babies. The objective of this study was to assess the efficacy and safety of isotonic and hypotonic fluids as intravenous maintenance fluids in neonates through a prospective, observational, multicenter study.

Method

This prospective multicenter observational study was conducted from December 30, 2020, to June 30, 2023, with protocol registered on ClinicalTrials.gov (NCT04781361, February 2021). The primary outcome was the hourly change in plasma sodium level (ΔpNa, mmol/L/h) during the first day of isotonic and hypotonic fluid therapy. Secondary outcomes included hyponatremia (plasma sodium <135 mmol/L), hypernatremia (>145 mmol/L), critical ΔpNa (>0.5 mmol/L/h), and treatment-related morbidities such as intraventricular hemorrhage, edema, apnea, seizures, hypertension, tachycardia, bradycardia, electrolyte imbalances, renal dysfunction, length of hospital stay, and mortality.

The inclusion criteria were as follows: (i) born at 37 weeks' gestation or later; (ii) completed the first 24 h of life and were less than 30 days old; (iii) had a Na level between 135 and 145 mmol/L; (iv) were receiving at least 50% of daily fluid requirements intravenously as prescribed by the attending physician; and (v) had written consent from the family or legal guardian. Neonates with severe dehydration, shock, cardiac or hepatic failure, metabolic disease, renal failure, adrenal insufficiency, diabetes mellitus, diabetes insipidus, hypoxic ischemic encephalopathy, congenital anomalies, diuretic therapy, significant edema, those receiving total parenteral nutrition therapy, and patients receiving non-standard fluid therapy were excluded from the study.

Each participating center submitted its case data to the Trials Network online system. All entries on the Trials Network (https://www.trials-network.org/neonatology) were rigorously screened for adherence to the inclusion/exclusion criteria. The study used an online case report form as the primary tool for documenting demographic data (postnatal age, mode of delivery, gestational age, birth weight, sex, diet) and clinical information. Case report form was designed for optimal collection of data in accordance with the study protocol and standardized to the needs of all those who handle the data such as investigator, biostatistician, clinical research monitor/coordinator, and data entry personnel according to the standart guidelines (11).

Clinical data, recorded daily for up to 72 h during intravenous fluid therapy, included primary diagnosis' ICD codes, baseline body weight, percentage weight loss, clinical hydration status, blood pressure, heart rate, parenteral fluid type, sodium content (mmol/L), daily intravenous fluid intake, daily enteral fluid volume and composition, medications for the primary illness, and daily urine and stool counts. Morbidities potentially influenced by fluid therapy, such as intraventricular hemorrhage, edema, apnea, and seizures, as well as morbidities related to the primary disease, mortality, and length of stay, were recorded.

Throughout the study, serum blood sugar, blood urea nitrogen, creatinine, electrolytes (sodium, potassium, chloride), pH, bicarbonate, urine density, and spot urine sodium and creatinine levels were monitored in the cases before treatment, and at 24, 48, and 72 h of treatment if fluid therapy was ongoing. Monitoring was also conducted when fluid therapy was discontinued or in the presence of severe hyponatremia (< 135 mmol/L) or severe hypernatremia (> 145 mmol/L), with at least a 3 mmol/L change from baseline during therapy, or when the clinician decided to change the treatment due to the baby's worsening clinical condition.

Sample size

Given the absence of any studies with a similar design in the literature, a power analysis using Cohen's t-test was conducted to determine the appropriate sample size. With an effect size of 0.5, a power of 95%, and a confidence interval of 95%, it was determined that each group would require 80 participants. Either group provides the predetermined sample size. Additional cases were included for adequate subgroup representation.

Statistical analysis

Administered fluids were categorized as hypotonic (<130 mmol/L NaCl) or isotonic (130–154 mmol/L NaCl), excluding sodium-free fluids. Data from both groups were subjected to the Kolmogorov–Smirnov test for normality. The t-test was used for normally distributed variables, the Mann–Whitney U test for non-normally distributed variables, and chi-squared analysis for categorical data. Subgroup analysis was performed using the Kruskal-Wallis test. Statistical significance was set at 0.05. Analyses were performed using IBM SPSS Statistics 25 software. If laboratory data for primary outcomes were missing, those infants were excluded. However, the sample size required for the primary outcome was still met. A linear mixed-effects model was employed using the PROC MIXED procedure in SAS to investigate the effects of time and treatment group on the outcome variable, "Na" (SAS software, Version 9.3; SAS Institute, Cary, NC, ABD). The model included fixed effects for group (hipotonic and isotonic), time, and their interaction allowing us to assess both the main effects and the interaction between these factors.

Ethical approval statement

The study was approved by both the Turkish Medicines and Medical Devices Agency of the Ministry of Health (TITCK, 17-AKD-174) and the Interventional Clinical Research Ethics Committee of Dokuz Eylul University (404-SBKAEK). It was conducted in strict accordance with the ethical standards of the 1964 Declaration of Helsinki and its subsequent amendments. The Turkish Society of Neonatology Online Studies Scientific Steering Committee approved the study protocol.

Data privacy

Each center reported the data of its own cases to the Trial Network web-based data recording system "Trials Network" (https://www.trials-network.org/neonatology) using a unique identification number. When the study coordinator needed to verify the data of any case, the responsible investigator at the center accessed the patient identification data through this unique number and verified it. During the study period, cases entered into the Trials Network were checked for inclusion and exclusion criteria, and monthly correction emails were sent to the centers. Corrected cases were transferred to the SPSS system after each check. Centers that logged into the system could only view their own data. Only the research coordinator had access to the aggregated, non-identifying data.

Results

Data was collected between December 30, 2020, and June 30, 2023, from 21 participating centers, resulting in a total of 502 patients being reported. After excluding 82 infants, 420 infants were included. The excluded infants were as follows: 42 patients were excluded due to incorrect or missing data, 12 patients were excluded because they initiated fluid therapy within the first 24 h of the postnatal period, 1 patient was excluded due to a pre-treatment sodium value of less than 135 mmol/L, 7 patients were excluded because the planned daily enteral volume was greater than the parenteral volume, 3 patients were excluded due to renal failure, and 17 patients were excluded because they received a sodium-free solution containing only dextrose (Figure 1). Cases excluded from the study did not cause bias because they did not affect the predetermined sample size in both groups.

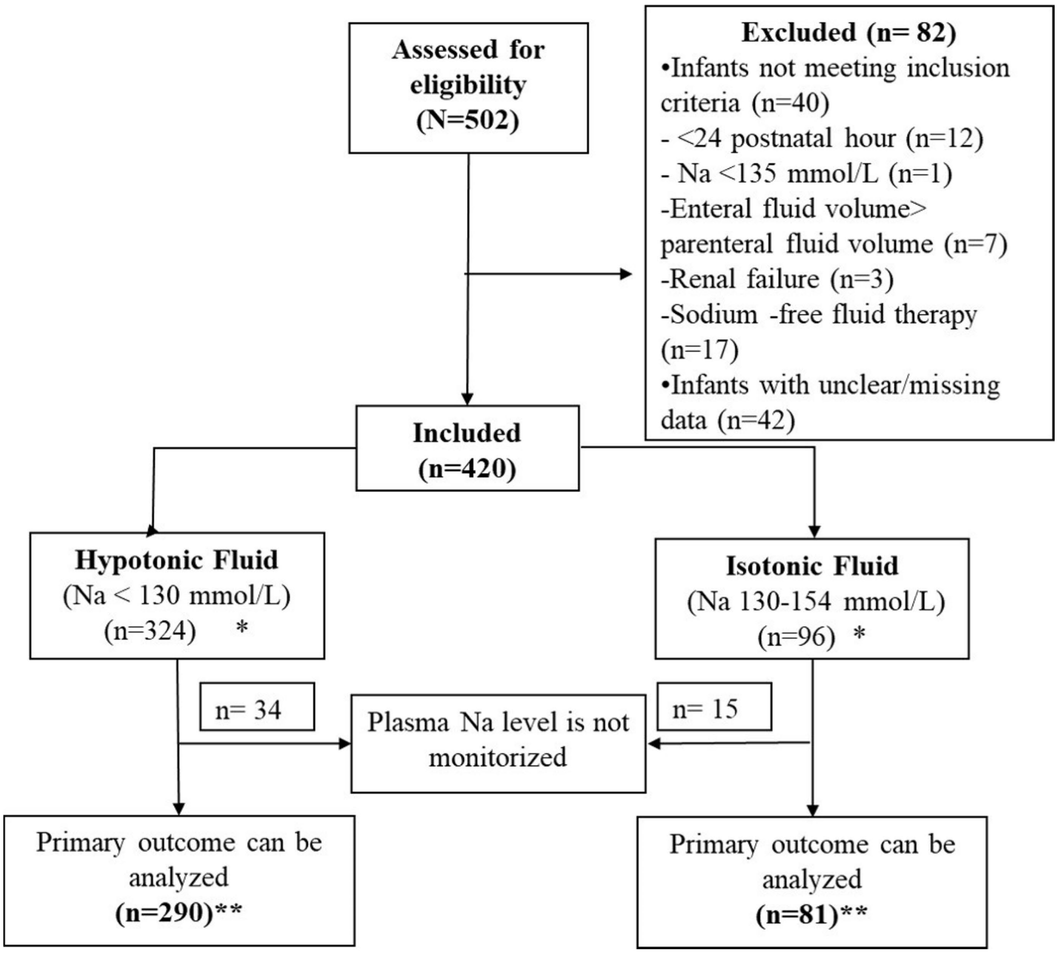

FIGURE 1
Flow diagram. *Demographic data and treatment-related morbidities were evaluated in 420 patients. **As the primary evaluated outcome was the hourly change in plasma sodium level (ΔpNa), cases without follow-up sodium levels were excluded from the primary outcome analysis.

According to the protocols of the participating units, a total of 324 patients received hypotonic fluid therapy, while 96 patients received isotonic fluid therapy. There were no significant differences between the groups for demographic and clinical variables ($p > 0.05$), except feeding status at the initiation of the fluid therapy. Almost half of the cases included in the study were diagnosed with feeding problems, transient tachypnea of the newborn and neonatal jaundice. Pretreatment laboratory values were also similar ($p > 0.05$) (Table 1).

Measurement of sodium levels within the first 24 h of fluid therapy was conducted in a total of 371 patients, with 290 receiving hypotonic fluid and 81 receiving isotonic fluid. When comparing ΔpNa (mmol/L/h) between the groups as the primary outcome, the hypotonic fluid group showed a negative change [−0.07 ± 0.03, 95% CI: −0.13 to −0.02]. In contrast the isotonic group demonstrated a positive change [0.04 ± 0.03, 95% CI: −0.02 to 0.09] ($p = 0.04$). Considering the distinct initial feeding types in the isotonic and hypotonic fluid groups, we evaluated the impact of feeding type on ΔpNa. Results showed no significant difference in median ΔpNa between subgroups categorized by infants' initial feeding type (Kruskal-Wallis test, $p = 0.99$). When a linear mixed-effects model study was used to evaluate differences over time between two treatments, the interaction between time and group was not statistically significant [$F(1,118) = 2.06$, $p = 0.1534$], implying that the trajectory of the outcome variable over time did not differ significantly between the groups (Figure 2).

For patients who continued fluid therapy beyond 24 h, a separate evaluation was performed between 24 and 48 h, involving 141 patients. Among these, 89 received hypotonic fluid and 52 received isotonic fluid. No significant differences were observed in terms of ΔpNa. Similarly, 15 patients in each group received fluid treatment between 48 and 72 h and there was no difference between the groups in terms of evaluated outcomes.

Furthermore, when the fluid treatments were categorized as extremely hypotonic (containing 20–50 mmol/L Na), moderately hypotonic (containing 60–130 mmol/L Na) and isotonic (containing 154 mmol/L Na), no significant difference in ΔpNa was observed between the groups.

To assess secondary outcomes, we analyzed cases with hyponatremia and hypernatremia at 0–24 h, 24–48 h and 48–72 h of fluid therapy. We also evaluated cases with ΔpNa greater than 0.5 mmol/L (increase or decrease). The results showed a higher incidence of hyponatraemia in the first 24 h in hypotonic fluid recipients compared with isotonic fluid recipients. In addition, the hypotonic fluid group had a sodium decrease of >0.5 mmol/L/h. No significant between-group difference was found for hypernatremia or sodium increase (Table 2).

TABLE 1 Demographic and pre-treatment data of the patients by maintenance parenteral fluid type*.

	Hypotonic fluid (<130 mmol/L) (*n*:324)	Isotonic fluid (130-154 mmol/L) (*n*:96)	*p*
Demographic data			
Gestational age (days)	271.4 ± 8.3	270.6 ± 0.7	0.446
Birth weight (gr)	3268 ± 29	3225 ± 45	0.449
Cesarean delivery	187 (57.7%)	58 (60.4%)	0.724
Male gender	202 (62.3%)	55 (57.3%)	0.405
Nutrition at the time of admission			
Not fed	34 (10.5%)	1 (1.0%)	**<0.001****
Exclusive breast milk	145 (44.8%)	66 (68.8%)	
Formula	47 (14.5%)	5 (5.2%)	
Breast milk + formula	98 (30.2%)	24 (25.0%)	
Fluid therapy data			
Postnatal age at which fluid therapy was started (hours)	96 ± 8	121 ± 16	0.130
Body weight (grams) at the start of fluid therapy	3207 ± 30	3139 ± 46	0.265
Planned total daily fluid volume (cc/kg/day)	106 ± 2	114 ± 4	0.139
Planned total daily parenteral fluid volume (cc/kg/day)	76 ± 2	83 ± 3	0.139
Planned total daily enteral fluid volume (cc/kg/day)	31 ± 1	30 ± 2	0.816
Pre-treatment laboratory values			
BUN (mg/dl)	13.6 ± 0.7	13.1 ± 1.0	0.748
Creatinine (mg/dl)	0.69 ± 0.01	0.60 ± 0.03	0.07
Sodium (mmol/L)	139.9 ± 0.2	139.8 ± 0.3	0.654
Potassium (mmol/ L)	4.8 ± 0.4	4.9 ± 0.1	0.401
Chlorine (mmol/L)	106.0 ± 0.3	107.0 ± 0.7	0.134
Glucose (mg/dl)	78.4 ± 1.1	77.0 ± 2.0	0.552
Serum pH	7.37 ± 0.01	7.35 ± 0.02	0.096
Serum HCO_3 (mmol/L)	22.2 ± 0.2	21.7 ± 0.8	0.455
Urine Sodium (mmol/L)	32.2 ± 4.3	41.1 ± 9.0	0.414
Urine Creatinine (mg/dl)	30.7 ± 6.0	18.1 ± 3.6	0.379
Urine pH	6.14 ± 0.06	6.20 ± 0.14	0.691
Urine Density	1009 ± 1	1009 ± 1	0.963
Urinary findings after fluid therapy			
Urine Sodium (mmol/L)	26.6 ± 3.5	38.2 ± 8.6	0.210

*Data are given as mean ± SD or number (%) as applicable.
**The differences were significant in all subgroups.

To analyze the effect of postnatal age, the study compared the risk of hyponatremia and hypernatremia between those treated within 24–72 h of birth and those treated after 72 h. Cases within 72 h had a higher incidence of hyponatremia [22 cases (8.6%) vs. 2 cases (1.7%), RR: 0.73, 95% CI: 0.64–0.85, p: 0.01]. In addition, the association between parenteral fluid volume in the first 24 h of therapy and the development of hyponatraemia was assessed, but no significant difference was found. Serum pH changes were compared between hypotonic and isotonic fluid recipients during the first 24 h of therapy and at baseline, with no significant difference between the groups.

As no other parameter was found to significantly influence the change in plasma sodium levels, logistic regression analyses were not performed.

Discussion

This study suggests that isotonic fluids may be a more appropriate choice for intravenous fluid maintenance therapy in term neonates who have completed the postnatal adaptation phase. Hypotonic fluids, which are traditionally used in maintenance therapy, were found to decrease serum sodium levels and cause hyponatremia. In contrast, isotonic fluids did not cause a significant increase in serum sodium levels or hypernatremia.

As seen in Table 1, there were nutritional differences between the two groups at the beginning of the study, but this did not cause any difference in laboratory data of the two groups before treatment. During the treatment, enteral and parenteral fluid intakes of both

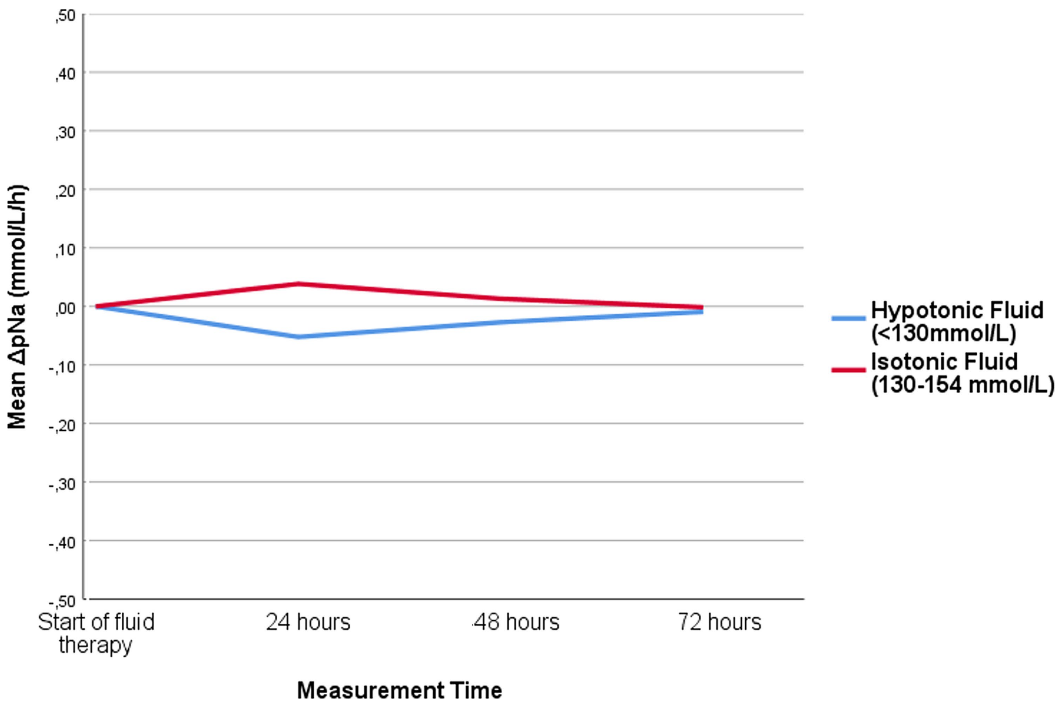

FIGURE 2
Hourly change in plasma sodium level of patients receiving isotonic and hypotonic fluid.

groups were planned to be similar. Therefore, the only factor affecting the primary and secondary results of the study was the use of hypotonic or isotonic fluid.

Adaptation to extrauterine life consists of three phases of fluid balance. After birth, there is an efflux of fluid from the intracellular to the extracellular compartment. This results in salt and water diuresis by 48–72 h of age. Loss of this excess extracellular fluid (ECF) and evaporative water loss from immature skin results in physiological weight loss during the first week of life. The first transitional period ends with maximum weight loss. The second intermediate phase is characterized by a decrease in insensible water loss with increasing maturation of the skin barrier, a decrease in urine volume to less than 1–2 mL/kg per hour and low sodium excretion. The third phase consists of stable growth and is characterised by continuous weight gain with a positive net balance for water and sodium. This issue is addressed in the NICE guideline as the completion of the postnatal adaptation phase of the initiation of postnatal diuresis and weight loss in term newborn babies (9). In this study, the postnatal adaptation phase is accepted the first phase of the first 48–72 h of life when diuresis begins. Therefore, both fluid groups were considered to have completed this phase.

Limited studies have questioned the maintenance of fluid management in neonates. Balasubramanian et al. found that the use of hypotonic fluids increased the risk of mild hyponatremia, whereas the use of isotonic fluids increased the risk of hypernatremia, and they suggested the use of a fluid solution with a salt content between 0.9 and 0.2% (12). However, Moritz et al. stated that isotonic fluids did not cause hypernatremia and that such a result may be due to the inclusion of hypernatremic patients and the fact that isotonic fluids did not make a significant difference in sodium levels (13). They emphasized that when isotonic fluid is administered in the presence of hypovolemia, the fluid will be retained until the volume depletion is corrected and will not result in a significant fall in serum sodium. Once the volume depletion is corrected, further fluid administration will result in natriuresis and free water will be generated to prevent the development of hypernatremia (14).

Tüzün et al. conducted a retrospective cohort study involving 108 neonates comparing 5% dextrose in 0.9% sodium chloride (NaCl) with 5% dextrose in 0.45% NaCl for maintenance fluid therapy (15, 16). They found that hypotonic fluids could critically lower serum sodium levels, whereas isotonic fluids did not lead to hypernatremia or other complications. The authors attributed this non-existent hypernatremia to the ability of neonates to excrete sodium in the urine after physiological adaptation.

Dathan et al. conducted a study comparing isotonic (sodium chloride 0.9% and dextrose 5%) and hypotonic (sodium chloride 0.15% and dextrose 5%) fluids for intravenous maintenance therapy in neonates over 34 weeks' gestation (17). They observed a higher incidence of hypernatremia in the isotonic fluid group, without showing superiority in preventing hyponatremia over hypotonic fluids. The authors attributed this to factors such as sodium load, limited urinary sodium excretion due to lower glomerular filtration rate and higher tubular sodium reabsorption, and the infants' medical conditions. In particular, the study included preterm infants older than 34 weeks with a variety of medical conditions that affect fluid-electrolyte balance. It's important to take these differences into account, including differences in fluid volume, when comparing results with our study.

In term neonates, the glomerular filtration rate is low and the ability of the newborn kidney to concentrate urine is limited but can dilute it

TABLE 2 Secondary outcomes related with plasma sodium level*.

	Hypotonic fluid (<130 mmol/L) *n* = 290	Isotonic fluid (130-154 mmol/L) *n* = 81	OR	*p*
Within 24h of fluid therapy				
Hyponatremia <135 mmol/**L**	23 (7.9%)	1 (1.2%)	6.5	0.03
Hypernatremia >145 mmol/**L**	12 (4.1%)	2 (2.5%)	–	0.74
Na increase rate ≥ 0.5 mmol/**L/h**	14 (8.9%)	6 (11.5%)	–	0.57
Na decrease rate ≥ 0.5 **mmol/L/h**	23 (12.2%)	1 (4.2%)	2.9	0.03

	Hypotonic fluid (<130 mmol/L) *n* = 89	Isotonic fluid (130-154 mmol/L) *n* = 52	OR	*p*
Within 24–48h of fluid therapy				
Hyponatremia <135 mmol/**L**	7 (7.9%)	1 (1.9%)	–	0.25
Hypernatremia >145 mmol/**L**	3 (2.1%)	0 (0.0%)	–	0.29
Na increase rate ≥ 0.5 **mmol/L/h**	0 (0.0%)	0 (0.0%)	–	–
Na decrease rate ≥ 0.5 **mmol/L/h**	0 (0.0%)	0 (0.0%)	–	–

*Data are given as number (%).
–Odds ratio is not applicable for the corresponding outcome.

(50–600 mOsm/kg) due to the immaturity of the luminal membrane Na-H exchanger, Na-glucose cotransporter and Na-K-ATPase (18–21). However, even healthy preterm infants can tolerate fluid intake of up to 200 mL/kg/day after the physiological adaptation period by excreting it in the urine (22). Furthermore, extracellular volume expansion has a natriuretic effect independently of glomerular filtration rate and it should be noted that various hormonal influences play a role in maintaining water and electrolyte homeostasis despite significant variations in intake (23). Factors such as desalination and translocational hyponatraemia should be taken into account in maintenance fluid therapy (24). The process of desalination involves the administration of isotonic solutions and the development of hyponatremia due to the loss of hypertonic urine. The antidiuretic hormone, with the associated suppression of aldosterone, causes the retention of electrolyte-free water formed as a result of hypertonic urine loss. Hyponatraemia due to desalination is rarely seen when isotonic fluids are administered postoperatively. In conditions such as hyperglycaemia or hypertriglycaemia, the osmotic gradient causes free fluid to move from the intracellular to the extracellular compartment. This leads to a decrease in the serum sodium concentration in the extracellular fluid. This is known as translocational hyponatraemia. However, desalination or translocational hyponatremia wasn't seen in cases included this study.

The metabolic rate of newborn babies is 20–30% lower than that of older infants during the first 10 days. Therefore, when determining fluid and electrolyte requirements based on weight, higher amounts are calculated. Based on the literature and a thorough evaluation and interpretation of current parenteral and enteral feeding guidelines, there are insufficient data to determine the optimal composition and timing of nutritional support in preterm and term critically ill neonates (25). Studies of resting energy expenditure (REE) during the first weeks of life in healthy preterm and term infants show that REE increases with increasing energy supply during the first weeks of life, and that REE is directly proportional to growth rate. In addition, the Holliday-Segar nomogram allocates approximately 50% of energy expenditure to growth, which may not be applicable to hospitalized infants. Therefore, during acute illness or in the postoperative period, the combined fluid loss (both sensible and insensible) may be approximately half of that suggested by Holliday and Segar (50–60 mL/kg/day) (26). Factors such as pain, stress, fever, infection, hypoxia and surgery can contribute to non-osmotic inappropriate secretion of antidiuretic hormone (ADH) (21). Traditional neonatal fluid therapy often neglects these aspects and overlooks the central role of tonicity in water-electrolyte balance, which is determined by plasma sodium levels. Tonicity, which is significantly influenced by intracellular potassium, controls fluid movement between compartments (26).

There are limitations to consider. The inability to randomize participants is a major drawback. The inclusion of only infants without serious health problems requiring maintenance therapy limits the generalisability of the results to the whole neonatal population. The results of this study cannot be generalized to the excluded infants, which include preterm infants, infants with severe dehydration, shock, heart or liver failure, metabolic diseases, renal failure, adrenal insufficiency, diabetes mellitus, diabetes insipidus, hypoxic–ischemic encephalopathy, congenital anomalies, significant edema, and those in the postoperative period. Excluding these 82 infants was necessary to maintain the integrity and consistency of the study data. However, it is important to note that these exclusions did not affect the predetermined sample size for both groups, thereby helping to mitigate concerns about significant bias. Although the subjects were monitored for 72 h, the number of infants requiring fluid therapy and the measured data showed a marked decrease over time. Plasma ADH levels, plasma and urine osmolality and tonicity were not measured in this study. In addition, the postnatal physiological adaptation period was clinically defined solely by the onset of urine output in the infants.

In conclusion, this study has provided evidence for the efficacy and safety of isotonic fluids for maintenance therapy in term neonates who have completed the postnatal adaptation period. In these babies, we can initially use isotonic crystalloids containing sodium in the range of 131–154 mmol/litre with 5–10% glucose. However, the neonate's age, diagnosis, fluid-electrolyte balance and medications should be taken into account, and serum electrolytes should be closely monitored during intravenous fluid therapy. When selecting intravenous fluids, it is important to consider not only sodium but also the individual electrolyte and glucose requirements of the newborn. If the results of this study are supported by other studies, hypotonic fluids, which have traditionally been used for maintenance fluid therapy in term infants, will be replaced by isotonic fluids.

What is known

- Traditional practice employs hypotonic fluids for maintenance intravenous therapy in newborns, lacking a definitive fluid composition consensus beyond NICE guidelines.

What is new

- Traditional use of hypotonic fluids in maintenance therapy led to reduced serum sodium levels, resulting in hyponatremia.
- Isotonic fluids could be a better option for intravenous maintenance fluid therapy in term newborns after the postnatal adaptation phase without causing significant serum sodium changes or hypernatremia.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Ethics statement

The studies involving humans were approved by the Dokuz Eylül Üniversitesi Klinik Araştırmalar Etik Kurulu, Dokuz Eylül University Protocol number: 404-SBKAEK. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

HO: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. ND: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. FT: Conceptualization, Data curation, Methodology, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing. FN: Resources, Writing – review & editing. CA: Data curation, Formal analysis, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing. EA: Resources, Writing – review & editing. MS: Resources, Writing – review & editing. MO: Resources, Writing – review & editing. AK: Resources, Writing – review & editing. AT: Resources, Writing – review & editing. MK: Resources, Writing – review & editing. SU: Resources, Writing – review & editing. SY: Resources, Writing – review & editing. RD: Resources, Writing – review & editing. BB: Resources, Writing – review & editing. CZ: Resources, Writing – review & editing. YK: Resources, Writing – review & editing. SS: Resources, Writing – review & editing. MT: Resources, Writing – review & editing. AA: Resources, Writing – review & editing. MB: Resources, Writing – review & editing. BK: Resources, Writing – review & editing. GT: Resources, Writing – review & editing. DC: Resources, Writing – review & editing. HC: Resources, Writing – review & editing. AO: Resources, Writing – review & editing. OO: Resources, Writing – review & editing. MD: Resources, Writing – review & editing. DS: Resources, Writing – review & editing. SC: Resources, Writing – review & editing. PK: Data curation, Formal analysis, Software, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2024.1410571/full#supplementary-material

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Determinants of recovery time from severe acute malnutrition among cholera-exposed and unexposed children in Ethiopia: a prospective cohort study

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Background: There is a vicious interplay between severe acute malnutrition (SAM) and diarrheal diseases including cholera. The lack of sufficient evidence on the time to recovery and its determinants among children with cholera prompted this investigation. The study aimed to evaluate the time to recovery and determinants among children with severe acute malnutrition, comparing cholera-exposed and unexposed children.

Methods: A prospective cohort study was carried out from September 10, 2022, to February 21, 2023, among 224 children below 15 years. The study was conducted at cholera treatment centers and nearby communities in the Bale and Guji Zones of Oromia Regional state in Ethiopia. A structured questionnaire was used to obtain information and anthropometric measurements were conducted weekly. After checking all assumptions, a multivariable Cox Proportional Hazards model was used to identify independent determinants of time to recovery using an adjusted hazard ratio (AHR) with a 95% confidence interval (CI). Statistical significance was declared at $p < 0.05$.

Results: Nearly 80% of participants recovered from SAM with a recovery rate of 40/1000 person-week observation and a median time to recovery of 21 days [Inter Quartile Range14-28]. The recovery time from SAM for cholera-exposed children was delayed by 54% [ARR: 0.46, 95% CI: 0.30–0.69] compared to unexposed children. Similarly, the recovery time from SAM for food-insecured families was delayed by 39% [ARR: 0.61, 95% CI: 0.38–0.96] compared to food-secured families. Moreover, children with more than three meal frequencies per day had 1.61 times [ARR: 1.61, 95% CI: 1.04–2.50] higher probability of fast recovery from SAM, compared to children with less than three meals. Children from families with good attitudes toward nutrition had more than two times [ARR: 2.23, 95% CI: 1.45–3.41] higher probability of faster recovery from SAM than families with poor attitudes.

Conclusion: The study revealed that cholera exposure is one of the main determinants of prolonged recovery time for children with SAM. Food insecurity, meal frequency, and the attitude of parents toward children's dietary habits were determinants for the recovery of children from SAM. The findings imply the need for designing interventions to enhance child feeding during cholera illness, focusing on key determinants.

KEYWORDS

children, cholera, Ethiopia, malnutrition, nutrition, severe acute malnutrition, time to recovery

Introduction

Childhood malnutrition continues to be a significant global health issue, resulting in illness, death, and disability. It encompasses various nutritional disorders, such as underweight, wasting, stunting, and micronutrient deficiencies. Wasting specifically refers to acute malnutrition caused by insufficient recent intake of necessary nutrients, which can be influenced by diarrhea and other acute illnesses (1, 2).

The world's children are facing an epidemic of malnutrition. In 2022, the 15 most severely affected countries account for over 30 million children suffering from wasting, a condition characterized by a significant loss of weight and muscle mass. Disturbingly, it has been observed that a mere 5 % increase in the actual cost of food elevates, the global risk of wasting by nearly 9 %. This highlights the vulnerability of children to the economic fluctuations affecting the affordability and accessibility of nutritious food (3).

Moreover, an estimated 45 million children under 5 years old were suffering from wasting worldwide. In 2024, the convergence of threats may further increase the number of children, and pregnant and breastfeeding women affected by acute malnutrition (4).

On the other hand, about 150 million under 5 years children are estimated to be too short for their age or stunted, and about 50 million are too thin for their height or wasted, most of the world's wasted children are living in South Asia and Sub-Saharan Africa (5). And account for about 50% of direct or indirect causes of global under-five mortality (6).

After years of grappling with undernutrition, Africa is now facing a concerning rise in overnutrition that is characterized by excessive intake of calories, leading to obesity and associated health problems. The rise in obesity rates can be partially attributed to changes in modern lifestyles. These lifestyle shifts include increased consumption of processed and high-calorie foods, as well as more sedentary behaviors and reduced physical activity (7). Despite the surge in overnutrition and the double burden of undernutrition remains an important public health problem in many African countries requiring a multidisciplinary for its solution (8). Populations in South Sudan, Somalia, and Ethiopia are experiencing starvation and concurrent outbreaks of cholera besides this, the combination of drought, conflict, and population displacement in certain countries has led to a significant increase in food insecurity and a higher prevalence of severe acute malnutrition (SAM) among the affected populations (9).

According to the United Nations Children's Fund (UNICEF), World Health Organization, and World Bank Group joint malnutrition estimate in 2018, about 14 million wasted children lived in Africa, and 4 million were specifically found in East Africa (10). Like many countries in sub-Saharan Africa (SSA), Ethiopia has a high burden of malnutrition among children with 36.6% stunted, 12.2% wasted, and 25.2% underweight (11).

Children with acute malnutrition (AM) have a higher incidence and longer duration of diarrhea due to mainly electrolyte imbalance, which in turn affects the treatment of dehydration, especially in severely malnourished children. The burden of acute malnutrition among children in Ethiopia also remains high, which might have an impact on treatment outcomes (12). Evidence showed that there is an intersection of cholera with malnutrition (12). However, data on the two together and the treatment outcomes among children having cholera and acute malnutrition are limited in Ethiopia. A study conducted in the Lay Armachiho district of Ethiopia found that children with poorly diversified diets and inadequate micronutrient intake are at a higher risk of impaired growth and development. This research highlights the prevalence of undernutrition among schoolchildren in a region where evidence has been limited (13).

The recovery time of children with SAM is influenced by age, dietary diversity, micronutrient intake, weight, vaccination status, poverty level, education, occupation, household food insecurity, and comorbidities such as pneumonia, stunting, shock, and deworming (7, 13–16). Household characteristics such as poverty level, education, occupation, household food insecurity, and dietary diversity are associated with subsequent wasting and stunting in children (16). Effective management of SAM with cholera remains a huge challenge in low-resource healthcare settings (17). Moreover, comorbidities were the main determinant factors; SAM children with severe wasting, pneumonia, vomiting, and anemia had prolonged stays in the stabilization centers without recovery (18).

Although there are guidelines and protocols for treating children with both cholera and SAM, specific research on their relationship is limited. For example, the Global Task Force on Cholera Control (GTFCC) provides detailed protocols for managing children with SAM during cholera outbreaks, emphasizing careful rehydration and monitoring to prevent complications such as over-hydration by overlooking nutritional intervention. However, most existing literature addresses the broader implications of infectious diseases on malnutrition without thoroughly examining cholera's unique impact on recovery time from SAM (19).

Previous studies conducted in Ethiopia (5, 14, 20–23) focused mainly on SAM and did not address the comorbidity of SAM with Cholera, and its impact on the recovery rate. This makes the effort to treat children with cholera and improve their recovery and survival rate very challenging. Thus, the need to study the comorbidity of SAM and cholera became evident and this study was conducted to fill this gap. Therefore, the study aimed to identify the time to recovery and

Abbreviations: AHR, Adjusted Hazard Ratio; CI, Confidence Interval; HF, Health Facility; IQR, Interquartile Range; MUAC, Middle Upper Arm Circumference; SAM, Severe Acute Malnutrition; WHO, World Health Organization.

its determinants among children with severe acute malnutrition with cholera and without.

Methods

Study design and setting

This prospective cohort study was conducted to examine the time to recovery and determinants influencing time to recovery among both cholera-exposed and unexposed children under the age of 15 years. Prospective cohort studies offer valuable insights into disease prevention and intervention effects on malnutrition. However, challenges arise when it comes to following participants, especially in cases of dropout or loss of follow-up. To ensure the robustness and reliability of our findings, we employ rigorous methods and address potential sources of bias.

The study was conducted at cholera treatment centers and nearby communities in the Bale and Guji Zones of Oromia, Ethiopia. The capital town of Bale, Robe, is located 402 kilometers away from Addis Ababa (Southwest direction). Bule hora, the capital of Guji zone is located 477 kilometers away from the capital city, Addis Ababa. The data were collected from September 10, 2022, to February 21, 2023. The cholera treatment centers (CTCs) were located in cholera hotspot districts in Ethiopia, as identified by the Ethiopian Public Health Institute (24). There were 14 CTC centers in Oromia Regional State during the study period. The study areas were selected due to the cholera outbreak occurrence during the study period.

Study population and sampling

The study population comprised two groups: cholera-exposed children with SAM under the age of 15 and cholera-unexposed children with SAM of the same age. The cholera-unexposed children with SAM were identified by screening the nutritional status of children from the nearby respective communities where the CTCs are located. The stratified random sampling method was used to select the participants exposed to cholera. The cholera hotspot areas served as the strata, and two cholera treatment centers (CTCs) in the Guji Zone and 12 CTCs in the Bale Zone were selected for inclusion in the study. Simultaneously, strata were identified in nearby communities for the control group, and participants were randomly selected from each stratum. For the unexposed group, strata were created based on the kebele where the cholera treatment center was established and the study participants were selected using a simple random sampling technique using the list of households as a sampling frame from the nearest kebele (strata) to the cholera treatment center.

Sample size determination

The sample size was determined using Epi StatCalc version 7.2.4 software, where P1 is the prevalence of wasting among unexposed children in Nepal, is 12.6% (25), and P2 is the prevalence of acute malnutrition among exposed children with cholera in Nigeria, which is 24% (12). With the power (P) = 90%, and the confidence level of 95%, by adding 10% for non-response, the overall sample size was 566 [550 with a 97.1% response rate], for those children undergoing SAM screening. A 1:1 (275:275) ratio for the exposed and unexposed groups was considered. Then, those who developed SAM from both groups were followed for this particular time to recovery study.

During the screening for severe acute malnutrition (SAM), 224 children in both study groups were identified as having a mid-upper arm circumference (MUAC) measurement below 11.5 cm. The screening was conducted at the CTCs for cholera exposed and house-to-house screening was conducted for non-exposed children. These 224 children with MUAC <11.5 cm were considered for this follow-up study.

Inclusion and exclusion criteria

The study included children under the age of 15 with SAM who were both exposed and unexposed to cholera. Additionally, only SAM children who were found from both groups were included in the final sample for follow-up. Both the exposed and unexposed groups of children with no parents or delegated caregivers, as well as with known chronic diseases, were excluded from the study. Cholera cases were confirmed by experts from the Ethiopian Public Health Institute.

Data collection techniques and tools

A structured questionnaire was developed in English and translated into local languages (Amharic and Afaan Oromo) for better understanding by the participants. To ensure consistency, the translated questionnaire was back-translated into English. The questionnaire was modified and adapted from Ethiopian protocols for the management of severe acute malnutrition as well as from various literature sources (26–32). The data collection team consisted of 10 professionals. Eight of them were data collectors who held Bachelor's degrees, and two were supervisors with Master's degrees.

The principal investigator provided training to the data collectors and supervisors, covering the study's objectives, the measurement techniques of each characteristic, completing the questionnaire, and addressing any issues encountered. Data were collected from cholera-exposed and unexposed children using the Open Data Kit (ODK) data collection tool and follow-up registration log book.

A well-structured questionnaire (Supplementary 1) was used in the data collection process that involved obtaining information by interviewing parents of cholera-exposed children at the time of their discharge from the CTC. MUAC measurements were taken from children during their follow-up time. Concurrently, data were gathered from the unexposed group within the community. The data collection procedure entailed conducting face-to-face interviews with parents or caregivers and measuring the mid-upper arm circumference (MUAC) of the sample children.

The study had two groups of participants (cholera-exposed and unexposed children), and the data were collected using an Open Data Kit (ODK) application. The data collection process involved obtaining information from the parents of cholera-exposed children at the time of their discharge from the cholera treatment center. Simultaneously, data were gathered from the unexposed group within the respective nearby strata in the community. The mid-upper arm circumference (MUAC) was measured. Severe acute malnutrition (SAM) was determined using a MUAC measurement with a cutoff value of less than 11.5 cm based on the Ethiopian SAM guidelines. From both Cholera-Exposed and Unexposed groups, children with MUAC measurement <11.5 cm undergo the follow-up to determine the time to recovery and the factors associated. Further definitions of key terms are included in Supplementary 2.

During data collection, children with a mid-upper arm circumference (MUAC) measurement less than 11.5 cm were identified as having severe acute malnutrition, regardless of whether they were in the exposed or unexposed groups. These participants with severe acute malnutrition were then included in the analysis.

The follow-up of SAM children was monitored weekly at health posts, health centers, and their homes for 6 weeks. Follow-up was done at health centers until SAM children were able to eat and move independently after which, they were linked to health posts for further follow-up. The SAM Children who can eat and move independently were followed at health posts that directly came from the health center, the CTC, or traced from the community using the SAM screening program weekly. All the SAM children were checked every week starting from the date of screening and diagnosis for SAM, and the event status was determined every week (outcome of interest or censored). Additionally, the study ensured regular monitoring of the children every week during the follow-up period, which helped to minimize the potential delays in determining the outcome of interest.

Data analysis

The main outcome variable is time to recover from SAM among children. The data were imported from the Open Data Kit (ODK) tool to SPSS and Stata for cleaning and analysis. Statistical Package for Social Science (SPSS) version 25 software was used for descriptive analysis and to generate lifetable. Most statistical analyses were done using STATA version 18 including generating a cumulative hazard plot of Cox-Snell residuals for model fitness and the Kaplan–Meier survival curve.

The outcome for each participant was dichotomized into either censored or event/recovered. Children whose mid-upper arm circumference (MUAC) measurement was greater than 11.5 cm were considered to have recovered. Participants who missed two or more consecutive weekly follow-up visits were classified as defaulters. Those children who defaulted (missed two or more consecutive weekly visits) or died during the study period were categorized as censored observations.

Life table analysis was employed, to estimate the cumulative proportion of survival time at different time points. The Kaplan–Meier test was used, to compare the median recovery time between various independent groups. The log-rank test was also used to examine the significant relationship between the time to recovery and the different independent groups. These analytical techniques were used to comprehensively understand the survival and recovery patterns within the study population and the potential influence of various independent determinants on the time-to-recovery.

To check the proportionality of hazards among different groups of individuals, the Proportional Hazards (PH) assumption was employed. This assessment was conducted subjectively using Kaplan–Meier estimators, predicted survival curves, and log–log plots of survival curves. In addition, an objective evaluation was performed using Schoenfeld residuals.

The analysis sought to identify variables that demonstrated a good fit within the model. Variables that met this criterion demonstrated parallel lines in the survival graphic presentation and yielded a global test statistic with a p-value greater than 0.05. These variables were considered to adhere to the PH assumption and included in the model. Finally, the Cox–Proportional hazard model was used after checking all the assumptions of the PH model. Variables with a p-value less than 0.25 in the bivariable analysis were selected and included in the multivariable analysis. A multivariable Cox proportional hazards model was fitted to control the confounding variables. The statistical analysis with a p-value less than 0.05 was declared as a statistically significant association.

Results

Background characteristics of children with SAM

In this study, a total of 550 children were screened for SAM with a 97.1% response rate. From the screened children, 224 children with SAM were included. Half of the screened children (275) were cholera-exposed. The children's mean (±SD) age was 3.6 (± 2) years. Among the participants 121 (54%) of the children were males. Of them, 158 (70.5%) children were under 5 years old. Three-fourths of the children 167 (74.6%) came from parents with more than four family members. A high percentage of parents, 202 (90.2%) had no formal education. Of the children included in the cohort study 178 (79.5%) [95% CL: 73.6–84.6] recovered from severe acute malnutrition (Table 1; Figure 1).

In the study, there are many independent variables and their profiles are recorded below in the table. That includes 176 (78.6%) of children who came from parents who suffered from food insecurity, and almost three-fourths, 166 (74.1%) of them had less than three times the frequency of meals per day. In addition, 194 (86.6%) of them had poor dietary diversity. Even though 133 (59.4%) parents had a good attitude toward nutrition, only 72 (32.1%) of the husbands were involved in child-feeding practices. On the other hand, 125 (55.8%) of parents had poor nutrition knowledge. Regarding food preference, 188 (83.9%) of children's food preferences were not kept rather they were forced to eat available food in the house (Table 1).

Most of the parents, 171 (76.3%) relied on unprotected water sources such as rivers, wells, or natural springs to meet their water needs. Only, 102 (45.5%) households employ any water treatment method to ensure the safety of their water supply. Of these households, 28 (12.5%) used chemicals for water treatment to make it safe for consumption. Regarding immunization practice, 29 (12.9%) of the children had received full vaccination against cholera (Table 1).

Time to recover from SAM and the recovery rate

In this cohort study more than three-fourths of children had recovered from SAM with a recovery rate of 40/1000 [95% Cl:

TABLE 1 Profile of independent variables on time to recovery among SAM children, at Bale and Guji Zones of Oromia Region, Ethiopia from 20 September 2022 to 21 February 2023 (n = 224).

Variables		Frequency; n (%)	Cholera exposure status	
			Yes, n (%)	No, n (%)
Sex of children	Male	121 (54)	88 (72.7)	33 (27.3)
	Female	103 (46)	65 (63.1)	38 (36.9)
Age of children	< 5	158 (70.5)	110 (69.6)	48 (30.4)
	5–14	66 (29.5)	43 (65.2)	23 (34.8)
Family size	≤ 4	57 (25.4)	41 (71.9)	16 (28.1)
	>4	167 (74.6)	112 (67.1)	55 (32.9)
Educational status of Parents	Did not Attend school	202 (90.2)	142 (70.3)	60 (29.7)
	Attend school	22 (9.8)	11 (50)	11 (50)
Husband involvement in child-feeding	No	152 (67.9)	99 (65.1)	53 (43.9)
	Yes	72 (32.1)	54 (75)	18 (25)
Food insecurity	Food security	48 (21.4)	43 (89.6)	5 (10.4)
	Food insecurity	176 (78.6)	110 (62.5)	66 (37.5)
Dietary diversity score	Poor	194 (86.6)	127 (65.5)	67 (34.5)
	Good	30 (13.4)	26 (86.7)	4 (13.3)
Food reference of child	Forced to eat	188 (83.9)	134 (71.3)	54 (28.7)
	Change the food	36 (16.1)	19 (52.8)	17 (47.2)
Meal frequency	<3 times	166 (74.1)	108 (65.1)	58 (34.9)
	≤ 3 times	58 (25.9)	45 (77.6)	13 (22.4)
Water source	None pipe	171 (76.3)	103 (60.2)	68 (39.8)
	Pipe	53 (23.7)	50 (94.3)	3 (5.7)
Water treatment practice	No	122 (54.5)	69 (56.6)	53 (43.4)
	Yes	102 (45.5)	84 (82.4)	18 (17.6)
Water treatment type	Traditional	74 (33)	69 (93.2)	5 (6.8)
	Chemical	28 (12.5)	15 (53.6)	13 (46.4)
Knowledge of nutrition	Poor	125 (55.8)	92 (73.6)	33 (26.4)
	Good	99 (44.2)	61 (61.6)	38 (38.4)
Attitude on nutrition	Poor	91 (40.6)	70 (76.9)	21 (23.1)
	Good	133 (59.4)	83 (62.4)	50 (37.6)
Oral Cholera vaccine status	Not fully Vaccinated	195 (87.1)	139 (71.3)	56 (28.7)
	fully Vaccinated	29 (12.9)	14 (48.3)	15 (51.7)
Recovery status	Recovered	178 (79.5)	120 (78.4)	58 (21.6)
	Censored	46 (20.5)	33 (81.7)	13 (18.3)

35/1000–46/1000] person-week observation, and with a median recovery time of 21 [95% Cl: 19–22, and IQR: 14–28] days.

The survival table shows that the cumulative probability of not recovering from severe acute malnutrition (SAM) decreased over time. On the 7th day, the cumulative probability of not recovering was 91%. By the 14th day, this probability decreased to 69%. On the 21st day, the cumulative probability was reduced to 38%, indicating that a significant proportion of individuals recovered from SAM at this point. As the follow-up continued, the cumulative probability of not recovering decreased even further. By the 28th day, only 17% of individuals did not recover from SAM in the follow-up. On the 35th day, this probability reduced to 5%, indicating that most individuals had successfully recovered from SAM at this time (Table 2).

Kaplan–Meier hazard curve and survival difference

The Kaplan–Meier curve analysis provides further insights into the survival and recovery rates of children with Severe Acute Malnutrition (SAM) over time. The results show a significant survival difference in the time of recovery from SAM for cholera-exposed children compared to unexposed children. The generated Kaplan–Meier curves for the two groups (exposed and unexposed) and the log-rank test to determine the statistical significance of the observed difference in recovery rates, evidenced by the log-rank test ($p < 0{\cdot}001$; Figures 1, 2).

Determinants of time to recovery among SAM children

The final model allowed for the simultaneous consideration of various determinants and their respective hazard ratios (HRs) while adjusting for potential confounding variables. In the study, the identified determinants include cholera exposure status, household food insecurity, meal frequency, and parent's attitudes toward nutrition. Accordingly, cholera-exposed children had 54% [ARR: 0.46, 95% CI: 0.30–0.69] less likely to recover quickly from SAM than unexposed children (Table 3).

Children from food-insecure families had a 39% [ARR: 0.61, 95% CI: 0.38–0.96] lower probability of fast recovery from SAM than children from food-secure families. In addition, the probability of faster recovery from SAM was 1.61 times higher among children who had three or more meals per day [ARR: 1.61, 95% CI: 1.04–2.50] compared to those who had less than three meals per day. Moreover, children having families with good attitudes toward nutrition had a 2.23 times lower probability of faster recovery [ARR: 2.23, 95% CI: 1.45–3.41] from acute malnutrition compared to their counterparts (Table 3).

After conducting the multivariable Cox Regression analysis, the overall Schoenfeld global test was applied to test the assumptions of proportional hazards objectively. Finally, to examine the overall fit of a Cox model, we applied the Cox-Snell plot as if the hazard function followed the 45-degree line. It revealed that the hazard function approximately has an exponential distribution with a hazard rate of one that indicates the model fits the data well (Figures 1, 3).

Discussion

The study findings indicate that the recovery rate was 79.5% [95% Cl: 73.6–84.6%]. This indicates that even though this finding falls within the acceptable international sphere standards (33), a significant proportion of children (one in five children) did not recover from SAM. This finding is alarming and shows further actions are required to increase the recovery rate of children with SAM. Consistent

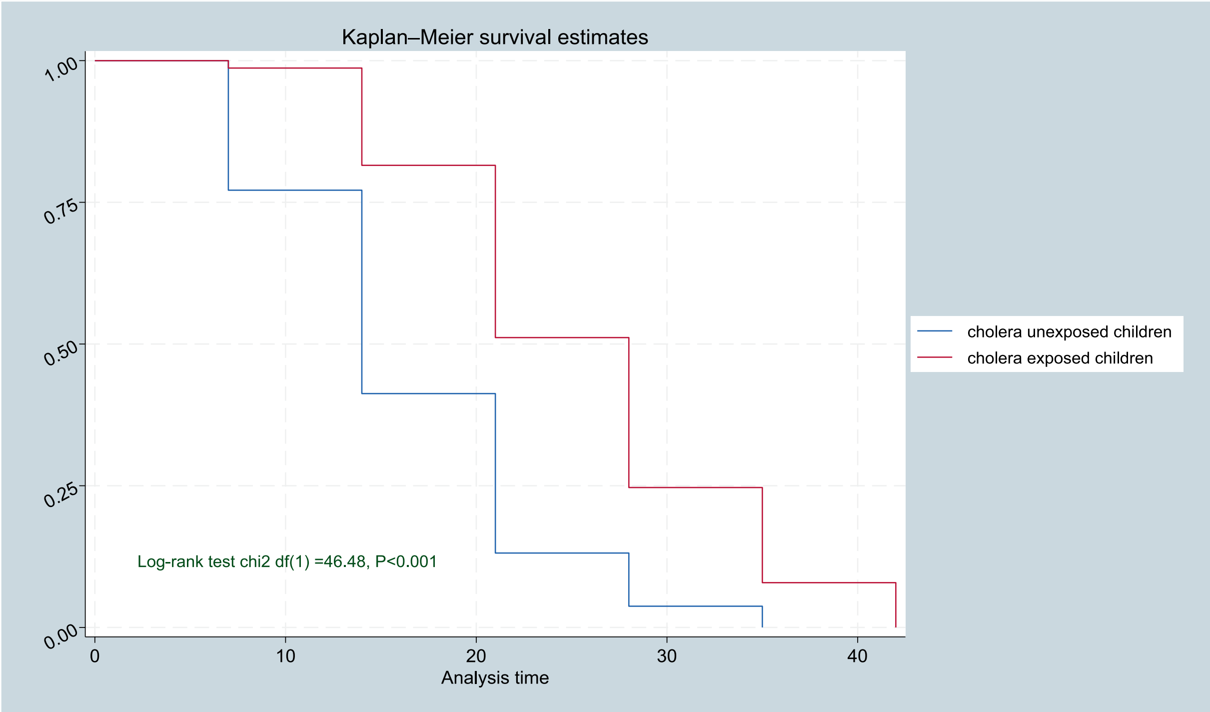

FIGURE 1
Kaplan–Meier survival function estimates of cholera-exposed and unexposed SAM children, in Bale and Guji Zones of the Oromia Region, Ethiopia from 20 September 2022 to 21 February 2023 (*n* = 224).

TABLE 2 Life table of cholera-exposed and unexposed severe acute malnourished children, in Bale and Guji Zones of the Oromia Region, Ethiopia from 20 September 2022 to 21 February 2023 (*n* = 224).

Interval start time	Number entering interval	Number withdrawing during interval	Number exposed to risk	Number of terminal events	Proportion terminating	Proportion surviving	Cumulative proportion surviving at end of interval
0	224	4	222	0	0.00	1.00	1.00
7	220	21	209.5	18	0.09	0.91	0.91
14	181	5	178.5	44	0.25	0.75	0.69
21	132	11	126.5	56	0.44	0.56	0.38
28	65	3	63.5	35	0.55	0.45	0.17
35	27	2	26	19	0.73	0.27	0.05
42	6	0	6	6	1.00	0	0

findings were shown in the study done in Addis Ababa and Southern Ethiopia (14, 23, 34), On the other hand, this study has a lower recovery rate than the study done in Eastern, Ethiopia (35). The possible reason for this variation might be due to Cholera exposure in our study. Cholera exposure can indeed impact recovery rates, as it is a serious bacterial infection that can lead to dehydration and other complications, and a lower recovery rate observed in the population might be linked to increased cholera exposure. In the study, cholera exposure appears to be one of the determinants that contribute to the lower recovery rate observed in the current study population.

The study showed the median time to recover from severe acute malnutrition was 21 days (IQR: 14 to 28 days). This median recovery time, and therefore the length of stay at the stabilization centers, was consistent with the accepted international minimum standard of (<30 days) for the management of severe acute malnutrition (33). Consistent with our study, the research conducted at Jimma University, and Bahir Dar Northwest Ethiopia findings reported a similar time to recovery of severe acute malnutrition in children (28, 29).

On the other hand, the studies conducted in Tigray region, Harar, Yekatit 12 Hospital, Hawassa University, Jimma University, and Woldia Hospital in Ethiopia were found to be a lower time to recovery from SAM than the median recovery time observed in the current study (14, 22, 36–40).

The possible reason for the longer recovery time from SAM in this study may be that it was conducted during an emergency in which

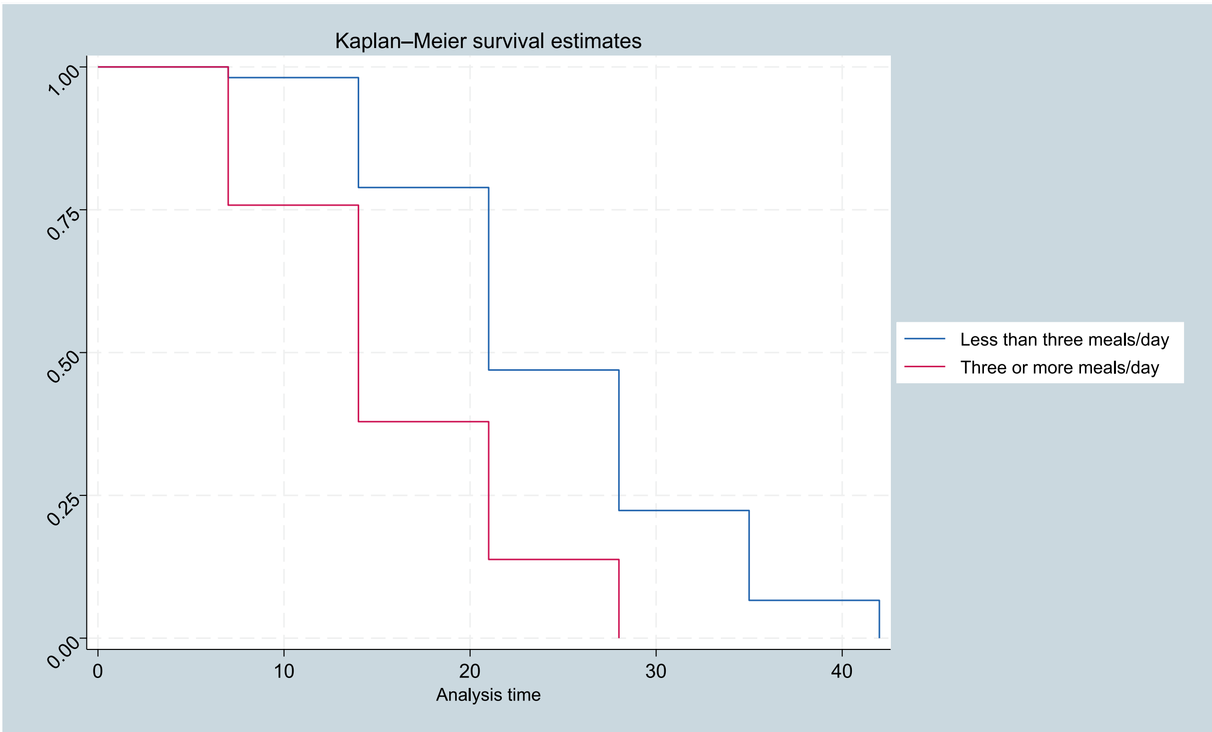

FIGURE 2
Kaplan–Meier survival function estimates by meal frequency of SAM children, in Bale and Guji Zones of the Oromia Region, Ethiopia from 20 September 2022 to 21 February 2023 (*n* = 224).

most of the participants were exposed to cholera, supply interruptions, and the quality of healthcare provided was called into question. These contextual factors likely contributed to the longer recovery times observed in this study compared to others. In addition, the severity of the included cases is also another factor, when severe cases would inherently require longer recovery periods compared with mild presentations of acute malnutrition, cholera exposure leads to the severity of cases.

Moreover, various studies conducted in the Borena zone of Ethiopia, Southern Ethiopia, and North Gondar zone, Northwest Ethiopia found a longer recovery time than the current study (21, 23, 34). The observed differences in median recovery time across these studies may be due to various factors including the study's setting, location, and sampling methods. For instance, one study was carried out in the Borena zone within the Oromia region of Ethiopia (23), which is a frequently drought-affected peripheral part of the country. In another study conducted in southern Ethiopia (34), the threshold used to identify children with severe acute malnutrition (SAM) was 11 cm, which captured more severe cases compared to the usual MUAC cutoff point of 11.5 cm. The third study was facility-based (21), exposing participants to additional health conditions that extended the recovery period from SAM.

In this study, the main identified determinants include cholera exposure status, food security status, meal frequency, and parents' attitudes toward nutrition. The study showed that cholera-exposed children were more than 60% times less likely to recover quickly from SAM. Consistently, various studies have shown that diarrheal diseases, such as cholera exposure, serve as significant determinants of SAM in children (12, 41–44). Diarrheal diseases can exacerbate nutrient deficiencies and wasting, making children more vulnerable to the severe consequences of SAM that make the recovery time longer. Reducing cholera exposure in children and other diarrheal diseases may be an effective strategy for reducing such life-threatening forms of malnutrition in children.

Food security encompasses the availability, accessibility, and utilization of food that meets individuals' dietary needs and preferences (45). In the context of this study, food security played a crucial role in the recovery process of children affected by severe acute malnutrition. Children from food-insecure families were more than 40% less likely to recover quickly from severe acute malnutrition (SAM) compared to children from food-secure families. Consistent with this finding, other studies conducted in Ethiopia have reported that children from food-secure families had shorter recovery times from SAM than those from food-insecure families (39, 46, 47). Additionally, another study found that an increase in monthly household income was associated with a reduced hazard of recovery from SAM in children (48).

In this study, children who had three or more meals per day were more than one and a half folds more likely to recover from acute malnutrition quickly compared to children who had less than three meals per day. Similarly, other studies have revealed that higher meal frequencies are associated with a lower risk of disease, and inadequate meal frequency is linked to a higher risk of prolonged recovery time from acute malnutrition in children (26, 27, 52).

In contrast to this, the research conducted in South Africa reported that meal frequency is not a reliable predictor of the time to recover from acute malnutrition in children (26). The reason for inconsistency findings may be attributed to differences in study settings which could introduce different variables and

TABLE 3 Bivariable and multivariable Cox regression analysis of determinants of cholera exposed and unexposed SAM children, at Bale and Guji zones of Oromia Region, Ethiopia from 10 September 2022 to 21 February 2023 (*n* = 224).

Variable		Cholera exposure		CHR [95%CI]	AHR [95%CI]
		Yes (%)	No (%)		
Food security status	Secure	43 (89.6)	5 (10.4)	1	1
	Insecure	110 (62.5)	66 (37.5)	0.76 [0.53–1.09]	0.61 [0.38–0.96]*
Attitude of parents	Poor	70 (76.9)	21 (23.1)	1	1
	Good	83 (62.4)	50 (37.6)	3.17 [2.21–4.54]***	2.23 [1.45–3.41]***
Meal frequency/day	< 3 times feed	108 (65.1)	58 (34.9)	1	1
	≥ 3 times feed	45 (77.6)	13 (22.4)	2.75 [1.87–4.04]***	1.61 [1.04–2.50]*
Cholera exposure status	Un exposed	71 (31.7)	0	1	1
	Exposed	153 (68.3)	0	0.41 [0.29–0.56]***	0.46 [0.30–0.69]***

NB: 1: Reference category; *p-value < 0.05; **p-value < 0.01; ***p-value < 0.001. 2: CHR, Crude Hazard Ratio; AHR, Adjusted Hazard Ratio. [1]The model was adjusted for the following 10 independent variables, age, Family size, educational status of parents' cholera exposure status, Food security status, Attitude of parents on nutrition, Meal frequency/day, OCV status, water treatment practice, and food preference of children.

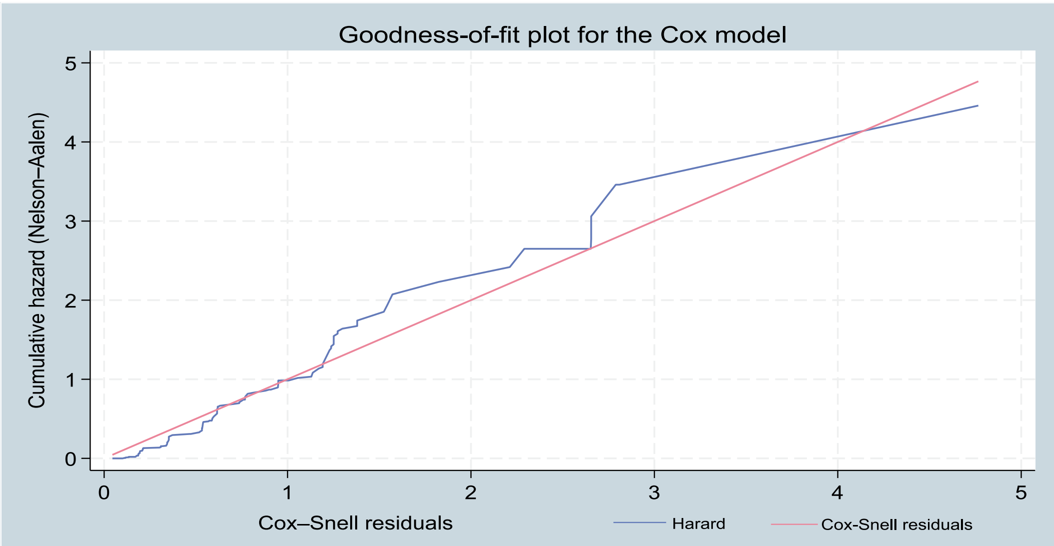

FIGURE 3
A cumulative hazard plot of Cox-Snell residuals for model fitness.

influences that impact the recovery process and types of food they eat. This study was conducted in a community-based setting, while the study in South Africa was conducted in a hospital setting, among children receiving quality medical care in a clinical environment, which may have contributed to a lower recovery time observed in that study.

Children from families with positive attitudes toward nutrition increased the recovery rate from severe acute malnutrition (SAM), compared to their counterparts. Similarly, a study conducted in central Ethiopia, found that fathers with positive attitudes toward nutrition were involved in child-feeding practices, compared to those with negative attitudes, studies done among Ugandan caretakers showed that those who had a positive attitude had absolute adherence to nutrition care (49–51). These findings underscore the significant impact that family attitudes and beliefs about nutrition can have on child health and feeding behaviors. Families with more positive, proactive stances toward nutrition appear to provide an environment that facilitates better recovery from malnutrition in children. The findings imply the need for enhanced clinical vigilance and follow-up of the children with SAM exposed to cholera to fasten their recovery and prevent associated mortality and prolonged stay in the health facility.

In the study area, communities frequently move to find food for their cattle. This continuous movement often resulted in missed follow-up appointments, as they would only return home in the evening. Due to this interruption, MUAC measurements could not be taken from the SAM children during their follow-up, leading to a higher rate of defaulters.

Conclusion

The study revealed that nearly two-thirds of the children recovered from SAM within 3 weeks. The study also showed that cholera exposure is one of the main determinants of prolonged recovery time SAM among children. Various studies had a shorter median recovery time compared to the results of this particular study because of cholera exposure status. Besides cholera exposure status, this study identified key determinants that influence the time to recovery from SAM in children, including, food insecurity, meal frequency, and the attitude of parents toward nutrition.

Healthcare providers and policymakers should take into account the complex interplay between different health conditions when designing interventions to improve recovery outcomes for individuals affected by severe acute malnutrition, especially in contexts where infectious diseases such as cholera pose additional challenges.

Targeted interventions to prevent or mitigate cholera exposure could potentially help improve recovery times among children. Additionally, food insecurity is a key determinant that can influence time to recovery from SAM and nutritional outcomes. Ensuring access to adequate, nutritious food is foundational to combating malnutrition. This emphasizes the importance of implementing interventions that target the underlying factors contributing to food insecurity, such as poverty and agricultural challenges.

Furthermore, adequate and frequent meals are crucial in the fight against malnutrition. Providing children with the necessary caloric and nutrient intake through regular, well-balanced meals can significantly contribute to their recovery and long-term health. Increasing community attitudes about balanced diets is also an essential intervention strategy to reduce malnutrition among children. Educating families on the importance of proper nutrition, feeding practices, and food preparation can empower them to make informed decisions and sustain positive changes in their children's diets. Developing interventions that account for this multifaceted reality could be more effective in improving recovery times and outcomes for children suffering from SAM, including cholera exposure, food security, meal frequency, and attitudes toward nutrition.

Data availability statement

The materials and data utilized in this study can be accessed upon request to the corresponding author with the approval of the Ethiopian Public Health Institute.

Ethics statement

The studies involving humans were approved by Gizachew Tilahun (Chair, JUIH-IRB), Jimma University Institute of Health, Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

ABA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. KA: Conceptualization, Formal analysis, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AMA: Formal analysis, Methodology, Software, Supervision, Visualization, Writing – review & editing, Writing – original draft, Data curation, Resources. YD: Data curation, Writing – review & editing, Investigation. MG: Data curation, Investigation, Writing – review & editing, Resources. TB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – review & editing, Writing – original draft, Project administration, Resources.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Transforming a hospital's organizational culture to promote parent-child relationships and child development

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Introduction: Early caregiving interactions and experiences profoundly shape a child's brain development. The American Academy of Pediatrics (AAP) recently advocated for a public-health approach to promoting safe, stable, nurturing relationships that is "founded on universal primary preventions", including consistent messaging on fostering family resilience, nurturing connections, and positive childhood experiences. Hospitals have unique access to families with children ages 0–5 and therefore play a key role in supporting these early experiences. This project sought to shift the organizational culture of maternity and pediatric units at a hospital towards promoting early relationships and child development through a physical messaging campaign paired with staff training. This study examined whether the messaging campaign and staff training shifted staff's self-reported knowledge, attitudes, and behavior.
Methods: Non-physician staff across six pediatric and maternity units in a large urban hospital participated in the intervention. Staff completed surveys before and after message installation and training.
Results: Analysis of 356 pre-intervention surveys and 320 post-intervention surveys showed significant changes in staff's knowledge, attitudes, and behaviors that promote early learning and parent-child relationships. Most staff also reported feeling more empowered in their work (88%) and that the hospital environment had become a friendlier place for parents and families (89%).
Discussion: A messaging and training intervention can create a culture whereby staff support early caregiving and child development in the hospital setting. Further research is needed to understand whether the intervention impacts caregivers and their children.

KEYWORDS

brain development, early learning, messaging campaign, healthcare, positive parenting, culture change, nurturing relationships, organizational culture

Introduction

Early caregiving interactions and experiences profoundly shape a child's brain development (1). Parenting engagement can influence a child's academic success (2), future relationships (3), social-emotional and cognitive growth (4) and even physical health (5). In addition, safe, stable, nurturing relationships (SSNRs) can buffer against the negative impacts of adversity and toxic stress on a child's development and health (6). The American Academy of Pediatrics (AAP) recently advocated for a public-health approach to promoting SSNRs that is founded on universal primary prevention, including consistent messaging on fostering family resilience, nurturing connections, and positive childhood experiences (1).

The hospital and health care system hold unique access to families with children ages 0–5 years – the most critical time for brain development – due to the regular frequency of well-child visits during these early years, and the need for treatment related to the frequent illnesses young children experience (7). In fact, one study found that during the first three years of life, children experience a median 94 days when they have infections (8), For families, it may well feel as though they are "constantly" at the doctor's office during this window in time. A large academic hospital leveraged these regular family interfaces with health care staff in order to deliver messaging and training that supports positive parenting interactions and child development. Existing hospital campaigns designed to provide information about safe sleep and breastfeeding have shown success promoting awareness and behavior change through a dual approach of staff training and public health messaging (9, 10). Harnessing this concept, we sought to apply a similar health communication model regarding the importance of SSNRs. This paper reports an overview of the project and data from the evaluation study.

The environmental transformation project

This project sought to communicate messages about early parent-child relationships and child development by transforming the organizational culture of maternity and pediatric units at a large, urban, teaching hospital. We employed Schein's theory of organizational culture (11), which has been widely used within healthcare organizations to catalyze cultural change (12–14). This theory posits that organizational culture exists on three levels. The first, the most visible, consists of physical artifacts, or the observable aspects of culture. These reflect the second level, which consists of values and beliefs, at least as articulated by individuals. These, in turn, are informed by basic underlying assumptions, the third level of organizational culture. These are the widely accepted beliefs about human nature and reality that may be unconscious and/or unstated.

Change that is not rooted in culture can often be transient. Schein suggests that every culture has strengths that can be drawn upon and reframed to be supportive of the desired change. In this way, new behaviors and values can be tied to existing assumptions and values, given legitimacy, and made more acceptable and less threatening. Over time, these new behaviors are tried, and if people recognize that they work well to bring about desired results, new assumptions arise to articulate the cultural lessons learned.

The Environmental Transformation Project was designed to change parents' and children's experiences of health care by targeting all three levels of the organizational culture surrounding caregivers and children aged 0–5 at our hospital. Consequently, the project entailed not only transforming the physical environment but also the values and assumptions held by all staff who interact in any way with caregivers of children in that age group. Physicians themselves were targeted in a separate, more intensive medical education curriculum initiative focusing on well child care. The underlying goal was to ensure that the messages being shared with patients through visible artifacts were reinforced through patients' interactions with all types of hospital staff. We now describe how that goal was achieved.

Methods

The intervention

Figure 1 depicts the three stages of project development. In the first step, a multidisciplinary team identified "touchpoints" throughout six units within the hospital for transformation: the Prenatal Clinic, Labor and Delivery, Postpartum Units, Neonatal

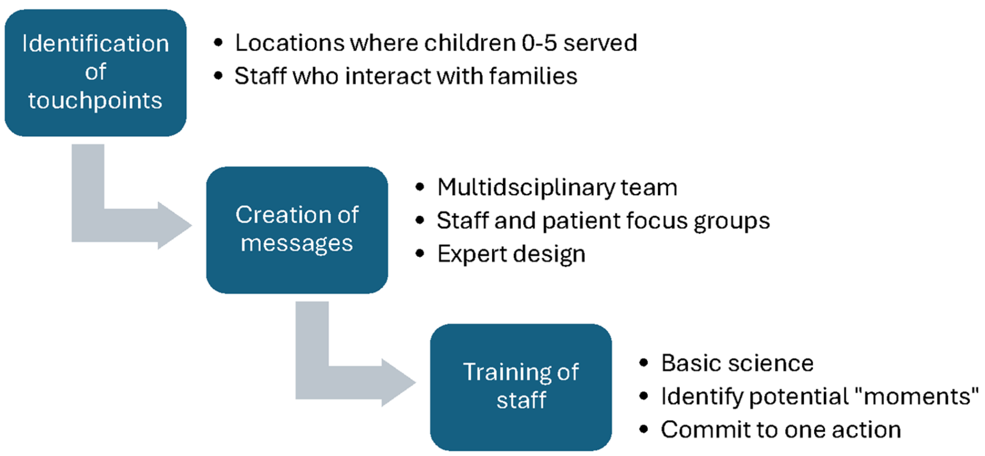

FIGURE 1
Design of the environmental transformation project.

Intensive Care, Pediatric Primary Care Clinic, and Pediatric Emergency Department. The Pediatric Inpatient Unit was not included because it does not specifically target young children. This involved, first, identifying all hospital staff who engage with infants and children up to age 5 and their parents. Staff represented food services, housekeeping, transport, and security, in addition to traditional non-physician clinical roles such as nurses, lactation consultants, and medical assistants. Second, the team identified the physical locations, such as elevator banks, front desks, mirrors, and hand sanitizers, which were most visible to families.

In the second step, the team created staff- and family-facing messages in English and Spanish to promote SSNRs and child development. These messages were intended to serve as prompts for interactions between caregivers and children and between staff members and caregivers. Unit staff and families from the hospital's Patient Advisory Committee reviewed the content for relevance and tone. Staff focus groups explored the feasibility and ease of integrating these messages into healthcare interactions, while family focus groups provided feedback on messages' content, inclusivity, and relatedness.

An expert design team created over 100 images to support the approved messages. A multidisciplinary panel then reviewed the final illustrated messages. They all shared a similar format. They each begin with "Did you know?" and then offer a piece of information about how children develop, followed by "Have you tried?" and a specific activity to encourage engagement between caregivers and children, followed by "It's science!" and a brief scientific explanation about why the activity is important. Messages focused on themes such as the rapid development of a young child's brain, the importance of everyday interactions with caregivers, and how professionals in all roles can support positive parenting by modeling, discussing, and praising (Figure 2). All messages were framed in a strengths-based fashion (i.e., building on families' existing competencies), which reflected the foundational values of respect and dignity, information-sharing, and participation in family-centered care (15). Whenever possible, messages were tied into the surrounding environment, e.g., meals served to postpartum mothers were set on a paper placemat messaging the importance of mealtimes as opportunities for caregivers to discuss family traditions with children.

The third step of the intervention was the creation and delivery of staff training forums. Shortly after the messages were installed, staff in the six selected units were invited to participate in a 45-minute training designed to teach any staff member, clinical or not, who interacts with caregivers and children how they can use existing opportunities in their workflow to promote SSNRs and early child development. A 10-minute introductory video explained early brain development and described specific parenting behaviors that support healthy child development. Following the video, facilitators encouraged staff to identify the ways they could apply these concepts to their specific role in the hospital. At the conclusion of the session, each participant identified a specific moment in their work (e.g., greeting families, making beds, delivering meals) when they could share messaging from the project, and committed to one action they would take in the future. Locke and Latham's (16) goal setting theory of motivation suggests that the formulation of this specific and clear

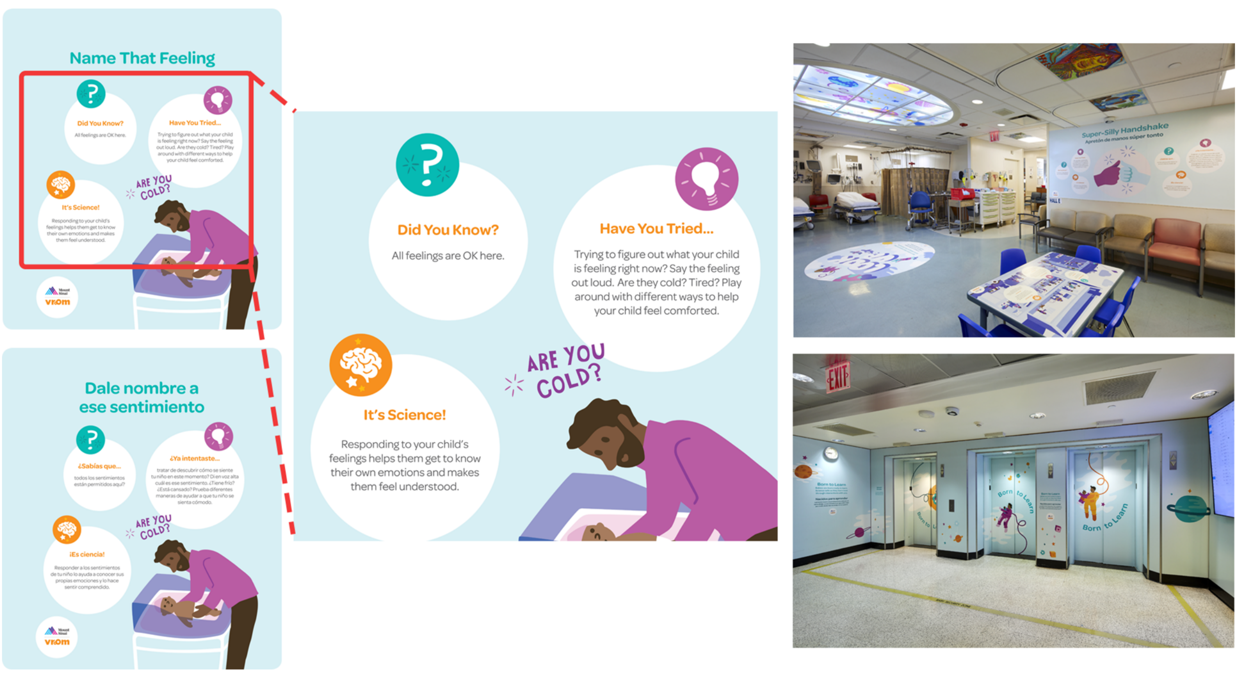

FIGURE 2
Project images.

intention may be linked to enhanced performance in practice. Two weeks after the training, an e-learning module was sent to staff to reinforce the training. In addition, monthly newsletters and frequent unit visits from project staff were also conducted to maintain engagement and awareness.

The evaluation

We conducted an evaluation to examine whether the environmental messaging and staff training shifted staff's self-reported knowledge, attitudes, and behaviors in the healthcare setting. Data collection first occurred between June 2019 through September 2020. There was a pause from March to August 2020 due to the COVID-19 pandemic, and data collection resumed in September 2020. The authors' Institutional Review Board deemed the study exempt.

Participants

Non-physician staff from the six participating hospital units were recruited 1–4 weeks before the messages were installed and the training occurred. Participants represented a wide range of roles, including nursing, medical assistants, social workers, lactation consultants, administration, housekeeping, food services, security, and transport. In each unit, we attempted to recruit 75% of staff for the pre-intervention survey.

We used a modified Delphi approach (17) to develop the survey instrument, which was reviewed by an interdisciplinary panel. Survey questions tapped participants' knowledge of early childhood development, attitudes about staff's role in promoting SSNRs and early brain development, their frequency of behaviors that promote SSNRs and early brain development, and perceived barriers to promoting SSNRs and early brain development.

Approximately 1–3 months after installing the messages and staff trainings, we administered a post-intervention survey. Almost all of the participants in the post-intervention survey attended a training. Furthermore, participation in the post-intervention survey was not conditioned on participation in the pre-intervention survey. All data collection occurred anonymously, making it impossible to link the respondents across the two surveys.

Measures

Both the pre- and post-intervention survey asked respondents to endorse five knowledge statements (e.g., "The brain grows fastest during the first five years of life") and two attitude statements (e.g., "Hospital staff can promote early brain development during typical interactions") using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). For the purpose of analysis, we selected the proportion who selected strongly agree. Respondents were also asked which of five strategies for early learning (e.g., responding to the child's sounds, actions or words) they discussed, modeled, or praised in interactions with caregivers, and which of five messages (e.g., "Positive relationships with caring adults are critical for early brain development") they discussed with caregivers using a yes/no checklist.

Three barriers to implementing the lessons from the training – lack of confidence, lack of buy-in (i.e., the belief that it was not part of their job), and lack of feasibility – were also assessed. Respondents were asked about their confidence, their buy-in and the feasibility of three behaviors: praising caregivers for what they are already doing, demonstrating positive adult-child interactions, and sharing information or messages about early learning and brain development. Responses were provided on a 5-point scale (1 = not sure, 5 = very much so); for analysis, we selected the proportion answering very much so. The post-intervention survey also gathered feedback on the training experience. The only information collected about respondents was their role and unit.

Analytic plan

Data were analyzed using IBM SPSS Statistics. Study respondents were characterized using descriptive statistics, and *t*-tests for independent samples were used to test for pre- and post-intervention differences on individual survey items. The *p*-value was set to 0.05.

Results

Staff knowledge, attitudes, and behaviors

The pre-intervention survey was completed by 356 staff across the six units, and the post-intervention survey was completed by 320 staff across the six units. There were no differences in terms of role and unit between the pre- and post-intervention survey respondents, with the exception of the Labor and Deliver unit, where the proportion of respondents who were nurses was higher in the post-intervention sample (see Appendix A for roles of participants).

Results showed that compared to before the intervention, after the intervention, staff scored statistically significantly higher on all attitude questions, and on four out of the five knowledge questions (Table 1). Staff were also statistically significantly more likely after the intervention than before to engage in all behaviors that promote early learning during interactions with caregivers (Table 2). They were also statistically significantly more likely to communicate all messages that promote early learning to caregivers.

Further, after the intervention, staff were more confident than before in their ability to engage in behaviors that promote SSNRs and early child development; more likely to believe that it was part of their role to routinely do so; and more likely to consider doing so feasible (Table 3). This was true of all three behaviors: praising caregivers, demonstrating positive adult-child interactions, and sharing information or messages. Further, 95% of staff reported that they were successful in making the change in practice they had resolved to make at the end of their training (not shown).

Post-Intervention perception of the hospital environment

We asked participants in the post-intervention survey to reflect on the impact of the project both on their perception of their role and on the hospital environment. Most staff (89%) agreed or strongly agreed that as a result of the project, they were more

TABLE 1 Knowledge and attitudes, Pre- and post-intervention.

	Pre-intervention (n = 356) % strongly agree	Post-intervention (n = 319) % strongly agree
Knowledge		
Positive relationships with caring adults are critical for early brain development	87	91
Parents can promote early brain development as part of daily routines	85	91*
It is important that parents talk to their children for early brain development – even before their children can talk	85	91*
Children start learning from the moment they are born	83	88*
The brain grows fastest during the first five years of life	76	88*
Attitudes		
At this hospital, we all have a role in encouraging children's early learning and brain development	66	84**
Hospital staff can promote early brain development during typical interactions	58	80**

*p < .05.
**p < .01.

TABLE 2 Behaviors, pre- and post-intervention.

	Pre-intervention (n = 356) % yes	Post-intervention (n = 319) % yes
Behaviors with caregivers/children		
Responding to the child's sounds, actions or words	83	91**
Making eye contact and looking into the child's eyes	82	92**
Paying attention to what the child is showing interest in	78	88**
Having back and forth interactions with the child (taking turns)	70	82**
Talking out loud about the things you are seeing, hearing and doing	70	84**
Asking the child open ended questions, like "what do you think about that?"	62	72*
Messages communicated with caregivers		
Positive relationships with caring adults are critical for early brain development	74	83**
Parents can promote early brain development as part of daily routines	71	80*
It is important that parents talk to their children for early brain development – even before their children can talk	71	83**
Children start learning from the moment they are born	74	88*
The brain grows fastest during the first five years of life	62	73**

*p < .05.
**p < .01.

TABLE 3 Potential barriers to implementation, pre- and post-intervention.

	Pre-intervention (n = 356) % very much so	Post-intervention (n = 319) % very much so
How confident do you feel in your ability to routinely…		
Praise caregivers for what they are already doing	64	77**
Demonstrate positive adult-child interactions	59	73**
Share specific information or messages about early learning and brain development	49	63**
To what extent do you believe it is part of your role to routinely…		
Praise caregivers for what they are already doing	70	81**
Demonstrate positive adult-child interactions	67	78**
Share specific information or messages about early learning and brain development	55	69**
In your setting, how feasible/realistic do you believe it is for someone in your role to routinely…		
Praise caregivers for what they are already doing	58	71**
Demonstrate positive adult-child interactions	50	68**
Share specific information or messages about early learning and brain development	42	62**

**p < .01.

patient- and family-centered in their interactions (not shown); most (88%) agreed or strongly agreed that they felt more empowered in their work; and most (89%) agreed or strongly agreed that the hospital environment had become a friendlier place for parents and families.

Discussion

This study evaluated a project that aimed to empower non-physician staff through a environmental messaging and training campaign focused on enhancing communications with families about early child development and positive parenting behaviors. Using visible artifacts and developing shared organizational values and beliefs through staff training led to significant improvement in staff's knowledge, attitudes, and behaviors. Prior to the intervention, staff reported high baseline knowledge around early child development, but did not report consistently communicating this information with caregivers as they did after the intervention. In addition, following the intervention, staff's beliefs and attitudes shifted so that the majority viewed the routine discussion of positive caregiver behaviors with families as one of their responsibilities. In fact, after the intervention, 95% of staff reported behavior change that promoted child development. This transfer from knowledge to practice, and from not viewing this to viewing this as part of their professional role, suggests that the project was successful in improving the hospital culture. The fact that 88% of respondents felt that the intervention made them feel more empowered also suggests that it may have enhanced the overall workplace environment.

Other hospital-based projects have successfully combined public-facing messages with in-staff training in the service of health promotion [e.g., Pineda et al. (18)], but such projects typically include clinical staff only. Lucarelli et al. (19) conducted training for front-line staff to familiarize them with, and prepare them for treating, children with autism spectrum disorder; these included front-desk staff but did not routinely involve staff from services such as housekeeping and food service. Yet an organization's culture is both internalized and expressed by staff in all roles, and any attempt to change that culture by transforming the physical environment alone is likely to be insufficient without concomitant attention to the values and assumptions held by members of that organization (12, 14).

Our aim was to provide both staff and caregivers with one consistent message: that young children's interactions with caregivers are of vital importance for child development. The evaluation results suggest that a highly targeted but relatively low-intensity intervention may be an effective way of delivering this message while also improving family-centered care. Existing research indicates that family-centered care models, policies, and programs designed to "help sustain" the caregiver role may "optimize care provision in the home" (20 p. 2). Establishing a clearer pathway of how professional interactions can contribute to positive family functioning may spotlight an important opportunity to mitigate risk factors and increase family resilience.

Limitations

This study has several limitations to consider. First, to some extent, respondents to the pre-intervention survey may not overlap with the respondents to the post-intervention survey. Second, those surveys relied on self-report, which may have been influenced by social desirability. Replication of this project with an observational study design would be valuable. Third, the post-intervention surveys were gathered within one month of the training, and lasting effects were not measured. Fourth, the COVID-19 pandemic disrupted data collection and had long-term implications for hospital flow and usage of unit space. The stress, strain, and hardship endured by patients and staff during the pandemic necessitated both structural and support changes that may have influenced the project's impact. Finally, it is unknown whether the intervention actually changed caregivers' knowledge, attitudes, and behaviors, and if so, whether those changes resulted in improved developmental outcomes for children.

Conclusion

This evaluation study is the first step towards understanding the effectiveness of a large-scale environmental messaging campaign aimed at engaging healthcare staff in strengthening SSNRs and promoting early child development. Evidence from other messaging and training campaigns (9, 10, 14, 18, 19), paired with the results from this intervention, suggest that shifting culture in healthcare settings is not only possible, but also worthwhile.

We believe this pairing of environmental prompts and professional guidance may serve as a health communication model for sparking change in the service of family-centered care practices and, in the case of our study, an increased sense of staff satisfaction and empowerment. Improvement in family-centered care and staff satisfaction are also key quality metrics for healthcare institutions, and interventions that can influence those outcomes warrant further investigation.

While designed for national adoption, long term assessment of this intervention is required to test whether this is a sustainable model to promote rich staff communication with families and positive parenting interactions and healthy development. Valuable avenues of future study might build on these initial findings to deepen the field's collective understanding of how visual assets, actionable messaging, and staff training can be combined and directed to different types of staff, and different populations of families, to achieve cultural change while improving family-centered care and supporting staff empowerment.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Icahn School of Medicine at Mount Sinai. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MB: Conceptualization, Writing – original draft, Writing – review & editing. CQ: Conceptualization, Writing – original draft, Writing – review & editing. AP: Conceptualization, Writing – original draft, Writing – review & editing. LF: Methodology, Writing – review & editing. RP: Writing – review & editing. EG: Conceptualization, Writing – original draft, Writing – review & editing. BH: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix A Participant roles and numbers.

Role	Pre-intervention *N* = 361	Post-intervention *N* = 328
Nurse	126	145
Business associate(BA)	47	32
Technicians	31	30
Social Worker	27	14
Patient care advocate/Associate	23	19
Registrars	14	12
Therapist/Specialist	10	9
Nursing assistant	9	7
Medical assistant/Associate	8	16
Nurse practitioner	7	3
Administrative staff	7	5
Midwife	4	2
Lactation consultant	4	4
Housekeeping	4	0
Food services	3	1
Clinical/Care coordinator	3	3
Photographer	2	3
Patient transporter	2	0
Guest/Patient services management	1	8
Clinical nurse manager	1	4
Other	15	9
Missing	13	2

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Omega-3 LC-PUFA consumption is now recommended for women of childbearing age and during pregnancy to protect against preterm and early preterm birth: implementing this recommendation in a sustainable manner

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Preterm birth (delivery prior to 37 weeks) appears to be rising globally, increasing the risk of a myriad of down-stream disorders which affect families, their offspring and society, including increased morbidity, mortality and economic costs. Strategies for prevention of preterm birth have therefore become a priority among healthcare providers. One proposed strategy is increased consumption of Omega-3 long-chain polyunsaturated fatty acids (LC-PUFAs), particularly docosahexaenoic acid (DHA) (from food or supplements) in women of childbearing age and during pregnancy. It is hypothesized that Omega-3 LC-PUFAs, through several different actions, reduce the risk of early onset labor or lengthen gestation. An expert group, acting on behalf of several relevant organizations, recently published guidance based on compelling trial evidence for increased Omega-3 LC-PUFA intake to protect women of childbearing age and during pregnancy from preterm birth (PTB) and early preterm birth (ePTB). Here, we consider how this guidance can be achieved in a sustainable manner. We present data on suitable, efficacious alternatives to fish as a source of Omega-3 LC-PUFAs, so that while aiming to protect families and society against PTB and ePTB there is no increased burden on other species on our vulnerable planet. Finally, how the guidance can be implemented in practice is discussed, with consideration for those most at risk and effective ways of communicating this important message.

KEYWORDS

omega 3 (n-3) polyunsaturated fatty acids, pregnancy, preterm (birth), sustainable omega 3s, maternal health

Introduction

Prevalence/incidence of preterm birth

Preterm (premature) birth (PTB) is defined as birth before 37 weeks gestation. The United Nations (UN) estimates that globally 13.4 million babies were born preterm in 2020, with nearly one million dying from preterm complications (1). This represents about 1 in 10 babies globally being born prematurely (1). Reports from Europe indicate that between 4.0 and 8.2% of all singleton live births are preterm, with significantly higher rates (up to 74.8%) in multiple pregnancies, although this may be artificially raised due to iatrogenic delivery of some multiple pregnancies, particularly monochorionic, prior to 37 weeks in accordance with guidelines (2). It has also been suggested that these numbers may be increasing in some regions (3). The Centers for Disease Control and Prevention (CDC) reported that the percentage of newborns delivered preterm in the United States (US) rose from 10.09% in 2020 to 10.49% in 2021 (4) with some groups, such as African Americans, experiencing increases of up to 14.4% (4). Globally, most (around 65%) PTBs occurred in sub-Saharan Africa and southern Asia with the greatest incidence rates seen in Bangladesh, Malawi and Pakistan (1). Around two-thirds of PTBs occur spontaneously in otherwise healthy women (5), while medically-induced or iatrogenic PTB also exists when in the best interest of the mother or baby, for example, in conditions such as preeclampsia. It is reported that PTB, and especially early PTB (ePTB: <34 weeks gestation), accounts for 85% of all perinatal complications (6).

The ripple effect of PTB and ePTB on infant/childhood well-being

Children born preterm have an increased risk of a myriad of disorders both physical and neurological, many of which can be lifelong, and these can exert substantial social, psychological and economic challenges on families and society (6). The annual economic cost of prematurity in the US was estimated to be as high as $25.2 billion (national aggregate costs in 2016) when lost productivity costs were also included (7), and increased by 4% from 2004 to 2016 when adjusted for inflation (7). Additional downstream costs related to illness resulting from PTB or ePTB (e.g., life-long management of conditions such as cerebral palsy) further add to this cost (8).

Studies suggest that increased survival of preterm, and especially early preterm, infants raises concerns due to the numbers who will go on to develop complex morbidities such as necrotising enterocolitis, broncho-pulmonary dysplasia, severe visual and hearing impairments, cerebral palsy, and cognitive developmental delay (9). In addition, there is an increased risk of developing non-communicable diseases (NCDs) such as cardiovascular disease, metabolic syndrome and obesity in later life (10, 11). These chronic morbidities place further challenges on the healthcare system.

Strategies for prevention of PTB and ePTB have therefore become a priority. In the UK for example, Saving Babies Lives version 3, The Department of Health's "Safer Maternity Care" report, extended the "Maternity 4 Safety Ambition" to include reducing preterm births from 8 to 6% (12). Multiple strategies have been proposed to do this, including implementing PTB leads and clinics in each healthcare organization, promoting smoking cessation and preventative methods such as cervical length scanning, progesterone use and cervical cerclage for those at high risk. Increasing the consumption of omega-3 long chain polyunsaturated fatty acids (LC-PUFAs) in women of childbearing age and during pregnancy has also been proposed as a preventative strategy (2).

Omega-3 long chain polyunsaturated fatty acids

Omega-3 fatty acids are a family of fatty acids that are considered essential nutrients for health. The parent fatty acid of this family is α-linolenic acid (α-LA) which cannot be produced by the human body due to the inherent inability of humans to desaturate oleic acid between the centrally-located double bond and its methyl terminus and therefore α-LA must be provided by the diet. One of the many important functions of α-LA is providing the LC-PUFAs docosahexaenoic acid (DHA) and eicosapentaenoic (EPA). DHA and EPA are synthesized from α-LA via desaturation and elongation, initially involving the sequential action of the enzymes delta 6 desaturase, elongase and delta 5 desaturase to produce EPA and then further desaturation and elongation to produce DHA. However, conversion from α-LA to the LC-PUFAs, especially to DHA, is considered to be relatively low (13). This places an emphasis on the need to consume preformed EPA and DHA in the diet. The richest dietary source of EPA and DHA is seafood, especially oily fish such as salmon, mackerel, sardines, and tuna. However, some freshwater fish such as trout are also rich in EPA and DHA.

Pregnancy imparts special nutritional needs on the mother and the fetus, and almost all nutrient needs are higher than in the non-pregnant state (14). The growing fetus has a requirement for preformed LC-PUFAs, such as DHA, which are supplied preferentially by placental transfer (15). Placental synthesis of LC-PUFAs is considered to be low (with limited activity of the requisite enzymes) and unlikely to meet fetal demands (16). Therefore, the mothers' stores (accumulated pre-pregnancy) and dietary intake (during pregnancy) represent the main supply of DHA to the fetus (16). Burdge et al. (17) reported that infants born to vegetarian mothers had lower status of DHA compared to those born to omnivores, possibly signifying the absence of preformed DHA in the mothers' diet. Recent interest has focused on the importance of these omega-3 LC-PUFAs, and especially DHA, in protecting against pregnancy disorders, such as PTB and ePTB. Currently, in many countries, including the United Kingdom, the benefits of consuming omega-3 LC-PUFAs in terms of protection against PTB and ePTB are not discussed with pregnant women.

The hypothesis—omega-3 LC-PUFAs protect against PTB

The hypothesis for protection from PTB by omega-3 LC-PUFAs was developed over 30 years ago based on data from the Faroe Islands (18). The authors proposed that omega-3 LC-PUFAs increased birthweight by prolonging gestation through interference with uterine prostaglandin (PG) production, inhibiting the production of the

2-series PGs involved in uterine contractions and promoting production of the 3-series PGs involved in cervical ripening (18). Omega-3 LC-PUFAs were also thought to be protective against placentation disorders (19). The proposed mechanism for this is that omega-3 LC-PUFAs, especially DHA, enhance the invasion of trophoblasts and the transformation of spiral arteries into larger vessels, reducing the risk of ischemia (19). Carvajal proposed that failure of normal placentation generates a series of clinical abnormalities called "deep placentation disorders" including preeclampsia, fetal growth restriction, preterm labor, premature rupture of membranes, *in utero* fetal death and placental abruption (19). Omega-3 LC-PUFAs also appear to support the relaxation of the myometrium, averting the early onset of labor through "antiarrhythmic" effects on the myometrium (20). Furthermore, omega-3 LC-PUFAs seem to limit oxidative damage and enhance reactive oxygen species (ROS) scavenging, as well as reducing inflammatory responses implicated in some PTBs (16). Finally, omega-3 LC-PUFAs have been associated with the regulation of oxytocin signaling which may prolong gestation (21). Consequently, omega-3 LC-PUFAs appear to protect against both spontaneous PTB as well as the need for medically-induced PTB, for example as a result of preeclampsia.

Numerous studies have been performed over the years demonstrating the benefits of omega-3 LC-PUFA consumption in the protection against PTB and ePTB, as well as many other additional benefits (22–24). These data have been eloquently summarized in the recently, supporting evidence-based guidance for intake of omega-3 LC-PUFAs in order to safeguard women of childbearing age, as well as pregnant women, against PTB and ePTB (2).

The recent guidance

Clinical practice guidance was recently developed by a group of international experts from several medical and scientific organizations (2), concluding that in order to reduce the risk of PTB and ePTB "*women of childbearing age should obtain a supply of at least 250 mg/d of docosahexaenoic acid (DHA)* + eicosapentaenoic *(EPA), from diet or supplements. While, during pregnancy they should receive an additional ≥ 100 to 200 mg/d of DHA*." In addition, the guidance proposes that pregnant women "*with a low status,* i.e.*, low DHA intake and/or low DHA blood levels*," who have an increased risk of PTB and ePTB birth should receive "*approximately 600 to 1,000 mg/d DHA + EPA respectively, or DHA alone*." This guidance is based on data from numerous clinical trials, showing that at this dosage there was a significant reduction of PTB and ePTB (6, 20, 25–31). Furthermore, the guidance proposes that "*this additional supply should preferably begin in the second trimester of pregnancy (not later than approximately 20 weeks' gestation) and continue until approximately 37 weeks' gestation or until childbirth if before 37 weeks' gestation*." The identification of women with inadequate omega-3 intakes might, the authors suggest, be achievable by using a set of standardized questions on intake. DHA measurement in blood was proposed as another option to identify women with low status, although the authors concluded that standardization of laboratory methods and appropriate cutoff values were still needed (2). Finally, it is suggested that "*information should be provided to*" women of childbearing age and pregnant women as well as their partners "*on how to achieve an appropriate intake*" of DHA or DHA + EPA.

These guidelines are based on compelling scientific evidence from randomized clinical trials (going back almost 25 years) demonstrating the benefits of omega-3 LC-PUFAs for the protection against PTB and ePTB; and constitute a formal consensus by experts in the field. As a follow-on from the guidelines, the European Board and College of Obstetrics and Gynaecology (EBCOG) came with a position statement where they concluded that the consumption of foods rich in omega-3 LC PUFAs, or supplements, was associated with a 11 and 42% risk reduction of early and late preterm births, respectively (32).

The aim of this review is to (a) discuss how to apply these important guidelines in practice and (b) consider how to achieve them in a manner that is sustainable for the planet.

Implementing the guidelines: practical considerations

Despite the undoubted importance of this new guidance, several considerations remain in terms of their implementation in practice. These include consideration for methods (i.e., how to get the correct message across knowing that current recommendations for omega-3 LC PUFA intake in the general population are not met), who the advice should be given to (all women, those with low omega-3 LC-PUFA status, those at high risk of PTB and, if advice is based on status, how to assess this in a cost-effective way), who should be responsible for giving the advice (data suggest pregnant women favor physicians who themselves need education), and the long-term viability of the guidance (thinking about sustainability/the planet).

Which groups are most at risk?

Women at risk of having a PTB or ePTB include those aged <20 years (33), those living with obesity (34), those with advanced age and complications during pregnancy (33, 35) and potentially those with a low omega-3 LC-PUFA status (6), especially DHA. In addition, when there is an economic crisis, which in some places worsened following the COVID-19 pandemic, pregnant women might be less able to source a healthy diet and/or acquire supplements (36). If money is an issue, women often prioritize their family before themselves, especially when they have other competing demands (37, 38).

Meanwhile, the risk of having low DHA status may be greater in women with pregnancy complications such as diabetes or preeclampsia, as well as obesity (39), and these conditions have been shown to have a negative effect on delta-6-desaturase activity (40–42), so reducing endogenous synthesis of omega-3 LC-PUFAs, as well as placental transfer of LC-PUFAs (39). Makrides et al. (25) reported that 80% of Australian women consumed some DHA during pregnancy, averaging ~150 mg/day. In the US, Gustafson et al. (39) reported that many women were taking prenatal DHA supplements with a mean intake of 104 mg/day. However, diet provided relatively small amounts of DHA, ~65 mg/day in the US (39).

Having a low omega-3 LC-PUFA status has been defined as red blood cell (RBC) phospholipid DHA (RBC-DHA) < 6% of total fatty acids (2). Simmonds et al. (24) found that women with a higher total omega-3 status (in RBCs) in early pregnancy had a lower risk of ePTB. Meanwhile Makrides et al. (25) reported that when DHA status was <6% at baseline then 1,000 mg of DHA had the biggest impact on ePTB protection. Women at risk of PTB include women with diabetes, those with a previous PTB or mid-trimester loss, previous preterm pre-labor rupture of membranes at less than 34 weeks, previous shortened cervix requiring cervical cerclage, previous uterine variant, previous birth by cesarean section at full dilatation, or previous cervical surgery including a Large Loop Excision of the Transformation Zone (LLETZ) procedure where >15 mm was removed or > 1 LLETZ.

Achieving these guidelines in a sustainable manner

It is well described that there are not enough fish in the oceans and rivers to sustainably support recommended intakes of omega-3 LC PUFAs (43). There were around 1.8 billion women of reproductive/childbearing age globally in 2019 and this is expected to increase to 2 billion by 2025 (44). If the omega-3 LC-PUFA guidelines were followed by just these women, the environmental impact would be huge. If each of these women were to consume at least 250 mg/d of DHA + EPA from fatty fish, this would equate to around 84 g of (skipjack, cooked) tuna/day or 29 g of (sockeye, cooked) salmon/day, or around 2–3 servings/week. When applied globally this would have a huge negative environmental impact and is not sustainable. The oceans and wild fisheries are already operating at full capacity causing concerns about the future quality and availability of food. The European Commission developed a common "*Fisheries and oceans pact towards sustainable, science-based, innovative and inclusive fisheries management*" which aims to focus attention on long-term sustainability for fisheries and aquaculture (45). This report states that fishing activities continue to adversely affect marine ecosystems, particularly through seabed disturbance, bycatch of sensitive species and effects on marine food webs (45). At the same time, the poor status of marine ecosystems is a direct threat to the sustainability of fisheries and aquaculture. Plastic, micro plastic and other pollutants from human activities at sea and on land (e.g., agriculture, fisheries, industry, shipping, waste waters) also have a negative impact on marine ecosystems and, consequently, on fisheries and aquaculture activities. Other aspects to consider are that the richest sources of omega-3 LC-PUFAs are cold water sea species, that these fish accumulate fatty acids via the food chain and that current sources of omega-3 LC-PUFAs are mostly fish-sourced. Raising ocean temperatures are likely to drive organisms lower down the food chain away from producing LC-PUFAs toward producing shorter chain and/or more saturated fatty acids which would reduce the entry of omega-3 LC-PUFAs into the food chain (46).

Are there alternatives to fish as sources of omega-3 LC-PUFAs?

Algae and algal oils

In recent years non-fish sourced DHA + EPA, mostly derived from algae, have become available. These are a sustainable alternative to consuming fish or using fish as the source of oil for supplements and help protect the planet by avoiding overfishing to meet human needs. Furthermore, algal oils are suitable for vegetarian and vegan consumers as supplemental sources of omega-3 LC-PUFAs. Heterotrophic microalgal species such as *Schizochytrium, Aurantiochytrium*, *Thraustochytrium*, and *Crypthecodinium cohnii* are essential producers of DHA (47). Oils produced from algae typically contain more DHA than fish oil (20–55% of fatty acids) with some EPA (Table 1) (47). Algal oils have been used in the infant formula industry for many years, providing DHA at a concentration to match that present in human breast milk, and evidencing their safety. Furthermore, algal oils have been shown to increase EPA and DHA status in blood cells in adults just like fish oil does (48). Algal oils providing DHA have been shown to raise DHA status in pregnant women (49) and such supplements have been used in many of the trials investigating omega-3 LC-PUFAs and risk of PTB.

Therefore, evidence supports that algal oils are a sustainable source of omega-3 LC-PUFAs for pregnant women. However, these alternative omega-3 LC-PUFA sources are not always available and can be expensive to purchase, adding to the already high cost of food which can be a challenge for some populations. For example, there are combinations of EPA and DHA from algae on the market with levels ranging from 100 to 165 mg EPA and 300–330 mg DHA per g of oil, but these supplements are expensive. To meet the most modest of recommendations, one capsule per day would be needed but to meet the less conservative recommendations two or even three capsules daily would be needed.

Oils from genetically-modified plants

Genetically-modified plants may represent a future sustainable source of omega-3 LC-PUFAs. Terrestrial plants do not usually produce EPA and DHA. Two oilseed crops, *Brassica napus* (rapeseed, also known as canola) and *Camelina sativa* have been genetically modified to produce EPA and DHA. Genetically modified canola lines have been developed that contain modest EPA and low DHA (7 and 1% of fatty acids, respectively) or modest DHA and low EPA (10 and 1%, respectively) (50). Several genetically modified Camelina lines have been generated, some producing high EPA (up to 30% of fatty acids) and relatively little DHA, some high DHA and modest EPA (12 and 3% of fatty acids, respectively), and others producing high

TABLE 1 Typical omega-3 fatty acid composition of commonly available plant and algal oils.

Oil source	Omega-3 fatty acids (% total fatty acids by weight)
Soybean	α-LA (5–10%)
Canola (rapeseed)	α-LA (6–14%)
Flaxseed	α-LA (40–60%)
Echium	α-LA (28.4%) and SDA (12.5%)
Ahiflower	α-LA (45%) and SDA (20%)
GM soybean	α-LA (9–12%) and SDA (15–30%)
Algae	
Heterotrophic species	Predominately DHA (20–55%)
Photosynthetic species	Predominantly EPA (36–46%)

α-LA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid and SDA, stearidonic acid. Data taken from Nandasiri et al. (60), Wan Ghazali et al. (61), Goyal et al. (62), Lefort et al. (63), Sijtsma and de Swaaf (64), Guil-Guerrero (65), and Deckelbaum and Torrejon (66).

amounts of both (e.g., EPA 12% and DHA 14% or EPA 11% and DHA 8%) (51). Therefore, the EPA and DHA contents in the oil from some camelina lines are similar to the amounts in standard fish oils. Oils from genetically modified canola and camelina lines have been studied in humans and they behave similarly to fish oils (52). Together these studies highlight the potential for oil from genetically modified terrestrial plants to be a sustainable alternative to marine-sourced EPA and DHA. Currently, there are no data to support the use of genetically modified oils in pregnancy, and there are several barriers to the use of oils from genetically modified plants, including regulatory issues, cost, and public acceptability. The challenges posed by genetic modification of plants to enhance their characteristics have been discussed elsewhere (53). Women may be more reluctant to accept genetically modified food than men (54) and this reluctance may be exaggerated by pregnancy. There needs to be an evidence-based strategy to communicate the likely benefits of oils from genetically modified plants that are rich in EPA and DHA.

Non-genetically modified plant oils

Non-genetically modified plant-sourced omega-3 fatty acids may also provide a sustainable alternative to omega-3 LC-PUFAs, relying upon biological activity in their own right or acting as precursors for biosynthesis of EPA and DHA (13). Omega-3 PUFAs derived from plants include α-LA and stearidonic acid (SDA). α-LA is found in green leaves, some seeds and nuts, and in some plant oils including soybean and canola oils. Flaxseeds and flaxseed oil are a very rich source of α-LA, which contributes about 55% of the fatty acids present. Chia seeds are also rich in α-LA (60% of fatty acids). α-LA has been shown to have some bioactivity in its own right, including reduction of total and low-density lipoprotein cholesterol (55) and production of bioactive oxylipins (56). Furthermore, α-LA is a precursor for omega-3 LC-PUFA synthesis and has been shown to increase EPA concentrations (13); however, evidence suggests conversion to DHA is limited. Increased consumption of α-LA may provide a sufficient increase in EPA levels, however, the required increases in DHA concentrations may not be met by α-LA (13).

SDA is found in some plant sources including seeds from members of the Boraginaceae family of plants, including the genera Borago (borage), Echium (e.g., Viper's bugloss), and Buglossoides (e.g., Corn gromwell). Some plant seed oils naturally contain SDA including those from *Echium plantagineum*, where SDA makes up about 12% of fatty acids, and from *Buglossoides arvensis*, known as Ahiflower, where SDA makes up about 20% of fatty acids (Table 1). These oils also contain α-LA (~33% and ~45% respectively) (Table 1). There is also oil from genetically modified soybean that contains SDA (15–30%) (Table 1). SDA has been shown to be a better precursor for EPA synthesis than α-LA. For example, James et al. (57) demonstrated that 1.5 g SDA per day for 6 weeks increased plasma and red blood cell EPA to a greater extent (~5-fold) than 1.5 g α-LA per day. Older studies with pure SDA or Echium oil reported similar but weaker effects than those reported for EPA and DHA (58), suggesting bioactivity of SDA is largely through conversion to EPA. More recent studies examining the effects of different doses of Ahilfower oil showed dose-dependent increases in SDA, its derivative eicosatetraenoic acid and EPA in plasma and in blood mononuclear cells, but no increase in DHA (59). Table 1 presents the typical omega-3 fatty acid content found in commonly available plant oils.

Communicating the message

To date, the message that omega-3 LC-PUFA consumption is protective against PTB and ePTB has not effectively reached key target populations. In order to achieve this, national and international organizations need to work together to come up with a consistent message on amounts and (safe, sustainable) sources of omega-3 LC-PUFAs needed for protection. Secondly, experts and organizations need to consider how to best disseminate agreed messages, considering educational tool needs. Consideration should be given to how to capture and engage specific target populations, for example, capturing women of childbearing age may pose an even greater challenge compared to pregnant women, who typically interact with midwives or obstetricians (especially in high-income countries), from whom they could receive advice. One way might be through school education platforms or government actions, similar to the folic acid campaign (see Table 2). Finally, advice could also be provided at specialist antenatal clinics in the form of e-learning modules, for example, to upskill those who interact with pregnant women, attended by those most at risk of having a PTB.

Summary

Recent international guidance based on compelling trial evidence favors consumption of omega-3 LC-PUFAs (EPA + DHA) to protect women of childbearing age and during pregnancy from PTB and ePTB. Fish is currently the major source of omega-3 LC-PUFAs either as a food or as the origin of most EPA and DHA supplements ("fish oils"). Here we discuss efficacious sustainable alternatives to fish/fish oils as a source of omega-3 LC-PUFAs, such as algal oils. These are safe and appear to be the most effective non-animal-based alternatives to fish in increasing EPA and DHA levels in humans; one barrier to their use though is that current sources are expensive. An alternative, terrestrial plant-based option that may be less expensive but that needs further exploration is oils that contain EPA and DHA from GM plants, although there are currently challenges to using these oils for direct human consumption. Another alternative is plant oils naturally rich in

TABLE 2 Potential ways to disseminate omega-3 LC-PUFA messaging at national and local levels.

At national/public health level: • Public education on increased consumption of omega-3 LC-PUFAs from a variety of sustainable sources • Legislation on the level of omega-3 LC-PUFAs required in antenatal supplements sold over-the-counter and on prescription • Education and training for healthcare professionals who provide first-contact care to pregnant women
At local level: • Education for pregnant women on safe levels of omega-3 LC-PUFA consumption from a variety of sustainable source • Prescription of omega-3 LC-PUFA supplements for pregnant women identified at high risk of preterm birth

α-LA and SDA which are precursors to EPA. How to communicate the message about omega-3 LC-PUFAs to target populations needs consideration, but we propose practical ideas on this.

Author contributions

EB: Writing – review & editing. PC: Conceptualization, Writing – review & editing. AK: Writing – review & editing. JB: Writing – review & editing. MM: Writing – review & editing. EK-R: Writing – review & editing. JG: Conceptualization, Writing – original draft, Writing – review & editing.

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Factors influencing concurrent wasting, stunting, and underweight among children under five who suffered from severe acute malnutrition in low- and middle-income countries: a systematic review

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Background: Wasting, stunting, and underweight in children are complex health challenges shaped by a combination of immediate, underlying, and systemic factors. Even though copious data demonstrates that the causation routes for stunting and wasting are similar, little is known about the correlations between the diseases in low- and middle-income nations.

Objective: The objective of this study is to evaluate the factors that concurrently affect wasting, stunting, and underweight in <5-year-olds with severe acute malnutrition (SAM).

Method: This review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We searched every electronic database that was available, from the medRxiv pre-print site, PubMed, MEDLINE, EMBASE, Cochrane Library, Web of Science, PsycINFO, CINAHL, Google Scholar, and Scopus, in addition to the Science Direct search engine. We considered research conducted in low- and middle-income nations on <5-year-olds with SAM. The Newcastle Ottawa Scale was used to assess the quality of the studies.

Results: After screening and selecting 12 eligible studies, 1,434,207 records were included for analysis. The prevalence of factors influencing concurrent wasting, stunting, and being underweight was 26.42% in low-middle -income countries (LMI). The prevalence was higher in men, with wasting, stunting, and underweight at 14.2, 4.1, and 27.6%, respectively. Unprotected drinking water was associated with stunting [odds ratio = 0.68; 95CI (0.50, 0.92)]. Being male is another factor (aOR = 2.04, 95% CI: 1.13, 3.68). Lack of prenatal care follow-up was associated with a lower risk of wasting (OR = 2.20, 95% CI: 1.04, 4.64), while low birth weight (<2.5 kg), diarrhea, having a younger child, and being from a poor household were associated with wasting, stunting, and underweight. Other factors included body mass index (BMI) for age aOR = 2.11, 95% CI: (0.07, 0.895); maternal education: stunting [aOR = 1.52, 95% CI: (0.09, 0.89)], underweight [aOR = 1.97, 95% CI: (0.01, 0.73)], and open defecation, stunting [aOR = 1.62, 95% CI: (0.06, 0.32)], underweight [aOR = 1.92, 95% CI: (0.042, 0.257)]). Likelihood of being underweight increased with birth order (second born, aOR = 1.92, 95% CI 1.09–3.36; third born, aOR = 6.77, 95% CI 2.00–22.82).

Conclusion: Inadequate dietary intake, illness, food insecurity, poor maternal and child care, poor hygiene and sanitation, and healthcare inaccessibility contribute to SAM.

KEYWORDS

concurrent wasting and stunting, underweight, severe acute malnutrition, under five, food insecurity

Introduction

Globally, over 500 million children under five are overweight or obese, while 45 million are wasted (too thin for their height) and 37 million are stunted (too short for their age). Undernutrition accounts for about half of all deaths in this age group. Concurrent wasting and stunting (WaSt) occur when a child experiences both conditions simultaneously (1). Currently, 50.5 million children under five are affected by wasting, including 17 million with severe wasting. In 2020, sub-Saharan Africa is estimated to have the highest prevalence of undernutrition, impacting 264.2 million people (24.1% of the population) (2). The likelihood of experiencing wasting, stunting, and underweight is influenced by insufficient breastfeeding practices, infectious diseases, lack of knowledge, poverty, family size, food insecurity, hygiene sanitation, poor maternal health, lack of antenatal care facilities, insufficient infrastructure, and poor absorption of nutrients (3, 4). Wasting is associated with energy deficiency, intake of carbohydrates and fats, breastfeeding practices, infectious diseases, lack of maternal nutrition knowledge, poor parenting, family size, food insecurity, hygiene sanitation, and low household income (4, 5). The major risk factors for stunting includes poor maternal health, lack of antenatal care facilities, insufficient feeding and care, and insufficient infrastructure and healthcare facilities (6, 7). A person may be underweight due to genetics, poor absorption of nutrients, increased metabolic rate or energy expenditure, lack of food (frequently due to poverty), low appetite, drugs that affect appetite, illness (physical or mental), or eating disorders such as anorexia nervosa (8, 9).

Stunting has more long-term or delayed developmental repercussions in comparison to wasting. Concurrent wasting and stunting (WaSt) is the term used to describe the state where wasting and stunting coexist (5, 10). The most severe forms of malnutrition occur when stunting, wasting, and underweight coexist (11). Compared to the risk of death associated with stunting and wasting independently, which were shown to be 1.47 and 2.30 times higher, respectively, than in healthy children, the risk of death in children with WaSt was found to be 12.75 times higher (12, 13).

According to a recent meta-analysis, the prevalence of WaSt varies from 0 to 8% across 84 countries, with fragile and conflict-affected areas showing the highest frequency (14). Wasting and stunting showed a significant correlation with the male sex, age of 12–23 months, infection, and having an underweight mother (15, 16). Both wasting and stunting have also been related to some risk factors, including low birth weight, low socioeconomic status, and maternal short height (17). Substantial research has also emphasized the risk factors and prevalence in low- and middle-income countries. Malnutrition has been a long-standing threat to children's lives in developing countries (18). Areas that experience prolonged violence have a substantial influence on the frequency of malnutrition (19, 20). The primary causes of malnutrition—food instability and restricted access to healthcare—have been made worse by the disruption of essential services, especially food distribution and medical care (21–26). The most impacted are marginalized communities, which already have significant socioeconomic and health inequalities (27–29). As such, it is anticipated that, among children who are marginalized, malnutrition, especially wasting and stunting, will be prevalent. The number of impoverished children under the age of 5 in developing nations who are also impacted by circumstances that lead to underweight, wasting, and stunting who suffer from severe acute malnutrition in low-and middle-income countries remains unclear. The purpose of this systematic review was to assess the variables that simultaneously impact underweight, stunting, and wasting in children under five who are experiencing severe acute malnutrition in low- and middle-income countries.

Methods

When conducting this investigation, the PRISMA (Preferred Reporting Items for Systematic Reviews) criteria were followed.

Among the databases that were searched were PubMed, MEDLINE, EMBASE, Cochrane Library, Web of Science, PsycINFO, CINAHL, Google Scholar, Scopus, MedRxiv pre-print, and the Science Direct search engine. A manual search was carried out in March 2022 via publisher and journal websites for research published from the inception of each database to February 28, 2023. The search plan was developed with input from a librarian. Medical Subject Headings (MeSH) terms were among the search terms used.

Study selection: This study comprises all studies involving children under five who have severe acute malnutrition.

Population: Children under five experiencing acute malnutrition.

Intervention: Nutritional supplementation programs (e.g., Ready-to-Use Therapeutic Foods).

Abbreviations: DAG, Dassie Arero Godana; FCHT, Tesfaye Chala Fantaye; CHGT, Tesfaye Getachew Charkos; EMS, Erba Midhakso Sento; TBF, Tolosa Fufa Balcha.

Comparison: Standard care or no intervention.

Outcome: Improvement in height-for-age z-scores or reduction in prevalence of stunting.

Inclusion and exclusion criteria

Children under five experiencing severe acute malnutrition were included in this review analysis. Exclusion criteria included reviewing secondary research, conference abstracts and posters, editorials/commentaries and protocols, unpublished literature, literature published before 2019, duplicated sources, irrelevant malnutrition questions/theses, dissertation manuscripts, case reports, and epidemiological studies. Underweight, stunting, and concomitant wasting in individuals over the age of five was also excluded.

Study quality assessment

To determine the quality of the research that was a part of our systematic evaluation, we used the Newcastle–Ottawa Scale (NOS), which has a grading system ranging from 0 to 9. A quality score range of 0–3 was considered low, 4–6 was considered fair, and 7–9 was considered exceptional. The five evaluators—DAG, FCHT, CHGT, EMS, and TBF—rated the studies separately, and any differences were resolved by consensus.

Extracting and analyzing data

Every reviewer extracted data using an identical data entry form. The original article was examined again to resolve differences among the five reviewers and reach a consensus. It was referred to as the consensus-building process.

Statistical analysis

The articles that were included in this systematic review for children under gender five all sought to look into different outcomes such as sex, being male sex, birthplace, child sexual abuse, parity, drug use, child labor, anemia, low birth weight, diarrhea, bottle feeding, initiation to complementary feeding, maternal age at birth and birth interval, family size, low income, marital status, poor diet, lack of animal protein, birth order, poor hygiene and sanitation, dietary diversity, vaccination status, sickness, illiteracy, food insecurity, water scarcity, maternal short stature, malaria, acute respiratory infection, divorce in the family, widowhood in the family, residing in a rural area, families' meals/day. The results were documented by each original article's predetermined objective and were assessed quantitatively.

Study characteristics

Table 1 summarizes the characteristics of the included studies in this systematic review. The study identified a total of 1,434,207 records from 12 studies (16, 19–21, 25, 26, 30–35) eligible for inclusion in the review. References (49–93) were excluded due to outdated publication years, incomplete results, and the geographic scope of the studies.

Across all studies, a total of 1,434,207 children under five were enrolled, with a mean age of 3.50 years and 57% being male. All included studies were conducted in low- and middle-income countries. The remaining studies were conducted in Europe, the United States, and Canada. All the included studies were original and quantitative and were published after 2019. All the studies included in this review used mid-upper arm circumference, weight-for-height, height-for-age, and weight-for-age measurements. The quality of the studies reviewed ranged from moderate to high, with each study achieving a score greater than 6 out of 9 on the no-quality assessment.

Data collection process

Data from reports was gathered by manual search and direct data extraction from journal articles and other study reports. This entails the use of structured data-gathering forms, which can be created using bespoke data systems, article forms, or electronic forms. Five reviewers independently collected data from each report, and after reading the reviewed manuscript, all the authors gave their approval.

Study risk of bias assessment

To determine the possibility of bias in the study, the five reviewers each worked on or evaluated the study on their own. The critical evaluation of the included articles was finished by those five reviewers (DAG, FCHT, CHGT, ESM, and TBF), and one reviewer (AG) dealt with conflicts. All reviewers used a set of 12 randomly selected articles to cross-check the reviewer's conclusions to ensure quality control.

Synthesis methods

The following method was used to synthesize the study's eligibility: Figure 1 shows the PRISMA flow diagram for systematic reviews, which includes database searches and screening. Additional records were found by hand searching through Science Direct, Google Scholar, and journal websites, as well as through organizations like the World Health Organization. The study complied with Cochrane guidelines for fast reviews and World Health Organization guidelines for treating malnutrition. The stages of the review included knowledge synthesis, report dissemination, procedure construction, literature search, research selection and screening, data extraction, risk of bias evaluation, and question refinement. The results of individual investigations and syntheses were tabulated or graphically displayed using quantitative data synthesis such as cross-sectional and analytical design. We summarized the findings in this systematic review and provided expert advice to support the decision(s). This systematic review did not, however, address the model(s), method(s) for identifying the presence and level of statistical heterogeneity, or software package(s) that were used. It did not employ any techniques to investigate the reasons behind the heterogeneity among subgroup studies, which would have entailed dividing all participant data into smaller groups frequently to compare them. However, a sensitivity assessment was performed using the analytical approach, assumptions from earlier research outcomes, and predictive variables from independent investigations.

Certainty assessment

We evaluated study limitations, heterogeneity, inconsistency, indirectness, imprecision, and publication bias in order to determine the degree of certainty in the body of evidence supporting a conclusion.

TABLE 1 Study characteristics.

Study population	Study type	Study design	Findings	Outcome	Determinants	Journals	Countries	Authors and publication year
Children under the age of five: ($n = 2{,}399$)	Original	Quant	Stunting, underweight, and wasting (13.5, 18.7, and 5.9%)	Concurrent wasting and stunting	Age of child, birthplace, child's anemia, prematurity	BMC PH	Gambia	Asmare and Agmas (2022) (16)
Children under the age of five: ($n = 209{,}60$)	Original	Quant	Incomplete	Concurrent wasting and stunting	Diarrhea, bottle feeding, initiation to complementary feeding	Nurture	LMIC	Andrew et al. (2023) (13)
Children under the age of five: ($n = 1{,}461$)	Original	Quant	Stunting 42.5, 63.8%, wasted: 90% and wasted 58.6%	Concurrent wasting and stunting	Mother's age at birth, education, and income level of parents	JMS	Yemen	Al-Sadeeq et al. (2024) (20)
Children under the age of five: (9854)	Survey	Quant	WaSt and under wt:10.9%, 15.4	Concurrent wasting and stunting	Birth interval, LBW, parent's education	BMC Nut	Mozambique	Zaba et al. (2023) (21)
Children under the age of five: (33,650)	Original	Mixed	Grain/roots/tuber as bought food (OR = 9.487, CI = 1.182–76.138, $p < 0.034$)	Concurrent wasting and stunting	Diarrhea, large family size, low-income, marital status	MCN	Ethiopia	Sahiledengle et al. (2023) (25)
Children under the age of five ($n = 566$)	Original	Quant	Incomplete	Older age, low-income, illiteracy	Diarrhea, poor diet, lack of animal protein, large family	Elsevier	Ethiopia	Fufa (2022) (31)
PSC ($n = 500$)	Original	Quant	Stunting (40.6%).	Stunting	Dietary diversity, child age, family size, parent education	Elsevier	Ethiopia	Argaw et al. (2022) (33)
Children under the age of five: ($n = 275$)	Original	Quant	Wasting, stunting, and <wht: 11.1, 45.8, 25.5%	Undernutrition	Un vaccinated, sick child, lack of dietary diversity score	Hindi	Ethiopia	Sewnet et al. (26)
<5 ($n = 5{,}355{,}000$)	Global report	Survey	Stunting: 115 M, wasting: 52 M	Malnutrition	Poor feeding practices, poverty, decision over resources, illiteracy	City research	London	Hawakes and Fanzo (2017) (18)
Children under the age of five: ($n = 352$)	Original	Qual	Stunting, wasting, <wt. 45.795CI (9.9, 27.8) resp.	Undernutrition	Large family size, age of children, low income, illiteracy	JFNS	Ethiopia	Teklemariam et al. (2014) (23)
Children under the age of five: ($n = 595$)	Original	Quant	Maternal height aOR = 1.52, 95% CI 1.02–2.26, aOR = 2.37, 95% CI 1.29–4.35.	Underweight	Home delivery, pre-lacteal food, being male child, non-immunized	PHJ	Ethiopia	Rahel et al. (2017) (25)
Children under the age of five ($n = 188$)	Original	Quant	<wt with birth order (aOR = 1.92, 95% CI 1.09–3.36; aOR = 6.77, 95% CI 2.00–22.82).	Growth delay	Food Insecurity, Poor mother and child care, poor hygiene and sanitation	IOSR-JDMS	India	Sourajit et al. (2015) (48)

(Continued)

TABLE 1 (Continued)

Study population	Study type	Study design	Findings	Outcome	Determinants	Journals	Countries	Authors and publication year
Children under the age of five (*n* = 450)	Original	Quant	Aged 6–23 m and 24–59 m stunted (aOR = 3.27, 95% CI 1.57 to 6.78 and aOR = 2.82, 95% CI 1.40–5.67)	Concurrent wasting and stunting	Illness, diarrhea, ARI, lack of vit. Suppl, large family size, poor sanitation, illiteracy, male gender, diarrhea, low income, not breastfed	JNS	Yemen	Al-Taj et al. (2023) (19)
Children under the age of five (*n* = 1,091)	Original	Quant	St. (aOR = 1.71.95% CI 1.14–2.55) and <wt (aOR = 2.11, 95% CI 1.16–3.82) unproved toilet	Factors influencing undernutrition	Poor toilet facilities, Poor water, diarrhea, LBW, unvaccinated, large family, child age, non-exclusive BF	BMJ Glob Health	Australia	Hall et al. (2020) (35)
Children under the age of five (*n* = 9,270)	Original	Quant	Incomplete	Undernutrition	Diarrhea, low income, child's age, being male, shortage of water	BMC	Rwanda, Uganda and Tanzania	Kingsley et al. (2019) (3)
Children under the age of five (*n* = 139,529)	Review	Quant	Incomplete results	Wasting and stunting	Maternal short stature, being male, and LBW	BMC	Niger	Kristin et al. (2021) (41)
Children under the age of five (*n* = 33,054)	Data analysis	Multilevel	Incomplete results	Concurrent wasting and stunting	Malaria, diarrhea, ARI, being male, child's age	MCN	Uganda	Gloria et al. (2021) (38)
Children under the age of five (*n* = 450)	Data analysis	Mixed level	Incomplete finding	Concurrent wasting and stunting	Being male, not breastfed, diarrhea, low income.	JNS	Yemen	Mansour et al. (2023) (16)
Children under the age of five (*n* = 5,753)	Original	Quant	Incomplete	Concurrent wasting and stunting	Higher birth order, income, low education levels of caregiver	IJPH	Ethiopia	Tamir et al. (2022) (42)
Children under the age of five (*n* = 240)	NFH Survey	Multilevel	Incomplete	Stunting and wasting	Income, Family size, birth interval, child age, diarrhea, unvaccinated, ECF	JN	Ghana	Francis et al. (2023) (43)
Children under the age of five (*n* = 4,764)	Original	Quant	Incomplete	Stunting	Divorce of widowship in the family, gender, rural residence, income, illiteracy, maternal age	JRHS	Indonesia	Hastin et al. (2021) (47)
Children under the age of five (*n* = 9,218)	Data review	Multilevel	Cont. WatSt. 24.8%, St. Wat. and <Wt.38,9.4, 25.2%	Multiple nut deficiencies	Birth order, sex, age of child, parity, hygiene and sanitation	BMC	Ethiopia	Geda et al. (2021) (32)
Children under the age of five (*n* = 9,218)	Original	Quant	Stunting 38.4%	Stunting	Being male, age, family's meals/day	BMC	Indonesia	Ramli et al. (2009) (44)
Children under the age of five (*n* = 8,064)	Review	Quant	Incomplete	Stunting and wasting	ARI, M.BMI, income, sex, age, LBW, poverty, illiteracy	PLoS One	Indonesia	Hayani et al. (2023) (45)
Children under the age of five (*n* = 1,260)	Original	Quant	HH FI, (OR = 2.079, CI = 1.182–3.658)	Stunting	Birth place, BFP, LBW, child sex, illiteracy	CCHD	China	Jiang et al. (2014) (46)

(Continued)

TABLE 1 (Continued)

Study population	Study type	Study design	Findings	Outcome	Determinants	Journals	Countries	Authors and publication year
Children under the age of five (n = 400)	Original	cross-sectional	Stunting:24.7%, Pre-mensuration mum (OR = 5.015, CI = 1.257–20.011, p < 0.022)	Factors influencing undernutrition	Poverty, failure to breastfeed exclusively, poor nutrition during pregnancy	Nutrient	Nepal	Giri et al. (2023) (34)

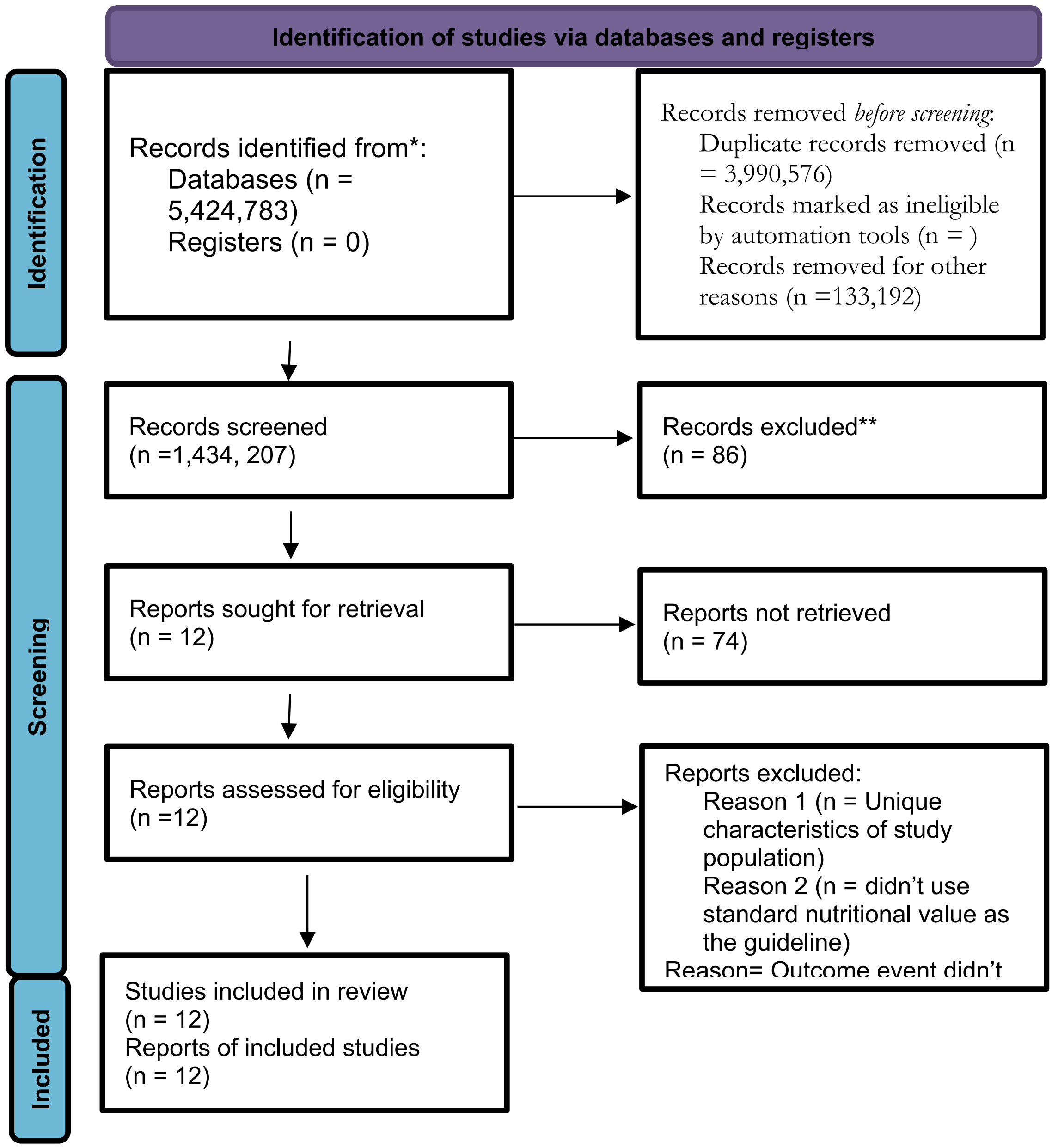

FIGURE 1
PRISMA flow chart diagram 2020.

Technical terms

The PICO is a framework used to formulate research questions, especially in health and clinical settings. It stands for:

- Population
- Intervention
- Comparison
- Outcome

Intervention: Nutritional supplementation programs (e.g., ready-to-use therapeutic foods).

Comparison: Standard care or no intervention.

Outcome: Improvement in weight-for-height z-scores or recovery rates from acute malnutrition.

When defining PICO for wasting, stunting, and underweight among children under five, here's how it might look:

1. Wasting:
Population: Children under 5 years old experiencing acute malnutrition.
Intervention: Nutritional supplementation programs (e.g., ready-to-use therapeutic foods).
Comparison: Standard care or no intervention.
Outcome: Improvement in weight-for-height z-scores or recovery rates from acute malnutrition.

2. Stunting:
Population: Children under 5 years old at risk of chronic malnutrition.
Intervention: Growth monitoring and nutrition education programs.
Comparison: Usual care or no intervention.
Outcome: Improvement in height-for-age z-scores or reduction in the prevalence of stunting.

3. Underweight:
Population: Children under five classified as underweight (weight-for-age z-scores).
Intervention: Integrated management of childhood illness (IMCI) with nutritional support.
Comparison: Routine healthcare without specific nutritional interventions.
Outcome: Change in weight-for-age z-scores or reduction in the prevalence of underweight.
This structure helps in designing studies, evaluating interventions, and analyzing outcomes related to child malnutrition effectively.

Results

In their pooled sample, the prevalence of wasting was 0.66 (95% CI: 0.64, 0.67) for children under 2 years old and 14% (95% CI: 13, 14) for children aged 2–4. In 87 nations, prevalence ratios were less than one, suggesting a reduced prevalence in children over two. Additionally, in 68 countries, the prevalence was statistically significantly lower than one at a non-adjusted 5% level. For boys and girls, as well as the wealthiest and poorest households, the prevalence of wasting was generally lower in children under two (16). Out of the 2,399 children under five that were examined in this study, 13.5, 18.7, and 5.9% experienced underweight, wasting, and stunting, respectively. The majority of the children (40.1%) came from the Gambia's Brikama local government region; male children made up 52.9% of the child population, and 63.3% of the children lived in urban areas. In light of the other predictors, the odds ratios (OR) for the relationships between stunting and underweight, underweight and wasting, and stunting and wasting were 15.87, 46.34, and 1.75, respectively. Compared to children who had a small birth size, the calculated odds ratios for stunting, underweight, and wasting outcomes were 0.965, 0.885, and 0.989 times higher for children with an average birth size (17). The study findings provide evidence for the co-existence of stunting among severely wasted children early in life. Wasting and stunting both need to be addressed simultaneously to reduce associated short- and long-term irreversible consequences (21). Compared to female and urban-born children, male children and those born in rural areas were more likely to suffer from severe and mild stunting, wasting, and underweight. The percentage of stunted, wasted, and underweight male children was 27.6, 4.10, and 14.2%, respectively. Stunting was linked to unprotected drinking water [odds ratio (OR) = 0.68; 95% confidence interval (CI): 0.50, 0.92].

A higher risk of underweight was linked to having a mother who was under 20 years old at birth (OR = 0.66; 95% CI: 0.45, 0.97) and being a male child (OR = 2.04; 95% CI: 1.13, 3.68). The lack of prenatal care follow-up (OR = 2.20; 95% CI: 1.04, 4.64) was linked to wasting, whereas diarrhea, low birth weight (<2.5 kg), a child's younger age, and three or more under-five children were substantially linked to underweight, wasting, and stunting in a household. Increased rates of stunting, wasting, and underweight were linked to several variables, including being a male child, being born in a rural region, having unprotected drinking water, being smaller at birth, not receiving prenatal checkups, having diarrhea, and having low household affluence. Therefore, policymakers needed to implement initiatives that prioritize utilizing prenatal care services, increasing household wealth, and enhancing access to safe drinking water to reduce stunting, wasting, and underweight more quickly (30). The single composite index of anthropometric indicators showed that 49.0% (19.8% moderately and 29.2% severely) of sampled children were undernourished. In the Brant test of proportional odds model, the null hypothesis that the model parameters equal across categories was rejected. Compared to ordinal regression models, partial proportional odds model showed an improved fit. A child whose mother's body mass index is less than 18.5 kg, is from a poor family, whose father is without education, and who is male has a severe under-nutrition status that is 1.4, 1.8, 1.2, and 1.2 times, respectively, more likely to be worse than the reference group.

The authors conclude that the fitted partial proportional odds model indicated that age and sex of the child, maternal education, region, source of drinking water, number of children under five, mother's body mass index and wealth index, anemic status of child and, fever in the child 2 months before the survey had a negative effect (36). Child's age [confidence intervals for (wasting = 0.02, 0.007; stunting = 0.042, −0.011)] and sex [confidence intervals for (underweight = 0.530, −0.151; stunting = 0.936, −0.243) (underweight = −0.025, 0.002)], maternal measuring mid upper arm circumference (MUAC) [confidence intervals for (wasting = 0.189, 0.985; BMI-for-age = 0.077, 0.895), maternal education (stunting, 0.095, 0.897; underweight = 0.120, 0.729), and open defecation (stunting = 0.055, 0.332; underweight = 0.042, 0.257)] were discovered to be significantly linked to anthropometric indicators. In contrast to some research, the anthropometric parameters of the aforementioned child do not indicate that maternal dietary diversity is significant (37). The findings from our study indicated that having diarrhea, having an acute respiratory infection (ARI), not having water availability all year, and not attending monthly child growth monitoring sessions were associated with undernutrition among children aged 0–59 months. Interventions aimed at improving undernutrition in these disadvantaged communities should target all children, especially those children from households with poor sanitation practices (38). In children under five, the coexistence of stunting with overweight/obesity ranged from 0.8% in the United States to over 10% in Ukraine and Syria, while the prevalence of coexisting wasting with stunting ranged from 0.1% in most of the South American countries to 9.2% in Niger. A decrease in the prevalence of coexisting forms of malnutrition (CFM) was observed in all countries except Indonesia. Studies in China and Indonesia showed a positive association between rural area and city of residence and coexistence of stunting with overweight/obesity. Evidence for other risk and protective factors for the CFM is too minimal or conflicting to be conclusive (3).

Discussion

This systematic review examined the factors that contribute to concurrent stunting, underweight, and wasting in children under five who are suffering from severe acute malnutrition in low- and middle-income countries. Concurrent wasting and stunting were defined as the proportion of measurements at a specific age when a child was both wasted and stunted at the same time (13). This combination represents a severe form of malnutrition among children, especially in vulnerable groups impacted by conflict, as this systematic review has shown (11, 13, 17, 21, 22, 39). As our recent fast analysis demonstrated, the proportion of concurrent wasting and stunting varies by country. For example, in Gambia, 13.5, 18.7, and 5.9% of children suffered from stunting, being underweight, and wasting, influenced by age of the child, child's anemia, place of birth, and small birth size (WaSt) (11); in low- and middle-income countries, the prevalence of wasting, stunting, and underweight were 10.0, 29.2, and 13%, respectively, while diarrhea, bottle feeding, and initiation to complementary feeding are related to wasting and concurrent stunting (13). In Yemen, the prevalence of severe stunting, moderate stunting, and severe wasting was 42.5, 63.8, and 58.6%, respectively, with 10.7% experiencing concurrent wasting and stunting. Concurrent wasting and stunting were associated with mother's birth age, birth interval, parents' education level, and socioeconomic situation (17). In Mozambique, a single study found that the prevalence of concurrent wasting, stunting, and underweight was 10.9, 15.4, and 60.9%, respectively. Concurrent wasting and stunting were associated with birth intervals <2 years, mothers' education, and low birth weight (17). In Ethiopia, the prevalence of stunting, underweight, wasting, and anemia was 38, 25.2, 9.4, and 58%, respectively (39). Another study in Ethiopia found that the prevalence of simultaneous wasting, stunting, and underweight was 11.1, 45.8, and 25.5% (22).

Ethiopia also has a high frequency of concomitant WaSt (5.8%), wasting (16.8%), stunting (53.9%), and underweight (36.9%) (40). Another multidimensional nutrition deficiency assessment conducted in Ethiopia found that the prevalence of stunting, underweight, and wasting was 38, 25.2, and 9.4%, respectively. Fifty-eight percent of children were anemic, and the prevalence of concurrent stunting and anemia was 24.8% (36), whereas birth order, parity, age and sex of child, parental education, religion, household wealth index, type of family structure, hygiene and sanitation, child feeding practice, and health service utilization, were the key variables, while poor nutrition, diarrhea, big family size, age of breastfeeding, lack of animal protein, illness, non-vaccination, and an inadequate dietary variety score influenced concurrent WaSt (36, 39).

In Niger, 14% of children were wasted, 80% were stunted, and 12% were simultaneously wasted and stunted (41). In India, the prevalence of WaSt has dropped from 8.7% in 2005–2006 to 5.2% in 2019–2020. From 6 to 18 months, the proportion of concurrent WaSt children increased rapidly, peaking at 19 months with 8% (42). In Ghana, the prevalence of stunting and wasting in children under five was 12.5 and 27.5%, respectively (43). In Indonesia, the prevalence of stunting and severe stunting was 29 and 14.1%, respectively. Stunting was seen in 38.4% of children aged 0–23 months (44). Factors linked with stunting included child age, sex, number of family meals/day, maternal BMI, birth weight, maternal weight and height, mother's education/illiteracy, and poor household status (44, 45). Finally, in China, the prevalence of stunting and severe stunting was 27.0 and 13.2%, respectively (34, 46), and the place of residence, caregiver's education, child's gender, low birth weight, and duration of exclusive breastfeeding were risk factors for stunting (35). Even though there is a widespread list of factors influencing concomitant wasting, stunting, and underweight, there is a dearth of sequential research on the coexisting factors influencing underweight, stunting, and wasting in children under five who suffer from severe acute malnutrition in low- and middle-income countries. In this systematic review, concurrent WaSt was found to more likely affect boys than girls, although the extent of this disparity varies and is more prominent in certain circumstances (3, 16, 17, 25, 36, 38, 39, 41, 44, 45, 47). This is primarily because boys typically consume more calories and have larger body frames and sizes than girls, and a larger body mass requires more food. Therefore, they might not have the same tolerance during a food crisis as girls do. These results indicate that malnutrition is still a major public health problem among children under five. The three main factors that are commonly associated with stunting, wasting, and underweight are the child's age, anemia level, and birth type. For children under five, being undersized at birth was strongly linked to an increased risk of stunting, underweight, and wasting. Additionally, wasting, WaSt, and underweight were associated with cough. Moreover, wasting was substantially correlated with maternal age, occupation, and being a child from a poor family.

Conclusion

Inadequate dietary intake, poor-quality diet, infectious disease, poor water quality, child's age, anemia level, birth order/type, large family, prematurity, a child from a malnourished mother, being a boy, hygiene and sanitation poverty, food insecurity, climate change, drought and conflict, healthcare inaccessibility, and poor cultural feeding practices are the factors that are usually associated with stunting, wasting, and underweight.

Recommendation

Addressing these factors holistically with interventions across health, education, and economic sectors can improve children's growth and health outcomes.

Strengths and weaknesses of the study

The strengths of the study

The strengths of this systematic review lie in its comprehensive approach, reproducibility, and precise articulation of outcomes. A concise background explanation outlining the reasoning behind the review, literature search, and reference management are given below:

- Both the review question and the topic sentences were stated clearly.
- A smart title (specific, quantifiable, attainable, reasonable, and time-bounded) could provide access to the review method.

Weakness of the study

The exclusion of certain features of the research population or unique characteristics of the study population and literature from earlier years of publication, incomplete findings, the lack of standard nutritional values as a guide in some of the analyzed papers, and inconsistent outcome events are some of the weaknesses.

Registration and protocol

Although there was no registration for this systematic review, eligibility was checked via screening.

Limitation

There are some limitations in this review. First, the shortcoming of this systematic review was that its search was not exhaustive. Second, only one reviewer was used at a time. Third, the possible appraisal and selection procedure was without blinding. Fourth, interpretation of the data may have been constrained or cautious and, lastly, there is no precise definition on what defines a systematic review.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

GD: Conceptualization, Data curation, Formal analysis, Writing – original draft, Investigation, Methodology. TChal: Methodology, Software, Validation, Writing – review & editing, Resources. TChar: Methodology, Project administration, Supervision, Validation, Writing – review & editing. MS: Data curation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. FB: Software, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Intra-household joint decision making on child feeding and associated social determinants in rural districts of South Ethiopia: a multi-site concurrent mixed method study

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Background: Improving joint intra-household decision-making by spouses is a promising solution to improve child-feeding practices. Therefore, this study aimed to assess the status and barriers of intra-household joint decision making on child feeding in rural districts of South Ethiopia from the perspectives of primary caregivers and key individuals.

Methods: A mixed-method study was conducted from July 15 to September 15, 2023 in three randomly selected rural districts: Arba Minch Zuria, Mierab Abaya, and Chencha, in Southern Ethiopia. We employed a cross-sectional study design to collect quantitative data. A computer generated random number technique was used to include 25% of the total kebeles from each district. A total of 20 kebeles; 8 from 32 kebeles of chencha, 6 from 24 kebeles of Mierab Abaya, and 6 from 24 kebeles of Arba Minch Zuria were included. A total of 1,479 women with their children aged 6–23 months were recruited from family folder of the health extension program using a simple random sampling technique. A descriptive qualitative study design was used to collect data from 51 focus group discussants and 12 key informants. Trained health professionals collected the data using a structured and pre-tested interviewer administered questionnaire and semi-structured interviewer guide for quantitative and qualitative data, respectively. Univariate analysis was used to determine the frequency and percentages while Binary logistic regression analysis was employed to identify the associated factors. The odds ratio with a 95%CI was computed to assess strength of the association. The principles of saturation were adhered during the qualitative data collection. Thematic analysis was used to analyze the data in themes and subthemes, using ATLAS.ti version 23.

Results: Overall, more than two-thirds (69.2%) of the intra-household decision-making regarding child feeding were found to be jointly decided by the spouses. Women with formal education (AOR = 1.84, 95% CI: 1.37–2.46), husband involvement in child feeding (AOR = 2.23, 95%CI: 1.70–2.92), having fewer than or equal to three children (AOR = 1.51, 95%CI: 1.11–2.04), women aged 25-34 years (AOR = 1.57, 95%CI: 1.19–2.07) and 35-49 years (AOR = 2.14, 95%CI: 1.38–3.33) were significantly associated with joint decision-making regarding child feeding practices. Moreover, large family sizes, large age gaps between husbands and wives, and gender inequalities were identified as barriers to women's engagement in intra-household decision making based on qualitative analysis.

Conclusion: In the rural districts of southern Ethiopia, joint intra-household decision making regarding child feeding was found to be satisfactory. Maternal education, husband's involvement in child feeding, mother's age, and number of children were independent variables that significantly influenced women's engagement in joint intra-household decision making on child feeding. Interventions targeted at improving women's engagement in decision-making should consider the following sociocultural barriers: extreme age differences between couples, large family sizes, and detrimental gender-oriented norms.

KEYWORDS

barriers, joint intra-household decision making, socio-economic, South Ethiopia, factors

1 Introduction

Joint intra-household decision making is an essential driver of child health and nutrition outcomes, as one dimension of women's empowerment determines how resources are allocated inside the household (1). Women's involvement in family decision making is an essential predictor of better nutritional outcomes in newborns and young children (2). Women's empowerment sometimes happens through navigating relational and societal dynamics through processes such as negotiation and manipulation during intra-household decision making (3). A systematic review and meta-analysis reported that, mothers involved in decision making were positively associated with recommended minimum dietary diversity feeding practices in Ethiopia. In Ethiopia mostly child feeding is the responsibility of mothers; therefore, involvement of mothers on their household matters can empower mothers to feed diversified diet for their child (4).

A variety of theoretical frameworks can be employed to analyze household decision-making, each offering unique insights into family dynamics. Notable models include the Collective Model, which acknowledges individual preferences and bargaining power that result in Pareto-efficient outcomes (5, 6), and the Unitary Model, which views decision-making as a unified process, overlooking the complexities present in households with multiple adults. The unitary model simplifies household decision-making as one entity with shared preferences, but critics say it overlooks complexities in multi-adult households (5, 7). Research in rural Ethiopia shows decisions in these households are not made by one person and lack Pareto efficiency. Spousal disagreement on women's roles is common (5). The Non-cooperative game theory perspective (8): This Theory sees decision-making as a strategic interaction aimed at maximizing utility, while bargaining Models examine how household members negotiate resource distribution based on their bargaining power, which is shaped by income and social norms (5). Additionally, scholars can develop conceptual frameworks that integrate socio-economic status, gender roles, and cultural norms to better understand purchasing behaviors (9).

In Ethiopia, household decision-making dynamics are shaped by gender roles, socio-economic status, and cultural norms, with only about 24% of women holding significant decision-making authority (10). However, there is a noticeable shift toward more collaborative decision-making between spouses (11, 12). The Gender Roles and Social Norms Framework is especially relevant, emphasizing the significance of women's autonomy in decision-making and its connection to better health outcomes for both women and children socio-economic status (13). The framework also can effectively captures the community and cultural complexities of decision-making processes within households (14), accounts socioeconomic factors such as education, wealth, and employment status, which significantly influence women's decision-making power (9, 14, 15), and can inform policies and interventions aimed at enhancing women's empowerment and improving health outcomes in the region (16).

Improving joint decision-making in intra-household decisions has been identified as a way of transforming the power-relations between men and women (17), thereby contributing to both women's empowerment and improved development outcomes. This understanding has influenced development efforts aimed at improving rural livelihoods. Targeting couples' decision-making, rather than women or men separately (18).Evidence shows that a higher level of decision-making power among rural women is linked with children's feeding practices; improvement of reproductive, neonatal, and child health; and increased expenditures on household health and nutrition (19, 20). Moreover, it has been proven to be associated with increased nutritional diversity in homes (19, 21).

Global policy and development initiatives acknowledge the need to enhance joint decision-making authority among households (22). According to Gender Action Learning System (GALS), centering on the decision-making process of couples, as opposed to individual men or women, represent a fundamental element of gender equity, which has been executed in development initiatives across diverse countries (23).

The past decade has increased attention to measuring women's empowerment and autonomy, motivated largely by the goal of identifying promising programs and policies for reducing gender inequalities. For the first time, the empowerment of women and girls is included in the Sustainable Development Goals as a stand-alone target (10, 24). In the social sciences, most approaches to defining and measuring empowerment are based on the concept of agency, defined by "ability to use those capabilities and opportunities to expand the choices they have and to control their own destiny," and focus on women's ability to participate in decision making over certain important matters." (24).

However, empirical investigation of decision-making has revealed substantial heterogeneity across decision-making domains (25, 26). Decisions made either jointly or individually, are subject to varied dynamics depending on the context. According to two different contexts analysis, women in Bangladesh believe that they will achieve better productive outcomes if their partners have some input and decision-making authority over productive domains and thus associate autonomy more strongly with joint decision making (24). A similar conclusion was reached in a study examining decisions over contraceptive use, whereby women who were able to engage in "egalitarian" decision making (defined as involving discussion and agreement with their partners) were more likely to have positive contraceptive use out-comes as compared to women who made decisions independently (27).

This phenomenon can be observed in households that comprise a spouse or parental figures, such as a father, mother-in-law, or even offspring, where decisions are more likely to be in collaboration owing to the sharing of resources and responsibilities among household members (1, 28).The other factor in the decision-making process is the influence of prevailing social norms (28). Where social norms are disproportionately patriarchal and disparities in gender abounds, it can be anticipated that if the father does not participate in feeding, he might not pay enough allowances to the mother for her children's food (29).

In rural Ethiopian households, it is common for three generations to coexist: 1. the older couples; 2. their sons, daughters-in-law, and unmarried daughters, and 3. grandchildren of married sons (30). Hence, it may be helpful to keep in mind that these household dynamics lead to an unequal distribution of resources and affect the health and nutritional status of mothers and children (10). It was demonstrated that gender inequality is both a cause and consequence of hunger and malnutrition in Ethiopia, and is associated with higher rates of both acute and chronic under nutrition. Furthermore, an equitable distribution of decision-making responsibilities is highly advantageous in interpersonal relationships between spouses. Therefore, as the nutritional benefits of increased income are determined by who controls the income and how it is distributed within the household, income alone is not enough to address under nutrition (10).

Previous studies in Ethiopia have focused on women decision making autonomy, without considering joint decision making specific to context to promote women empowerment. Although previous studies highlighted that variables such as: socio-demographic characteristics, child characteristics, maternal and child health characteristics, and household characteristics had correlation with women engagement in intra-household decision making (31–37), they lacked a comprehensive examination of how quantitative findings relate to sociocultural norms and beliefs in these contexts. Moreover, qualitative methods could provide profound insights into the lived experiences of individuals within households, revealing the complexities and nuances often overlooked in quantitative studies. Therefore, this study aimed to assess joint intra-household decision-making status and its socio-cultural factors in rural districts of southern Ethiopia.

2 Methods

2.1 Study setting and design

This study was conducted in three randomly selected rural districts of southern region of Ethiopia, Gamo zone. Gamo zone is located 450 kilometers distance from capital of the country, Addis Ababa with both highland and lowland topography. The three districts: Mirab Abaya, Arba Minch Zuria, and Chencha, were randomly selected to represent the eight districts in the zone. According to the 2023 data of the respective districts, Mirab Abaya district had 24 rural kebeles with 15,584 households, Arba Minch Zuria district had 24 kebeles with 25,047 total households, and Chencha district had 32 rural kebeles with 12,618 households. These districts were located in the Gamo zone of southern Ethiopia and had a total populations of 295, 882, according to the 2007 national census data projection of Ethiopia. A community-based, concurrent, mixed study design was conducted using both quantitative and qualitative approaches. Quantitative and qualitative data were collected using a community-based cross-sectional study design and a descriptive qualitative study design, respectively. Both quantitative and qualitative data were collected from July 15 to September 15, 2023.

2.2 Sampling methods

Study participants were selected by simple random sampling technique using health extension workers' family folder and the participants were interviewed face to face. FGD discussants and KII participants for qualitative data were recruited based on the rich information they had about the context of decision making in the area.

2.3 Study method

Quantitative data were collected using a closed-ended interviewer-administered questionnaire prepared from different studies on household decision-making (38–41). This method was used because of the literacy level of study participants to understand the questionnaire, as the study was conducted at rural households most study participants might not understand self-administered questionnaire. The qualitative data were collected by prepared interviewer-administered guide.

2.4 Study population and sampling technique

The source population for this study was married women with children aged 6–23 months living in the rural districts of southern Ethiopia. Married women aged 15–49 years who had 6–23 months old children and lived for at least 6 months in the study area with their husbands at the time of the study were enrolled, while single mothers living with their children were excluded. This population was targeted because of the aim of the study was to determine the joint decision making status of the households about infants and young children complementary feeding. Study participants were selected using a multistage sampling technique because of the nature of the study requires sampling at three steps: at district, kebele level and at household level. Three rural districts were randomly selected from eight districts in the zone. Then, 25 % of the kebeles from each district: six kebeles from 24 rural kebeles located in Mirab Abaya district, six kebeles from 24 kebeles located in Arba Minch Zuria district, and eight kebeles from 32 kebeles located in Chencha district were randomly selected. Then, considering all the eligible households at each district, the total calculated sample (1502) was proportionally allocated to each district followed by proportional allocation again to each kebele. The number of households with children aged 6–23 months at each kebele was used for proportional allocation. Consequently, the allocated numbers of samples were drawn by a simple random sampling technique using computer-generated random numbers from the family folder at each kebele level. Finally, community leaders were used as a guide to reach out to households. Purposive sampling was used to select participants and information saturation was used to limit the sample size. The purpose was to find out information rich sources about facilitators and barriers of joint intra-house hold decision making.

2.5 Determination of sampling size

The total sample size was calculated using a single-population proportion formula from an online open source (Open Epi version 3) for quantitative data. We calculated the required sample size using the following assumptions: population size (N) = 1,000,000, hypothesized % frequency of outcome factor in the population (p) = 20% (10), confidence limits as % of 100(absolute +/− %)(d) = 3, 95% confidence interval, and design effect (for cluster surveys-*DEFF*) = 2 because of the level we went through to reach out the study units. Hence, relatively the largest sample size was 1,502. As 98.4% of the participants responded for the study, 1,479 participants gave information for this study. However, since non-response rate was considered during sample size determination and design effect was considered for the multistage sampling, the sample included in this study was adequate. For qualitative data, six focus group discussions (FGD), each consisting of eight to nine discussants and four in-depth interviews from each district, a total of 12 KII with religious leaders, community elders, women representatives in the community, and health extension workers were conducted. The sample size for qualitative data was decided based on the information saturation principle.

2.6 Variable measurements and study instruments

The dependent variable of the study was joint household decision-making (1 = joint intra-household decision-making among the spouses, 0 = Intra-household decision making was done without involvement of either spouse).

Joint intra household decision-making was measured by asking the participants for the following three questions: determining their own healthcare, making major household purchases, and visiting their family or relatives. Each question had six responses: (1) women had a final decision after discussing with their husband, (2) women and husband decided jointly, (3) husband's final decision, (4) women and other family members, (5) another family member alone, and (6) others. We dichotomized response 1 and 2 into one category as 'Joint decision'. In this group, the classification was made if the decision is made either after discussion where both have sufficient understanding or the less dominant one does not feel disempowered as long as the partner had sufficient understanding and intention (42) and recoded it into a score of '1.' The second group was made for the rest of the responses as 'No joint decision' and it was given a score of '0' (33). The mean score was calculated to dichotomize the three variables into one composite variable. Thus, a score above the calculated mean of 2.55 were considered having joint decision-making, otherwise not.

The **independent variables** in this study were socio-demographic characteristics (age categories of the mother, religion of the mother, educational status of the mother, educational status of the husband, occupational status of mother, occupational status of husband), child characteristics (age, sex, episode of known new-born sickness, complementary feeding initiation time, and breastfeeding status), maternal and child health characteristics (parity, ANC follow-up, place of delivery, postnatal care attended, number of children, husband involvement in infant feeding), and household characteristics (drinking water source, knowledge of infant feeding practices, mothers' attitudes toward infant feeding practice).

Knowledge about infants and young child feeding (IYCF): This was measured using five items measuring child feeding-related knowledge. Based on the summation score, a score of less than 60% considered as low knowledge, a score of 60–75% average knowledge, and a score greater than 75% was high knowledge (41).

Women's attitude toward child feeding in this study was measured as: There were seven questions overall. The scoring order is as follows (5 = strongly disagree, 4 = disagree, 3 = neutral, 2 = agree, and 1 = strongly agree). The total score is calculated by computing the values for each item. Finally, the score ≥ of the mean value was considered 'favorable attitude,' while the corresponding was taken as 'unfavorable' attitude' (38).

Improved source of water: Water from piped, boreholes or tube wells, protected dug wells, and protected springs sources, while an unimproved source of water was obtained from unprotected dug wells or springs and surface water (e.g., lakes, rivers, streams, ponds, canals, and irrigation ditches) (43).

Household food security: Was assessed using the Food Insecurity Experience Scale (FIES), developed by the Hungary initiative of the United Nations Food and Agricultural Organization to enhance simplicity and acceptability demands (44, 45). It has eight items: (1) worried about not having enough food; (2) Could not eat healthy and nutritious food); (3) Only a few kinds of foods; (4) Had to skip a meal; (5) Ate less than you thought you should; (6) Household ran out of food; (7) Were hungry but did not eat; and (8) Went without eating for an entire day. All cases responding 'No' were coded as 0 and those with a repose 'Yes' was labeled in to '1.' Likewise, Food Secure was declared if the response to all items were 'No' or 'Yes' for the first questions. Thus, [(Q1 = 0 or Q1 = 1) and Q2 = 0 and Q3 = 0 and Q4 = 0 and Q5 = 0 and Q6 = 0 and Q7 = 0 and Q8 = 0 and Q9 = 0] are considered food-secure. If at least one of the following criteria was fulfilled: (1) if [(Q2 = 1 or Q3 = 1 or Q4 = 1) and Q5 = 0 and Q6 = 0 and Q7 = 0 and Q8 = 0 and Q9 = 0]; (2) if [(Q5 = 1 or Q6 = 1) and Q7 = 0 and Q8 = 0 and Q9 = 0]; or (3) if [Q7 = 1 or Q8 = 1] (39). Qualitative data were collected through focus group discussions (FGD) and an in-depth interview guide developed from different studies (46, 47).

2.7 Data quality assurance

Twenty B.Sc. holder data collectors and three M.Sc. holder supervisors collected the data after 5 days of training on how to use the application and the meaning of each variable. The data collectors were clinical professionals with experience in application-based data collection. The data collectors covered 6–7 households per day. The closed ended questionnaire developed by reviewing different related literatures. The questionnaire had five sections such as socio-demographic, knowledge, attitude, food security and, maternal and child health related characteristics. The Kobo-collect application-based questionnaire was pre-tested in 5% of mothers in the study area, which was not included in the actual study, and necessary corrections were made such as the decision-making questionnaire was reduced from eight to three for the convenience of the participants' understanding. Moreover, we checked Cronbach alpha to test the reliability of the questionnaire. Accordingly, the overall Cronbach alpha value was 7.3, 7.8 and 8.5 for knowledge, attitude and intra-household decision making questionnaires, respectively. All questionnaires were checked daily for accuracy and cleaned before analysis. Participants were asked to have a private room or space to reduce social desirability bias. Five data collectors collected qualitative data, and the data collectors were M.Sc. with experience in qualitative data collection and fluent speakers of the local language. Key informant interviews were held at the offices, each lasting 30–45 min, and audio-recorded. The FGD lasted for 60–80 min, and the discussions were audio-recorded. Participants engaged in informal conversations in the form of unstructured, spontaneous discussions to obtain the opportunity to ask pertinent questions on different occasions. This could minimize the possibility of participants purposefully altering their responses or holding back information on sensitive issues.

> The focus group discussion continued till saturation was first perceived. The mood of the focus group participants was the indication followed to data saturation. Data saturation was obtained when participants had no additional ideas to contribute during discussion. Furthermore, saturation was also noticed during coding of the focus group transcripts. We confirmed data saturation by reading and re- reading transcripts and developing initial codes. During thematic analysis, coding stopped when no new codes emerged and was considered as indication of data saturation (48). Data saturation was maintained during transcript's coding by assigning different coders, the two authors (KF, ZHA), and whenever there was a difference in codes, the authors decided the coding saturation by discussion.

2.8 Data management and analysis

Quantitative data were exported from the KoboCollect server to SPSS version 22 and analyzed. Univariate analysis was performed for frequency and used to determine the joint decision making status of the households along with other independent variables. All regression assumptions were checked before running logistic regression. Multicollinearity was checked using the variance inflation factor (VIF), and model fitness was checked using the Hosmer-Lemeshow goodness of fit test. The full model has a significant prediction performance ($X^2 = 91.89$; df = 9; $p < 0.001$), and the model also has a good fit because the Hosmer and Lemeshow Test could not reject the hypothesis of model appropriateness, as Chi-square was 4.84 and $p = 0.68$. The model correctly classified 70.5% of cases overall. All variables with a p-value less than 0.25 were selected and fitted to the final logistic regression model to identify variables associated with joint decision making status. In multivariable regressions, p-values less than 0.05, at a 95% confidence interval, were considered a cutoff to declare variables as predictor variables using stepwise backward regression. Transcriptions of the qualitative data were obtained from audio recordings, and field notes were used to characterize the participants. The transcripts were first read several times to obtain an overall picture, and then translated. Transcripts were analyzed using ATLAS Ti9 software and to familiarize with the data, we read and reread the transcripts. After familiarization with the interviews, we conducted initial open coding independently (KF and ZH) and reviewed it by two independent experts (AT and BT). The development of themes were determined by the content of the interview guides combined with the inductive development of codes as they emerged from the data. After the themes were identified from the codes, connections across themes were identified through ordering and re-ordering using the ATLAS Ti9 software. Using an iterative process, revisions and corrections were made to the codebook to reflect emerging themes throughout the analysis. The identified themes were discussed and structured. The results were interpreted to answer the following research question: socio-cultural factors contributing to joint decision making of spouses.

3 Results

3.1 Socio-demographic characteristics of study participants

A total of 1,479 mother–child paired respondents participated in this study, with a response rate of 98.4%. The mean age of the mothers was 27.31 (SD = 5.78) years. Of study participants, More than half (52.7%) of the mothers were 25–34 years old. More than one third (37.6%) of the mothers and one third (32.5%) of the husbands attended primary education. More than three quarters (77.4%) of the mothers and more than one half (55.8%) of husbands were housewives and farmers, respectively. Four in five of the households (83.3%) had improved sources of water for drinking and food preparation (Table 1).

3.2 Characteristics of participants in the qualitative interviews

A total of 63 individuals participated in the study for both the six FGDs and 12 KIIs. The mean age of the study participants was 34.9 (SD ±6.45) years (range, 22–50 years). More than half (58.7%) of the participants were between 30 and 40 years of, and half (50.8%) of the participants were female. Majority (55.6%) of the participants had secondary or higher educational status. Nearly half (47.6%) of the participants were government employees by occupation (Table 2).

TABLE 1 Socio-demographic characteristics of the study participants at rural districts of south Ethiopia, 2023.

Variables	Frequency (n = 1,479)	Percent (%)
Age categories of the mother		
15 to 24	475	32.1
25 to 34	780	52.7
35 to 49	224	15.1
Religion of the mother		
Protestant	900	60.9
Orthodox	536	36.2
Others[a]	43	2.9
Educational status of the mother		
Unable to read and write	324	21.9
Able to read and write	167	11.3
Primary school	556	37.6
Secondary school	318	21.5
College and above	114	7.7
Educational status of the husband		
Unable to read and write	205	13.9
Able to read and write	196	13.3
Primary school	481	32.5
Secondary school	391	26.4
College and above	206	13.9
Occupational status of mother		
Housewife	1,145	77.4
Merchant	123	8.3
Farmer	89	6.0
Government employee	63	4.3
Private employee	30	2.0
Others[b]	29	2.0
Occupational status of husband		
Farmer	825	55.8
Merchant	203	13.7
Daily laborer	183	12.4
Government Employee	123	8.3
Private employee	145	9.8
Water sources of the household		
Improved	1,232	83.3
Unimproved	247	16.7

[a]Catholic, Muslim.
[b]Daily laborer, weaver.

TABLE 2 Socio-demographic characteristics of qualitative study participants, South Ethiopia, 2023.

Characteristics	Frequency	Percentage
Age in years		
20–30	18	28.6
31–40	37	58.7
41–50	8	12.7
Sex		
Female	32	50.8
Male	31	49.2
Educational status		
Had no formal education	4	6.3
Primary	24	38.1
Secondary plus	35	55.6
Occupational status		
Farmer	17	27.0
Government employer	30	47.6
Merchant	7	11.1
Private employer	9	14.3

3.3 Knowledge, attitude, food security, and breast feeding related characteristics

As for complementary feeding, greater number of mothers started complementary feeding 1,447 (97.8%), and most started the complementary feeding after 6 month of the child's age 1,204 (83.2%). Related to household food security, out of the total 1,479 households 1,275 (86.2%) were found to be food insecure. Most of the mothers, 956 (64.6%), with children aged less than 2 years, had high knowledge of complementary feeding. Of the total of 1,479 mothers, 807 (54.6%) had favorable attitudes toward complementary feeding (Table 3).

3.4 Maternal and child health related characteristics

More than half (54.4%) of the women were multipara, and 1,417 (95.8%) of the women had antenatal care follow-up during their recent pregnancy. Approximately 902 (61%) attended postnatal care. Approximately 70 percent of households had fewer than four children (Table 4).

3.5 Intra-household decision making related to child feeding practices

Most of the study participants, 1,024 (69.2%; 95CI: 60, 77.8%) were involved in joint household decision-making, while 455 (30.8%) of the mothers reported no joint participation. Regarding health services seeking decisions, 1,374 (93%) participated jointly with their husbands. Three-quarters of the participants jointly decided on large household purchases. In the majority of households, 1,282 (86.7%) decisions regarding family visits were jointly made (Figure 1).

TABLE 3 Knowledge, attitude, food security, and breast feeding related characteristics of the study participants, south Ethiopia, 2023.

Variables (*N* = 1,479)	Frequency (n)	Percentage (%)
Ever heard of child feeding practice		
Yes	1,240	83.8
No	239	16.2
Ceased breast feeding		
No	1,244	84.1
Yes	235	15.9
Started complementary feeding		
Yes	1,447	97.8
No	32	2.2
Complementary feeding starting time		
After six months	1,204	83.2
Up to six months	243	16.8
Food security		
Food secure	204	13.8
Food insecure	1,275	86.2
Knowledge on complementary feeding		
Good Knowledge	956	64.6
Average knowledge	363	24.5
Poor knowledge	160	10.8
Attitude on complementary feeding		
Favorable Attitude	807	54.6
Unfavorable attitude	672	45.4

TABLE 4 Maternal and child health related characteristics of participants living in rural distrits in south Ethiopia, 2023.

Variables		Frequency(n)	Percent (%)
Parity	Primiparous	352	23.8
	Multiparous	869	58.8
	Grand multiparous	258	17.4
ANC follow up	Yes	1,417	95.8
	No	62	4.2
Place of delivery	Home	206	13.9
	Health center	954	64.5
	Public hospital	311	21
	Private clinic	8	0.5
Postnatal care attended	Yes	902	61
	No	577	39
Number of children	One to Three	1,043	70.5
	Four and Above	436	29.5
Husband involvement in infant feeding	Yes	1,175	79.4
	No	304	20.6
Sex of children	Male	804	54.4
	Female	675	45.6
Age of children (months)	6–11	460	31.1
	12–17	479	32.4
	18–23	540	36.5
Episode of the child sickness	Yes	1,043	70.5
	No	436	29.5

3.6 Factors/barriers associated with women's decision making participation on child feeding practices

Logistic regression was performed to identify the variables associated with household decision-making. Variables such as age, mother's educational status, husband's educational status, mother's occupation, husband's occupation, access to television or radio, household food insecurity, number of children per household, husband's involvement in child feeding, sex of the child, episodes of child sickness, mother's cessation of breastfeeding, complementary feeding started, mothers' attitudes toward child feeding, mothers' knowledge of child feeding, and parity affected joint intra-household decision-making.

The full model has a significant prediction performance ($X^2 = 91.89$; df = 9; $p < 0.001$), and the model also has a good fit because the Hosmer and Lemeshow Test could not reject the hypothesis of model appropriateness, as Chi-square was 4.84 and $p = 0.68$. The model correctly classified 70.5% of cases overall. Therefore, maternal education, husband's involvement in child feeding, mother's age, and number of children significantly determined women's participation in household decisions (Table 5).

Three main themes were generated from the FGD and KII data that explain the barriers to women's participation in decision-making regarding child feeding practices in rural districts in southern Ethiopia. The themes were economic, demographic, and socio-cultural.

Mothers who attended formal education were twice as likely to participate in joint household decision-making as compared to those who did not attend formal education (AOR = 1.84, 95% CI: 1.37, 2.46).

Key informants and participants in the FDG discussion reported that educated women are able to make joint decisions about what they think is important to their children, whereas illiterate women give their children what recipes are easily found at home.

> *"There is a difference between educated and uneducated women. Since educated women are able to plan for the needs of their newborns, including the duration of breastfeeding and the appropriate diet for the child and on the other hand, uneducated women tend to take the fact of being alive as a blessing, educated women convince their husbands about child nutrition and get engaged in resource allocation for household food consumption, particularly for children.* [43 years old male FG discussant].
>
> *"Educated and uneducated women were not the same. Thus, educated mothers could prepare different recipes. However, an uneducated person consumes and eats what is available in the house. If adults eat corn, they can feed their babies only with corn.*

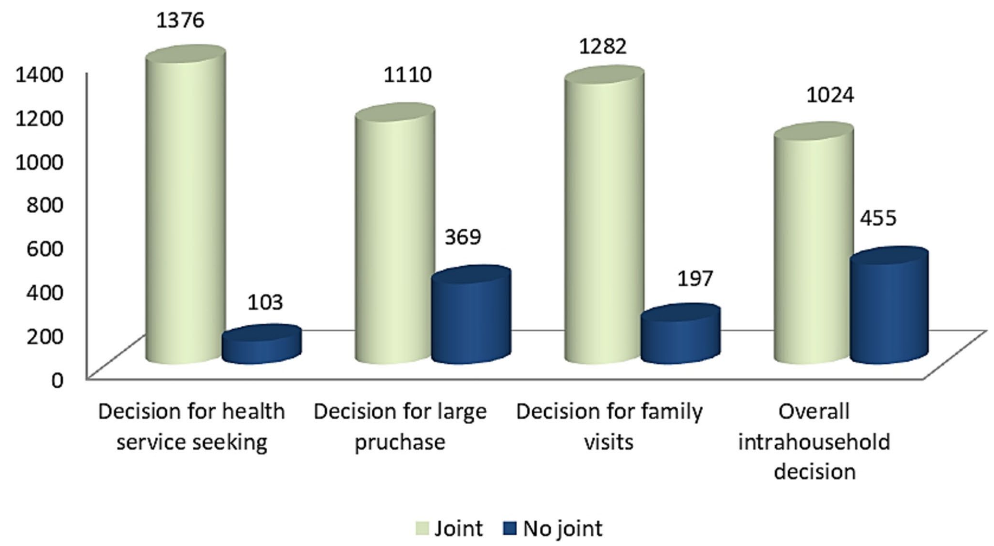

FIGURE 1
Status of intra-household decision making in rural districts of South Ethiopia, 2023.

TABLE 5 Factors associated with joint intra-household decision making in rural districts of South Ethiopia, 2023.

Variables	Household decision making		Crude odds ratio with 95% confidence interval	Adjusted odds ratio with 95% confidence interval	*p*-value
	Joint	Solo			
	Number (n)	Number (n)			
Mother education					
Formal education	837	318	**1.93(1.49–2.49)*****	**1.84(1.37–2.46)**	0.00
No education[a]	187	137	1	1	
Husband involved in child feeding					
Yes	864	311	**2.5(1.92–3.24)*****	**2.23(1.70–2.92)**	0.00
No[a]	160	144	1	1	
Husband occupation					
Farmer	542	283	0.62(0.37–1.04)	0.64(0.37–1.11)	0.11
Merchant	155	48	1.04(0.57–1.89)	0.99(0.54–1.84)	0.99
Civil servant	149	37	1.30(0.70–2.41)	1.01(0.53–1.91)	0.98
Day Laborer	116	67	0.56(0.31–1.00)	0.66(0.36–1.22)	0.19
Others*[a]	62	20	1	1	
Mother's age					
25–34	555	225	1.27(0.99–1.62)	**1.57(1.19–2.07)**	**0.002**
35–49	155	69	1.15(0.82–1.62)	**2.14(1.38–3.33)**	**0.001**
15–24[a]	314	161	1	1	
Household food insecurity					
Secured	555	252	0.95(0.76–1.19)	1.36(0.96–1.94)	0.08
Not secured[a]	469	203	1	**1**	
Number of children					
One to Three	747	296	**1.45(1.14–1.84)****	**1.51(1.11–2.04)**	**0.01**
Four and Above	277	159	1	**1**	

NB: [a]reference group, *Weaver, ** < 0.01, *** < 0.00.

> *The level of education of mothers affects their dietary decisions."* [A 30 years old female KI].
>
> *"She [the educated woman] has a positive influence on children's health and nutrition decisions. An educated mother has a positive influence on her children. Because she knows how to take care of them, wash them, dress them, clean them, and treat them well."* [A 36 years old female KI].

The women whose husbands involved in child feeding was two times more likely to practice joint intra-household decision making than those did not (AOR = 2.23, 95%CI: 1.70, 2.92).

Findings from the qualitative method showed that when men are engaged in caring for their children and sharing their family responsibilities, it provides a space for women to make joint decisions with their husbands.

> *"Men think washing and feeding the children is her [wife's] task; therefore, he does not get engaged. When giving money to buy food items, men limit the amount, then she (the wife) says this is not enough, and he says, 'How not enough?' A few days later, if she asks him again, he says, the last day you bought much, where did it go? .... This hampers her decision-making capacity and freedom."* [A 40 years old male FG discussant].
>
> *"Some husbands are not willing to give already prepared ready feeding for their children rather they wait until she [the wife] comes back from where she goes. It is my duty to keep children when the mother has some task or if she goes to social issues."* [A 35 years old male FG discussant].
>
> *"...Yes, it [husband involvement in child feeding] affects joint decision making on children's feeding. Since our area is in a rural setting where there is a lack of awareness about many things, for example, in rural areas, men do not cook lunch......... If the children at home are hungry, but he sits and watches, do not attempt to work on feeding them. Therefore, he may not understand what to purchase for children"* [43-year-old female, KII participant].

Women above the age of 25 to 34 years were 1.5 times more likely to participate in intra-household decision making about child feeding as compared to aged less than 25 years of age women (AOR = 1.57, 95%CI: 1.19, 2.07). Older mothers aged 35 to 49 are 2.14 times (AOR = 2.14, 95%CI: 1.38, 3.33) more likely to participate in decision making with their spouse compared to younger women aged less than 25 years.

The majority of the respondents from the qualitative study reported that when the age of the women was smaller, their husbands loved to order and even insulted the younger women they married. Since husbands are older adults, wives submit themselves but with conflicts of interest against the decisions made by husbands.

> *"...A small age is not necessarily related to irrelevant thinking. She [women at a younger age] may have a good idea, but because of age differences, her husband would like to order, insult, and prescribe everything in the house. Communication, dealing, dialogue, and discussions were highly affected. ...., therefore good communication habits are important."* [A 39 years old male FG discussant].
>
> *"Women who are younger may say things like, "I am a child; I do not want to suffer for my child if there is communication difficulty." When there is little to no age gap, women put up with their husband's behavior, even when it makes him angry. When the husband and wife argue, the younger wife takes her frustrations out on the kids and neglects to take care of them...."* [A 33 years old female FG discussant].

The findings also showed that women with fewer children were 1.5 times more likely to participate in household decision making in relation to child feeding practices than those with four or more children (AOR = 1.51, 95%CI: 1.11–2.04).

Most focus group participants explained that when family size increases, there is an imbalance between a household's consumption needs and available resources. There is no cash to feed children. If there are several children living at home, the situation worsens.

> *"If the number of children is too much, the need is very high; therefore, there is much missing between need and supply. It is not easy to feed many children. For example, our work is 'shema' (waving), and when a social issue happens we stop working for three or more days. There will be no money for child's food. This condition complicates what women should decide for the child."* [A 32 years old female FG discussant].
>
> *"Many children in one household is really difficult to manage, the older children took the youngster's food. Mother should have followed them, but mother takes care of the younger. But most women go to market prepare food for the children and put in the house, the older children eat all the food, the younger stay without food. In this case women are not decision maker with the limited resources they have"* [A 29 years old female FG discussant].

4 Discussion

In numerous sub-Saharan African nations, such as Ethiopia, men hold primary control over household decision-making, resulting in women being placed in a subordinate position across all decision-making aspects (49, 50). This includes their ability to make decisions regarding their child's feeding practices, which is crucial as they are the primary caregivers for infants and young children (51). Research has shown that when women have greater authority in decision-making within the household, including the purchase of significant household assets, daily necessities, freedom of movement, and their own healthcare, it has a positive impact on child-feeding practices (52). However, women's involvement in decision making related to major household purchases is predominantly determined by their husbands (49). In Ethiopia, the majority of women reside in rural areas, where sociocultural barriers may hinder their decision-making regarding infant and young child-feeding practices (53, 54). Therefore, this study aimed to determine the status of joint decision-making and the associated sociocultural barriers in rural districts of the southern Ethiopian region.

The joint decision-making on infant feeding practices in the present study accounted for 69.2%. Aligning with a similar study conducted in Mizan Aman, South West Ethiopia, where the percentage was 67.2% (37), a study conducted in Dawro Zone 64.2% (55) a secondary analysis based EDHS 70.55% (34), northwest Ethiopia (75.1%) (32), pooled prevalence 70% (56), Ghana (75%) (33)and a study conducted in India (68%) (57). Furthermore, this finding was higher than those in Ghana (52.8%) (2), Nigeria (38.9%) (31), Nepal (47.1%) (58), Senegal (6.26%) (43), and Pakistan (28%) (36). The variation in the socio-demographic profiles of the settings could explain the observed discrepancies. For instance, a study conducted in a low-income country revealed that, as individuals age, their awareness of household matters increases, leading to greater involvement in decision-making processes (56). Additionally, differences in the timing of studies, the level of attention given to the issue, and the existence of policies and strategies aimed at promoting women's autonomy in household decision making contribute to the observed variation. A study carried out in Senegal provides additional insights into the impact of sociocultural norms on women's decision making. This highlights that the majority of decisions (80.3%) (59) are made by husbands, indicating their dominant role (60) influenced by specific cultural norms (35, 61). Consequently, this limits women's participation in decision-making processes, particularly concerning their freedom of movement, access to healthcare services, and making choices regarding significant purchases or essential needs for their children.

This study also discovered a significant statistical association between joint decision making and educational status. This finding is in agreement with several studies conducted in Ethiopia (34, 41), Senegal (59), Zambia (35), Nepal (58), and Ghana (33). This implies that educated women are more likely to possess the necessary personality, decision-making ability (62), mobility, and directly contribute to the socioeconomic development of households (49), and help build self-confidence (62) to negotiate on matters they perceive they should take part in, which also provides them with equal decision-making roles and the possibility of being employed. On the other hand, the current study also outlined education as one of the barriers hindering collaborative decision-making, which indicates that the attainment of education empowers women to have increased involvement in household decisions (63). Overall, educated women can be aware of their right to freedom of movement and are capable of exercising it as far as child-feeding is concerned. Empowering women with education is a crosscutting issue for key stakeholders such as the Ministry of Education and other program implementers.

Husband/partner involvement in child feeding was found to be an independent factor affecting women's decision-making in the household. This was supported by a multinational study conducted in a sub-Saharan African setting. Partner involvement positively empowered women to actively participate in household decision-making (64). In Nepal, partner or husband participation is strongly associated with joint decision making (65). This suggests that increased women's participation in household matters works in synergy with their husbands' involvement, mainly related to child-feeding practices. It also provides the insight that couples that used to cooperate in household decisions are likely to view child feeding as a shared practice. In fact, the enhanced availability of food for children in the household can be achieved through husbands' engagement rather than by nominating children feeding a role assigned to women (66). Thus, women with active participation in household matters are more likely to attain their preferences, and this can assist implementation strategies, as husbands' participation in child feeding is viewed as an acceptable norm and also benefits couples without underestimating women's decision-making. In contrast to its positive implications, disengagement of the husband is one of the barriers to this study. In the current study, decision-making power was hindered by the lack of collaborative or shared roles in the household. This was supported by a study in Gambia, which revealed that the patriarchal nature of a household can influence women's right to make decisions regarding resource allocation, education, and childcare (47).

This study also shows that women's decision-making in household matters, particularly related to child-feeding practices, was positively associated with participants' age, indicating that advanced women's age influences women's decision-making in rural households. Several studies conducted in Albania (67), Senegal (59), rural Ethiopia (68), Zambia (35) and Nepal (58) support this finding. This indicates that the tradition of viewing older women has an important or influential position in society, which implies a change in the role of women as their age advances (69). However, compared to men, the view of society toward women of the same age generally lacks recognition of providing equal value or position, regardless of their age (70). In support of this, the current study also revealed that age differences between couples could be a barrier to the active participation of women in household decision-making. This implies that women no longer tend to feel shy or ashamed as they age; rather, they feel confident and find it difficult to express their thoughts freely and participate in household decision-making. In line with the current study, qualitative studies conducted in India (71), Columbia (72), and Ethiopia (73) also showed that the influence of age variation on the active participation of women in household decision-making is a viable factor shared by these countries.

Another finding of this study is that women with fewer children are more likely to participate in household decision making. In agreement with the quantitative findings, the FGD discussant in the qualitative section of this study also outlined that having a larger number of children in the family is a barrier to household decision-making. This could be because of the scarcity of resources to be shared, including time spent with children, which makes the mother worried more about choosing what her baby needs. This observation shows that women living in regions with high fertility are likely to suffer from low participation in household decision-making (74). However, this explanation can also imply that for women living in patriarchal households, having children, especially sons, can help improve their participation in household matters (75). In contrast, a qualitative study from South Asia showed that women's participation in household decision-making can be enhanced in the presence of daughters, which is consistent with a theoretical model in which mothers have greater relative preferences for spending on their daughters than fathers, and thus seek more autonomy to direct resources to their daughters (76). Although the literature has argued the importance of the sex of the child, we do not know whether a large number of daughters or sons will leave women with autonomy unaffected (77). Nevertheless, women who exercise active participation either by themselves or under circumstances are less likely to need many children as a prop for their status. This is support by the "theory of allocation of time," proving the idea that there has been a shift from investing in the quantity of offspring to investing in their quality, as proposed by Gary Becker and his colleagues (78). This concept works for the decision-making process of parents who face resource constraints, such as time and money, which is common in developing nations, such as Ethiopia. Educated women are more likely to opt for fewer children because they understand the opportunity cost of childbearing, which falls mainly on them (79). The costs of having more children, in terms of productivity and time opportunity costs, increase with each additional child.

4.1 Strengths and limitations

Data were collected using both quantitative and qualitative approaches and employed the perspectives of husbands, wives, and other information sources. This study employed joint decision-making questions from large-scale studies, which could improve the validity of the measurement. We employed a large sample size, which could enhance the generalizability of our findings to a similar context; however, the identified context specific socio-cultural factors in this study may not be generalizable to other settings. Moreover, the findings of this study in general might not represent the urban contexts as we collected the data from rural districts. The study participants were selected from health extension program's family folder this might have affected the actual random selection. Due to the self-reported response, we also acknowledge the social desirability bias; to reduce this bias, a short questionnaire was used over a large number of questions. As this study was observational in nature, the identified associations did not guarantee causality between independent and dependent variables, hence, further research in the area should focus on experimental and longitudinal studies. Suggest future research using longitudinal or experimental designs to explore causal relationships. Qualitative data were collected by focusing on socioeconomic determinants, which limited the exploration of more information from qualitative data sources.

5 Conclusion/recommendation

This study found that the majority of participants reported joint decision-making. It is imperative to note that women's joint participation in household decisions is highly affected by their age, educational status, number of children, and husbands' involvement in child-feeding. Programs aimed at promoting shared decision-making—especially those that include educational initiatives and engage men in childcare—should be given due attention in policy goals. This could involve the education sector in favor of improving women's literacy or family guidance in providing family planning services to limit the number of children. Furthermore, programs targeting women and children should also consider male involvement.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Arba University institutional review board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

KF: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AT: Conceptualization, Methodology, Project administration, Supervision, Visualization, Validation, Writing – review & editing. BT: Conceptualization, Methodology, Project administration, Supervision, Visualization, Writing – review & editing. ZA: Conceptualization, Methodology, Project administration, Supervision, Validation, Visualization, Data curation, Formal analysis, Funding acquisition, Investigation, Resources, Software, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Influence of mothers' and frontline health workers' knowledge, attitude, and practices on infant and young child feeding and child nutrition: a cross-sectional study in aspirational districts of Assam, India

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The knowledge, attitude, and practices (KAP) of mothers and frontline health workers (FLWs) regarding optimal Infant and Young Child Feeding (IYCF) are essential for mitigating undernutrition and associated morbidities among under-five children. The study assessed the KAP of mothers (of children aged 0–60 months) and FLWs regarding recommended IYCF practices, the association of mother's KAP with their demographic characteristics and children's nutritional outcomes, and the prevalence of stunting, wasting, and underweight among children aged 0–60 months in five high-focus districts of Assam. Data were collected from 389 mothers, 456 children, and 138 FLWs using a standard method. Of the 389 mothers, 29% had good KAP scores, 42% scored average, and 29% had poor KAP scores regarding IYCF practices. The mean KAP score increased significantly with improvements in variables such as community, language, education level, monthly income, and living conditions ($p < 0.01$). Less than half of the children were stunted (40%), one-third were affected by wasting (28%), and approximately 43% were underweight. Children whose mothers had a KAP score of less than 40% were 2.05 times more likely to experience stunting (CI = 1.04–4.02) than those whose mothers scored above 60%. Similar findings were reported for wasting and underweight. Of the 138 FLWs, 56% had good KAP scores, 30% had average scores, and 14% had poor scores. There was a noticeable gap in the KAP of the mothers regarding IYCF practices compared to that of FLWs. A comprehensive intervention plan to improve feeding practices can enhance the nutritional status of under-five children.

KEYWORDS

IYCF practices, knowledge, attitude, practices, undernutrition, aspirational districts, Assam

1 Introduction

Malnutrition is a critical public health concern influencing child morbidity and mortality, accounting for one-third (35%) of global deaths and two-thirds (68%) of deaths among under-five children in India (1). Globally, 25% (approximately 159 million) of under-five children are stunted, 16% are underweight (101 million), and 11% are wasted (52 million). South Asia has 38% of children who are stunted and 33% who are wasted, with India contributing significantly: 32.1% of children are underweight and 35.5% are stunted, largely due to chronic undernutrition (2–4).

Although India's infant mortality rate has decreased from 89 per 1,000 live births (in 1990) to 28 (in 2020) per 1,000 live births, progress in managing undernutrition remains unsatisfactory. For instance, the rate of wasting changed only marginally from 19.8% (NFHS 2005–2006) to 19.3% (NFHS 2019–21) in the last decade (2, 5, 6). In Assam, a northeastern Indian state, the indicators are even more concerning: 35.3% of under-five children are stunted, 32.8% are underweight, 21.7% are wasted, and 9.1% are severely wasted, reflecting a decline compared to the 2015–16 NFHS data (2, 7, 8). Key nutrition indicators for India, Assam, and globally are provided in Table 1.

The World Health Organization (WHO) recommends optimal Infant and Young Child Feeding (IYCF) practices to ensure adequate child growth and development. These recommendations include initiating breastfeeding within 1 h of birth, exclusive breastfeeding for the first 6 months and continuing for 2 years or more, and providing nutritionally adequate, age-appropriate complementary feeding after 6 months (9–11). Although the IYCF practices in India have improved, they remain below optimal standards. In Assam, only 49.1% of newborns are breastfed in a timely manner and 63.8% are exclusively breastfed for the first 6 months (5).

Optimal breastfeeding could reduce under-five mortality rates by 13–19%, with an additional 6% reduction from complementary feeding (9, 12, 13). Breastfeeding also offers benefits to mothers by lowering health risks and delaying the return of fertility (14). However, women in rural areas are often found lacking appropriate knowledge and compliance with IYCF practices, which places children at risk for adverse health outcomes (15–17). Cultural and traditional feeding practices, including poor attitudes and unhealthy IYCF practices by primary caregivers, also hinder child development (18, 19).

To address these challenges, the National Institution for Transforming India (NITI) Aayog launched the 'Aspirational Districts Transformation (ADT)' program in 2018, targeting 115 underperforming districts across 24 states (20). The program focuses on health, nutrition, education, and various other sectors to track and improve outcomes. The Piramal Foundation also supported its implementation in 25 aspirational districts (including 5 in Assam) to enhance health and nutrition indicators.

1.1 Objectives

In our study, we assessed the following: (i) the knowledge, attitude, and practices (KAP) of mothers (of children aged 0–60 months) regarding recommended IYCF practices and their association with demographic characteristics and children's nutritional outcomes; (ii) prevalence of stunting, wasting, and underweight among 0–60-months-old children; and (iii) the KAP of frontline workers (FLWs) regarding recommended IYCF practices in five districts of Assam.

2 Materials and methods

2.1 Study settings

The study was conducted in five high-focus, aspirational districts of Assam, namely Baksa (population: 988,247; health blocks: 6); Barpeta (population: 1,772,211; health blocks: 7); Darrang (population: 996,915; health blocks: 4); Dhubri (population: 2,069,000; health blocks: 7), and Goalpara (population: 1,057,927; health blocks: 6) (21). These districts have poor nutrition indicators, with high rates of stunting (48.5% in Dhubri) and underweight prevalence (37.8% in Dhubri), compared to the state averages (stunting: 35.3%; underweight: 32.8%) and national averages (stunting: 35.5%; underweight: 32.1%) (5, 7, 8). The key nutrition indicators for all five districts are provided in Table 2, based on the NFHS-5 (2019–21) data.

2.2 Sampling method and sample size

A cross-sectional study was conducted over 3 months, from April to June 2019. A multi-stage sampling technique was employed for the selection of the participants. In the first stage, a total of 10 blocks, 2 blocks from each of the 5 districts, were randomly selected to ensure adequate representation of the districts. In the second stage, 10 villages per block that conduct regular Village Health Sanitation and Nutrition Days (VHSNDs) were randomly selected. In the third stage, the sample population attending the VHSNDs and fulfilling the inclusion criteria was selected. The sample size of mothers and children was calculated using *Open Epi version 3.01*. Among the five districts, Dhubri recorded the highest prevalence of children under 3 years of

TABLE 1 Key nutrition indicators globally, in India, and in Assam.

Indicators (in %)	Globally	India		Assam	
	2019	NFHS-IV (2015–16)	NFHS-V (2019–21)	NFHS-IV (2015–16)	NFHS-V (2019–21)
Wasting	6.9	21	19.3	17	21.7
Underweight	13	35.7	32.1	29.8	32.8
Stunting	21.3	38.4	35.5	36.4	35.3

Sources: The World Bank (3); International Institute for Population Sciences (2); International Institute for Population Sciences (5); International Institute for Population Sciences (IIPS) and ICF (6); International Institute for Population Sciences (IIPS) and ICF (31).

TABLE 2 Key nutrition indicators of all five aspirational districts of Assam.

Indicator	Assam	Baksa	Barpeta	Darrang	Dhubri	Goalpara
Children under the age of 3 years who were breastfed within 1 h of birth	49.1%	34.9%	46.4%	51.7%	57.9%	45.7%
Children under the age of 6 months who are exclusively breastfed (%)	63.6%	60.6%	62.9%	61.1%	66.4%	*
Total children aged 6–23 months receiving an adequate diet (%)	8%	14%	5.5%	9.1%	7.4%	7.5%
Children under 5 years who are stunted (height-for-age)	35.3%	41.2%	29.8%	42%	48.5%	38.9%
Children under 5 years who are wasted (weight-for-height)	21.7%	17%	19.5%	27%	21.5%	24.3%
Children under 5 years who are severely wasted (weight-for-height)	9.1%	6.2%	7.5%	9.1%	6.7%	14.3%
Children under 5 years who are underweight (weight-for-age)	32.8%	34%	26.2%	33%	37.8%	35.4%

Sources: International Institute for Population Sciences (5).

age who were breastfed within 1 h of birth (57.9%) (8). Considering this prevalence, a design effect of 1.5, a precision of 5%, and a non-response rate of 10%, we calculated a sample of 398 mothers to obtain statistically significant results. Similarly, we estimated a sample size of 440 for children aged 0–60 months using a 26.2% prevalence of underweight from Barpeta (7). A total of 94 VHSNDs across the 10 health blocks were visited to collect data from 389 mothers, 456 children, and 138 frontline workers.

2.3 Study participants

Inclusion criteria: All women residing in the aforementioned five aspirational districts of Assam, primigravida and multigravida women, and mothers with children aged 0–60 months, who attended the VHSNDs in the selected villages. It also included female FLWs who were involved in community health, such as Accredited Social Health Activists (ASHA) or Anganwadi workers, who conducted the VHSNDs and consented to participate in the study. *Exclusion criteria:* Mothers or FLWs who refused to participate in the study were excluded, even if they satisfied the inclusion criteria.

2.4 Study variables

Outcome variables: The primary outcome variable (s) were the knowledge, attitude, and practices (KAP) of the mothers regarding infants and young child feeding practices. The interview schedule included 43 questions to assess the knowledge (13), attitude (10), and practices (20), based on the WHO infant and child feeding guidelines (11). If a person answered all questions correctly, they were awarded 43 scoring points. The total KAP score was categorized as good (correct answers ≥60%), average (correct answers between 40 and 59%), and poor (correct answers <40%) (22). The knowledge questions were scored with one point for correct answers and zero for wrong or uncertain responses, with a score range from 13 to 0. Individuals with more than seven correct answers (≥60%) were considered to have good knowledge of IYCF, while those with seven or fewer correct answers were considered to have poor knowledge. Attitude was assessed using a Likert scale ranging from −2 (strongly disagree) to +2 (strongly agree), with a total score ranging from a maximum of +20 to a minimum of −20. An attitude score greater than 11 (≥60%) was considered good, while a score of 11 or less was considered poor. For practices, the score range was from a maximum of +20 to a minimum of 0, with one point awarded for correct responses and zero for wrong or uncertain responses. Practices were classified as good with a score greater than 11 and as poor with a score of 11 or less. Anthropometric measurements were recorded to assess nutritional outcomes among the children aged 0–60 months, including (i) wasting (weight-for-height below −2 SD), (ii) stunting (height-for-age below −2 SD), and (iii) underweight (weight-for-age below −2 SD).

Predictor variables: Predictor variables were selected based on our previous knowledge of the factors affecting the knowledge, attitude and practices of the mothers regarding IYCF practices, such as sociodemographic variables (family size, socioeconomic status, religion, etc.) and environmental conditions (sanitation, drinking water, etc.).

2.5 Data collection

Data collection was conducted using an interviewer-administered, structured, and semi-structured interview schedule, along with an existing validated questionnaire on Infant Young and Child Feeding practices by the World Health Organization. This questionnaire was translated into the native language of the respondents to gather relevant sociodemographic characteristics, as well as the knowledge, attitude and practices of the mothers regarding IYCF. Trained staff collected anthropometric measurements of the children's weight (kg), height (cm), and mid-upper arm circumference (MUAC) (cm). The interview schedule was pretested among 15 respondents before administering it for the data collection. These samples were not included in the main data analysis. The data obtained from the participants were kept confidential and anonymous.

2.6 Data analysis

The data analysis was conducted using licensed IBM SPSS statistics version 25 (23). All categorical variables were presented as frequencies and percentages, and all continuous variables were presented as mean ± standard deviation. The association between the demographic features and the mean knowledge, attitude, and practices scores was analyzed using one-way ANOVA to determine the level of significance. A *p*-value of less than 0.05 was considered statistically significant. The internal consistency of the mothers' responses to the questions on knowledge, attitude, and practices regarding IYCF practices was assessed using Cronbach's alpha reliability coefficient. A reliability coefficient of 0.70 or higher was considered "acceptable." The association between stunting (below −2 SD), wasting (below −2 SD), and underweight (below −2 SD) and the mother's KAP was assessed using the odds ratio (24, 25).

2.7 Ethical approval

The Institutional Ethics Committee of Piramal Swasthya Management and Research Institute (PSMRI) approved the study (IEC Study Ref No: PSMRI/2019/12). The purpose of the study was explained to participants and the Participant Information Sheet was provided in the native language of the respondent (Assamese for the study). The signed informed consent was obtained before enrolling the participants into the study.

3 Results

A total of 389 mothers with children aged 0–60 months participated in the study. The mean age of the mothers was 25.5 (± 5.1) years. The majority (70%) of the mothers were from the Muslim community, and more than half of them (54%) had completed schooling up to high school (class 10). The mean family size was 5.8 members (± 3.5), with an average monthly earning of INR 11,591 (± 6,611). Only one-fifth (22%) lived in pucca houses, and almost all households (97%) had access to a toilet, either kaccha or sanitary. The sociodemographic characteristics of the mothers are provided in Table 3.

The Cronbach's alpha reliability coefficient was in the range of 0.81 (knowledge), 0.84 (attitude), and 0.63 (practices). The overall reliability coefficient for the 43 questions on the mothers' KAP regarding IYCF was 0.89. Of the 389 participants, 112 (29%) had good knowledge, attitude, and practices, whereas 162 (42%) had average KAP and the remaining 115 (29%) had poor KAP regarding IYCF practices. The mean KAP scores increased significantly with improvements in variables such as community, language, education level, source of family income, monthly income, type of toilet at home, source of drinking water, and method of safe drinking water ($p < 0.01$). A comparison of the sociodemographic characteristics of the mothers with the mean KAP scores is provided in Table 3.

Of the 456 children aged 0–60 months whose anthropometric measurements were taken, 52% were male individuals and 48% female individuals, with a mean age of 20 (±15) months, an average weight of 8.7 (±2.9) kg, and a mean length of 73 (±15) cm. Approximately less than half of the children were stunted (40%, 185/456), one-third had wasting (28%, 127/456), and approximately 43% were underweight (43%, 96/456), all below −2 standard deviations, according to the WHO standards. The nutritional status of the children (0–60 months) is provided in Table 4.

The odds of developing stunting, wasting, and underweight among the children aged 0–60 months increased as their mother's knowledge, attitude and practices regarding appropriate IYCF practices declined. The odds of the children developing stunting were 2.05 (CI = 1.04–4.02) times higher when their mothers' KAP score regarding IYCF optimal practices was less than 40%, compared to those whose mothers scored more than 60%. Similar findings were reported for wasting (OR = 2.01, 0.93–4.35) and underweight (OR = 2.93, 1.47–5.85) for the mother whose KAP score was less than 40% compared to those who scored more than 60%. The association between the children's stunting, wasting, and underweight and the mothers' KAP score is provided in Table 5.

Of the total 138 FLWs, only 56% had good KAP scores regarding IYCF, followed by 30% with average scores and 14% with poor scores. Of the 389 mothers, 29% displayed good KAP scores, 42% had average scores, and 29% had poor scores. The KAP scores of the mothers and FLWs regarding IYCF practices are presented in Figure 1. It could be seen that the KAP of the FLWs and mothers varied widely. Despite 56% of the FLWs demonstrating good knowledge of IYCF practices, it appeared that only 29% of the mothers received this knowledge from the FLWs. Except for Baksa and Barpeta, the other three districts, where the minority population is high, showed a significant difference between the KAP of the FLWs and the mothers. Specifically, in Darrang, the difference was 26% for the FLWs and 8% for the mothers; in Dhubri, it was 44% for the FLWs and 17% for the mothers; and in Goalpara, it was 60% for the FLWs and 17% for the mothers.

4 Strengths and limitations

There is a lack of literature on the knowledge, attitude, and practices of mothers regarding Infant and Young Child Feeding in Assam. The strength of the study lies in the fact that we collected a sample from five different districts of Assam, which are high-priority and aspirational and have some of the poorest child nutritional indicators. There are 115 aspirational districts in India based on the composite index score (18). The findings of the present study may be applicable to other districts with similar poor health and nutrition indicators but may not be generalized to other districts of Assam.

There is a possibility of recall bias among the older mothers. The study findings will be useful for redesigning the mode of imparting programs or languages used in delivering nutrition interventions and behavior change interventions. In addition, the study provides insights into the association between a child's nutritional outcomes and the mother's KAP regarding IYCF practices, considering sociodemographic, maternal, and sanitation factors.

5 Conclusion

There is a noticeable gap in the overall knowledge, attitude and practices of the mothers of children aged 0–60 months regarding appropriate IYCF practices. These are high-priority districts in the

TABLE 3 Comparison of the sociodemographic characteristics of the mothers with the mean KAP scores.

Characteristics	N = 389	Mean knowledge	p-Value	Mean attitude	p-value	Mean practice	p-value
District	389	7.2 (3.4)	0.00	7.4 (4.5)	0.00	10.9 (3.1)	0.00
Age (years)							
Mean (SD)	25.5 (5.1)						
16–20	72	7.6 (3.4)	0.02	9.0 (4.3)	0.00	11.3 (3.0)	0.20
21–25	132	7.6 (3.2)		7.8 (4.3)		11.0 (2.9)	
26–30	134	7.2 (3.2)		6.8 (4.2)		11.0 (3.0)	
30 and above	51	6.0 (4.0)		6.1 (5.3)		10.1 (4.1)	
Religion			0.01		0.64		0.00
Hindu	112 (29)	7.9 (3.1)		7.6 (4.5)		11.7 (2.7)	
Muslim	274 (70)	6.9 (3.4)		7.4 (4.5)		10.6 (3.3)	
Christian	3 (1)	10.3 (1.5)		9.6 (2.5)		12.3 (2.0)	
Community			0.00		0.00		0.00
General							
Socially disadvantaged	184 (62)	7.6 (2.8)		8.65 (3.9)		11.4 (2.5)	
Did not answer	111 (38)	6.0 (4.2)		4.44 (4.1)	0	9.6 (3.8)	
Language			0.00		0.00		0.00
Assamese	241 (62)	8.2 (2.9)		8.4 (4.2)		11.4 (2.8)	
Bengali	105 (27)	5.7 (2.9)		6.3 (4.3)		10.5 (2.9)	
Others	43 (11)	5.6 (4.9)		5.0 (5.1)		9.2 (4.7)	
Education			0.00		0.00		0.00
No formal schooling	52 (13)	4.7 (3.3)		3.9 (4.0)		10.0 (3.1)	
Primary	66 (17)	6.4 (2.7)		6.8 (3.2)		11.0 (2.3)	
High school (class 10)	209 (54)	7.5 (3.4)		7.9 (4.4)		10.8 (3.3)	
Higher Secondary and above	62 (16)	9.4 (2.3)		9.5 (4.7)		12.0 (3.0)	
Marital status			0.00		0.00		0.47
Married	386 (99)	7.3 (3.4)		7.5 (4.5)		10.9 (3.2)	
Widow	3 (1)	1.6 (1.1)		0.00		9.6 (0.5)	
Type of family			0.61		0.16		0.01
Joint	223 (57)	7.2 (3.5)		7.2 (4.6)		10.6 (3.4)	
Nuclear	166 (43)	7.3 (3.2)		7.8 (4.3)		11.4 (2.7)	
Number of family members			0.11		0.04		0.2
Mean, Median, SD	5.8, 5.0, 3.5	7.5 (3.1)		7.6 (4.1)		11.2 (2.6)	
Five members	221	6.8 (3.7)		7.0 (5.0)		10.6 (3.7)	
6–10 members	153	7.8 (3.9)		10.0 (4.0)		11.2 (3.3)	
More than 10 members	15						
Source of family income			0.00		0.00		0.00
Daily Wager	164 (42)	6.5 (2.9)		6.6 (3.7)		10.6 (2.3)	
Agriculture	77 (20)	5.7 (4.1)		6.0 (5.0)		9.8 (4.4)	
Government service	25 (7)	10.1 (1.6)		7.6 (3.5)		11.4 (2.5)	
Private service	21 (5)	7.1 (3.4)		7.9 (4.2)		10.1 (2.6)	
Self-employed	102 (26)	8.9 (2.9)		9.7 (4.7)		12.4 (2.9)	
Monthly income (INR)			0.00		0.00		0.00
Mean, Median, SD	11,591, 10,000, 6,611	7.7 (3.9)		9.0 (2.9)		12.1 (2.7)	
Less than 5,000	32	6.4 (3.2)		6.8 (4.1)		10.3 (3.1)	

(Continued)

TABLE 3 (Continued)

Characteristics	*N* = 389	Mean knowledge	*p*-Value	Mean attitude	*p*-value	Mean practice	*p*-value
5,000–10,000	195	7.0 (3.1)		6.6 (4.5)		10.7 (3.1)	
10,001–15,000	89	9.6 (2.8)		9.5 (5.3)		12.3 (2.8)	
More than 15,000	73						
Type of housing			0.00		0.00		0.73
Kaccha	197 (51)	6.9 (3.1)		6.8 (3.7)		11.0 (2.6)	
Semi Pucca	105 (27)	6.8 (3.8)		7.5 (5.1)		10.7 (3.7)	
Pucca	87 (22)	8.6 (3.2)		8.7 (5.1)		11.0 (3.5)	
Type of toilet at home			0.00		0.00		0.00
Not available	12 (3)	6.9 (2.6)		6.6 (3.5)		11.0 (2.0)	
Kaccha	150 (39)	6.5 (3.1)		6.5 (3.8)		10.1 (3.1)	
Sanitary	227 (58)	7.8 (3.5)		8.1 (4.9)		11.5 (3.1)	
Source of drinking water			0.00		0.00		0.00
Hand pump	340 (87)	7.2 (3.2)		7.3 (4.3)		10.8 (3.1)	
Tube well	15 (4)	3.6 (3.7)		2.5 (4.6)		9.4 (3.1)	
Public tap	12 (3)	9.2 (3.5)		9.0 (2.7)		12.1 (3.2)	
Household water supply	22 (6)	8.9 (3.4)		11.7 (4.5)		14.1 (2.3)	
Method of safe drinking water			0.00		0.00		0.00
Directly from the source	140 (36)	6.5 (2.6)		6.9 (3.0)		10.6 (2.5)	
Boiling at home	25 (6)	4.5 (4.2)		4.5 (4.2)		8.0 (3.9)	
Water filter at home	219 (56)	8.0 (3.5)		8.0 (5.1)		11.4 (3.2)	
Others	5 (1)	7.6 (2.1)		11.2 (3.5)		14.2 (1.6)	

TABLE 4 Nutritional status of the children (0–60 months).

	Total	Baksa	Barpeta	Darrang	Dhubri	Goalpara
		N (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)
	456	85 (19)	89 (19)	91 (20)	94 (21)	97 (21)
Conventional indices						
(Below −2 SD)						
Stunting (height-for-age)	185 (40)	44 (52)	21 (24)	52 (58)	53 (57)	8 (9)
Wasting (weight-for-height)	127 (28)	19 (22)	13 (15)	30 (33)	35 (38)	33 (34)
Underweight (weight-for-age)	96 (43)	33 (39)	9 (11)	47 (52)	55 (58)	51 (53)
Severe indices						
(Below −3 SD)						
Stunting (height-for-age)	106 (23)	29 (34)	9 (11)	33 (37)	24 (26)	7 (7)
Wasting (weight-for-height)	63 (14)	12 (15)	5 (6)	12 (14)	13 (14)	24 (25)
Underweight (weight-for-age)	110 (24)	14 (17)	3 (3)	25 (27)	30 (32)	38 (39)

state of Assam, with the highest levels of undernutrition, especially stunting. The present study highlights that nutritional information regarding IYCF practices is influenced by the education, language, living conditions, and economic status of the caregiver and has a positive impact on the health status of children (26–29). Despite having good knowledge, a mother may have a poor attitude toward following standard IYCF practices.

Suggestions: There is an urgent need for strategic information, education, and communication (IEC) activities focusing on social and behavioral change communication (SBCC) to improve both acute and chronic outcomes of childhood nutrition. It is important to note that, although the entire family was involved in the process of child feeding, none of the members were aware of the recommended guidelines. Extensive awareness interventions for all family members, along with

TABLE 5 Association between stunting, wasting, and underweight (below −2 SD) in the children (aged 0–60 months) and the KAP score of their mothers (*N* = 259).

	Stunting (height-for-age)		Wasting (weight-for-height)		Underweight (weight-for-age)	
KAP score (of mothers)	Crude Odds Ratio (OR)	*p*-value	Crude Odds Ratio (OR)	*p*-value	Crude Odds Ratio (OR)	*p*-value
Good (≥60%)	Ref*.		Ref*.		Ref*.	
Average (40–59%)	1.58 (0.89–2.78)	0.11	1.65 (0.85–3.21)	0.13	1.76 (0.97–3.17)	0.06
Poor (<40%)	2.05 (1.04–4.02)	0.03	2.01 (0.93–4.35)	0.07	2.93 (1.47–5.85)	0.00

KAP score: Good (correct answers ≥60%), Average (correct answers between 40 and 59%) and Poor (correct answers <40%).
*Ref. = 1.00.

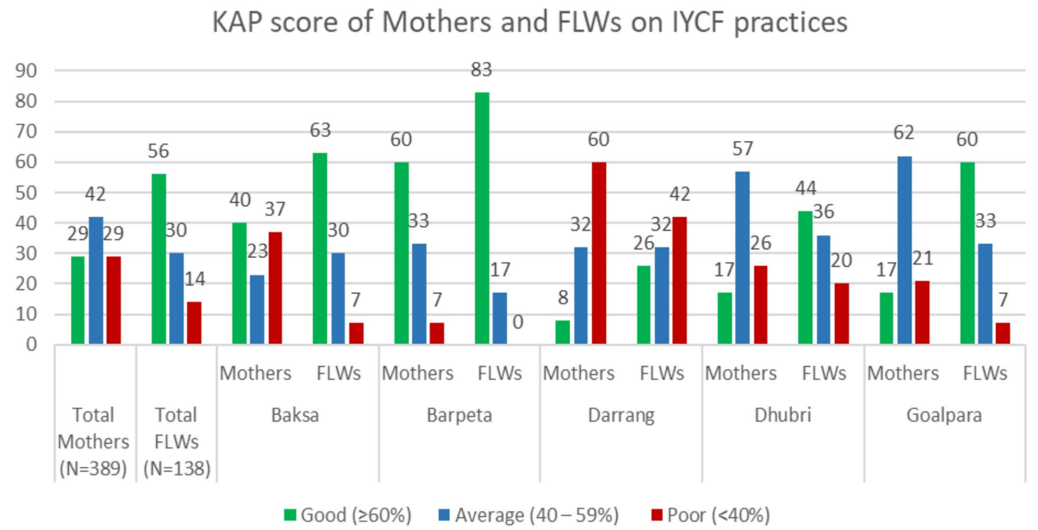

FIGURE 1
KAP scores of the mothers and FLWs regarding IYCF practices.

primary caregivers, regarding IYCF practices are essential. The SBCC program for interfaith leaders had some success in bringing about a change in the community's acceptance of health programs (30). The same strategy can be used to educate family members alongside mothers. Teenage pregnancy is also one of the key concerns in Assam. Specific interventions targeting adolescent girls should be explored to bridge the gaps in IYCF practices. The involvement of community health workers at the peripheral level is crucial for conducting continued sensitization workshops.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by The Institutional Ethics Committee of Piramal Swasthya Management and Research Institute (PSMRI) approved the study (IEC Study Ref No: PSMRI/2019/12). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SR: Conceptualization, Formal analysis, Writing – original draft. MC: Data curation, Investigation, Methodology, Supervision, Writing – review & editing. DC: Writing – review & editing. RB: Writing – review & editing. SH: Supervision, Writing – review & editing. PB: Writing – review & editing, Validation. VD: Formal analysis, Resources, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Mala flavor preference increases risk of excessive gestational weight gain mediated by high-carbohydrate dietary patterns in Chongqing, China: an ambispective cohort study

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Taste preference drives food selection, acceptance, or rejection and influences nutritional status and body mass index. Nevertheless, there are few reports concerning pregnant women. Mala flavor, characterized by its “numbing” and “spicy” sensations, is a distinctive taste of Sichuan cuisine, created by the combination of Chinese prickly ash and chili peppers. We conducted a cohort study in Chongqing, China to analyze the impact of Mala flavor, on excessive gestational weight gain (GWG). The study included 495 pregnant women aged 20–45 years, without chronic diseases, who conceived naturally and had single pregnancies from May 2021 to November 2022. Demographic information and pregnancy outcomes were collected during the second trimester and post-delivery, respectively. Food intake and taste preferences, including fatty, salty, and Mala flavors, were assessed during the third trimester. Latent Profile Analysis revealed three dietary patterns: “high-carbohydrate diet” (HCD), “low-carbohydrate diet” (LND), and “moderate nutrient diet” (MND). Multiple logistic regression indicated that pregnant women preferring Mala flavor were more likely to follow an HCD and had a higher risk of excessive GWG. Moreover, those adhering to an HCD were at an increased risk of excessive GWG. Mediation analysis showed that the preference for Mala flavor influenced excessive GWG through HCDs, with a significant indirect effect and an insignificant direct effect. Our study suggests that a preference for Mala flavor is positively associated with excessive GWG, mediated by HCD patterns. However, these findings should be approached with caution due to the exploratory nature of the study.

KEYWORDS

pregnant women, dietary patterns, taste preference, gestational weight gain, mediation analysis

1 Introduction

The "Developmental Origins of Health and Disease" theory posits that early-life nutrition is a key determinant in the development of chronic conditions such as hypertension, diabetes, and cardiovascular disease in adulthood (1). Gestational weight gain (GWG) serves as a direct measure of maternal nutrition and is an independent predictor of both perinatal and long-term health outcomes for both the mother and the infant (2). Studies show that inadequate GWG can raise the risk of infants being small for gestational age and having low birth weight, while excessive GWG may precipitate conditions like pregnancy-induced hypertension syndrome, preeclampsia, gestational diabetes mellitus, large for gestational age, and an increased need for cesarean section (3–5). Furthermore, excessive GWG can have lasting health repercussions, predisposing women to diabetes and cardiovascular diseases later in life and increasing the risk of childhood obesity in their offspring (6–8).

Nutrition during pregnancy is crucial, as it impacts not only the mother's health but also profoundly influences the growth and development of the fetus (9). A balanced and well-rounded diet is fundamental to controlling GWG and preventing pregnancy-related diseases (10). Analyzing dietary patterns, rather than individual foods or nutrients, provides a more effective approach to evaluating overall dietary status (11). There are various methods to assess dietary patterns: Priori methods, are based on existing dietary guidelines or scientific dietary recommendations and use scores to reflect the degree of adherence, such as index or score analysis (12, 13). Posteriori methods, aim to identify factors that explain variations in dietary patterns or classify individuals into distinct groups. Examples include factor analysis, cluster analysis, and latent profile analysis (LPA) (14–16).

The variations in geography, climate, history, customs, and assessment methods contribute to the diversity in reported dietary patterns across studies. Consequently, the impact of these patterns on GWG is a subject of inconsistent findings. A recent Danish study highlighted the advantages of a high-protein, low-glycemic index diet, particularly in reducing GWG and associated complications, such as a decreased rate cesarean deliveries among overweight or obese women (17). A retrospective study identified a negative association between GWG and adherence to the Mediterranean dietary pattern, which is characterized by a high consumption of vegetables, whole cereals, nuts, fish, and olive oil and a low consumption of refined cereals, snacks, and desserts (18). Additionally, a prospective cohort study from central China revealed that a dietary pattern rich in beans and vegetables is beneficial for managing GWG effectively and for promoting higher birth weight in newborns (19).

Recent studies have sought to explore the potential correlations between specific tastes preference, dietary habits, and obesity. A systematic review, which meticulously examined 19 articles, revealed a possible association between obesity and taste preferences, particularly a moderate inclination toward salty, bitter, and fatty flavors, as well as a heightened preference for sour flavors (20). However, there remains a significant gap in the literature concerning the relationship between taste preference and GWG.

In Chongqing, southwest China, the distinctive Mala flavor is a cornerstone of local cuisine. This flavor, characterized by its "numbing" and "spicy" qualities, is typically achieved by the addition of Chinese prickly ash, known for its tingling effect, and chili peppers to a variety of dishes including fish, poultry, meat, and soy products (21). Originating from Sichuan cuisine, the Mala taste has transcended regional boundaries, becoming a beloved seasoning across China and gaining international recognition for its unique sensory experience. However, the impact of this flavor profile on body weight remains largely unexplored in scientific literature. Furthermore, research on the connection between diet and GWG in Chongqing is scarce, which poses a challenge for the development of tailored nutritional intervention. In light of these gaps, our study aims to investigate the correlation between dietary habits, including taste preferences and dietary patterns, and GWG among pregnant women in Chongqing.

2 Materials and methods

2.1 Study population

This ambispective cohort study was conducted at Chongqing Kaizhou Maternal and Child Health Hospital. Pregnant women aged 20–45 years who underwent routine prenatal care at the hospital obstetrics department at 24–27 gestational weeks and were expected to deliver at the hospital were invited to enroll in the cohort from May 2021 to November 2022. Women who had undergone assisted reproductive technology (ART; e.g., ovulation induction, *in vitro* fertilization, intracytoplasmic sperm injection treatment, or intrauterine insemination); had chronic medical and surgical diseases or pregnancy complications; were confirmed to have multiple pregnancies; or had cognitive impairment, dementia, or severe mental illness were excluded from this study.

The ethics committee of Chongqing Kaizhou Maternal and Child Health Hospital approved this study. Written informed consent was obtained from all participants.

2.2 Measures

The participants were interviewed by trained obstetric nurses three times: at enrollment (24–27 gestational weeks), during the third trimester (32–36 gestational weeks), and after the delivery. Demographic information was collected at the time of enrollment. Data on dietary status, including taste preference and food intake over the previous month, were collected at 32–36 gestational weeks. Pregnancy outcomes were recorded after the delivery. GWG was calculated by subtracting the pre-pregnancy weight from the weight at the end of pregnancy. Inadequate or excessive GWG were defined, respectively, as GWG not meeting or exceeding the recommended GWG for each pre-pregnancy BMI category by gestational age at delivery on the basis of the Institute of Medicine guidelines (IOM) (22). Taste preference—fatty, salty, or Mala flavor—was recorded. The degree of preference was categorized as no or light, medium, or heavy. A streamlined and improved version of food frequency questionnaire (FFQ), building upon the 2014 edition (23), was utilized to collect data on dietary intake during pregnancy. The FFQ comprises 15 food items covering nine distinct categories, namely, cereals, vegetables, fruits, beans, meat, poultry, aquatic products, eggs, and dairy. For each food item in the FFQ, participants reported the frequency of consumption and portion size.

The sufficiency and quality of food consumption were determined using the Chinese Balanced Dietary Pagoda (CBDP) 2022 version for pregnant women (Supplementary Figure 1). The CBDPs, established and updated by the Chinese Nutrition Association, are visual representations of dietary guidelines for special groups of Chinese residents, including average adults, children, adolescents and pregnant women (24). These guidelines are crafted in accordance with principles of nutritional science and take into account the unique aspects of the Chinese dietary structure. CBDPs is structured into five distinct levels, each with a diminishing size from the base to the pinnacle. This hierarchy corresponds to the recommended daily consumption levels for five key food groups: cereals, vegetables and fruits, animal-based foods, legumes and nuts, and finally, cooking oils and salt.

2.3 Statistical analyses

Participants' characteristics, taste preferences, and daily food intakes were presented as mean ± standard deviation for continuous variables and as frequencies with proportions for categorical variables. Differences in variables between groups were evaluated using an analysis of variance (ANOVA) for continuous variables, and Pearson Chi-square tests for classification. Owing to low frequency, heavy taste preference was merged into the medium category for analysis.

LPA was used to identify mutually exclusive dietary patterns. The quartiles of daily food intake were used as exogenous variables. The optimal number of latent profiles was determined comprehensively by evaluating the goodness of fit of each model according to Akaike Information Criteria (AIC), Bayesian Information Criterion (BIC), and adjusted BIC (aBIC), as well as Entropy, Bootstrap Likelihood Ratio test (BLRT), and Lo–Mendell–Rubin likelihood ratio test (LMR) (25). Lower statistical values of AIC, BIC, and aBIC indicated a better fit. Entropy values range from 0 to 1, where a value closer to 1 indicates a more accurate classification. If $p < 0.05$ for LMR or BLRT, the k-category model is superior to the k-1 category model (25).

The association between taste preference, dietary pattern, and excess GWG was analyzed using a multiple logistic regression model, and adjustments were conducted for potential confounders that were selected on the basis of ANOVA. The mediating effect of dietary patterns on the relationship between taste preference and excess GWG was examined using mediation analysis.

LPA and mediation analysis were conducted using Mplus version 7.4. The rest of the analyses were performed using SPSS version 21.0. There was one missing value for BMI, which was replaced with the average value in the relative analysis.

3 Results

3.1 Demography of the pregnant women

Among the 635 pregnant women screened, 135 were excluded for intending to deliver at a different hospital ($n = 3$), undergoing ART ($n = 1$), having multiple pregnancies ($n = 2$), and having chronic medical disease ($n = 129$). Of the remaining 500 pregnant women, three were lost to follow-up, and two had stillbirths. Therefore, a final sample of 495 women was analyzed.

The pregnant women in this study had an average age of 27.8 (±4.4) years, with a mean pre-pregnancy body mass index (BMI) of 21.4 (± 0.7 kg/m^2). More than one-third were first-time pregnancies (36.0%), and the majority were from agricultural households (73.9%). Additionally, more than half had a junior high school education or below (51.3%), and the majority did not hold official employment roles (71.9%).

The pregnant women gained an average of 14.0 (±4.9) kg throughout their pregnancy. Of the total participants, 23.4 and 30.3% had inadequate and excessive GWG, respectively. Table 1 presents the demographic characteristics of pregnant women according to GWG. We noted only one significant difference in pre-pregnancy BMI among the three GWG groups ($p < 0.01$).

3.2 Dietary status of pregnant women

Most of the pregnant women had medium taste preferences for fatty, and salty flavors (82.2, and 77.6%, respectively) and had no or light taste preferences for Mala flavors (73.7%).

Their daily intake of cereals, meat, poultry, and eggs approached or exceeded the recommended levels. Their intake of vegetables, beans, and aquatic products fell significantly short, with less than 60% of the pregnant women meeting the minimum recommended intake for these food categories (Table 2).

As shown in Figure 1, compared with those with no or light preference, women with a medium preference for Mala flavors had higher intakes of cereals, vegetables, fruits, beans, meat, poultry, and aquatic products. Most food intakes did not differ significantly between women with different fatty (excepting for fruits, beans, and meat) or salty (excepting for cereals, meat, and dairy) flavor preferences.

The goodness of fit for the models examined indicated that the three-latent-profile solution demonstrated the most favorable fit indicators (Table 3). Class #1, comprising 182 (37%) participants, was characterized by an extremely high intake of cereals and labeled as "high carbohydrate die" (HCD). Class #2, including 124 (25%) participants, exhibited low intake across cereals, vegetables, fruits, meat, poultry, and aquatic products, and was categorized as "low nutrient diet" (LND). Class #3, consisting of 189 (38%) participants, was marked by moderate food intakes and termed "moderate nutrient diet" (MND) (Figure 2).

Table 4 indicates that women with a medium preference for fatty or salty flavors had a lower proportion of HCDs and a higher proportion of LNDs and MNDs. Women with a medium preference for Mala flavors had a higher proportion of HCDs and a lower proportion of LNDs.

A flowchart that categorizes the different groups of pregnant women based on the flavor preference and dietary patterns was shown in Supplementary Figure 2.

3.3 Relationship between taste preference, dietary pattern, and GWG

In Figure 3, women with a medium preference for Mala flavors had a higher risk of excessive GWG (adjusted odds ratio [aOR]: 1.80, 95% confidence interval [CI]: 1.13–2.86) compared with those with no or light preference. Additionally, women with HCDs had a higher

TABLE 1 Demographic characteristics of pregnant women in Chongqing according to gestational weight gain.

Variations	Total population	Gestational weight gain, *n* (%)			*p*
		Inadequate	Adequate	Excessive	
N	495	116	229	150	
Age, y					0.326
~25	136 (27.5)	36 (31.0)	63 (27.5)	37 (24.7)	
~30	222 (44.8)	46 (39.7)	111 (48.5)	65 (43.3)	
>30	137 (27.7)	34 (29.3)	55 (24.0)	46 (32.0)	
Pre-pregnancy BMI, kg/m^2					< 0.001
<18.5	55 (11.1)	11 (9.5)	37 (16.2)	7 (4.7)	
18.5 ~ 23.9	359 (72.5)	80 (69.0)	171 (74.7)	108 (72.0)	
≥24	81 (16.4)	25 (21.6)	21 (9.2)	35 (23.3)	
Gravidity					0.331
1	178 (36.0)	35 (30.2)	86 (37.6)	57 (38.0)	
>1	317 (64.0)	81 (69.8)	143 (62.4)	93 (62.0)	
Place of residence					0.393
Agricultural	366 (73.9)	91 (78.4)	164 (71.6)	111 (74.0)	
Non-Agricultural	129 (26.1)	25 (21.6)	65 (28.4)	39 (26.0)	
Educational qualifications					0.611
Junior high school or below	254 (51.3)	60 (51.7)	116 (50.7)	78 (52.0)	
Senior high school	141 (28.5)	38 (32.8)	63 (27.5)	40 (26.7)	
University and above	100 (20.2)	18 (15.5)	50 (21.8)	32 (21.3)	
Occupation					
Farmer	24 (4.8)	9 (7.8)	6 (2.6)	9 (6.0)	0.070
Business/working	42 (8.5)	5 (4.3)	26 (11.4)	11 (7.3)	
Teachers/civil servants/staff	55 (11.1)	9 (7.8)	29 (12.7)	17 (11.3)	
Unemployed	356 (71.9)	86 (74.1)	160 (69.9)	110 (73.3)	
Others	18 (3.6)	7 (6.0)	8 (3.5)	3 (2.0)	

BMI: body mass index.

TABLE 2 Daily food category intakes of pregnant women in Chongqing.

Food categories	Recommended dietary intakes (g)	Mean ± SD	
		Actual dietary intakes (g)	Relative intake (%)[a]
Cereals	225–275	214.4 ± 108.5	95 ± 49
Vegetables	400–500	83.4 ± 70.1	21 ± 18
Fruits	200–350	129.0 ± 111.3	65 ± 56
Beans	20	10.5 ± 13.6	53 ± 68
Meat and Poultry	50–75	43.9 ± 47.4	129 ± 112
Aquatic products	75–100	12.8 ± 17.3	17 ± 23
Eggs	50	50.2 ± 27.0	101 ± 54
Dairy	300–500	205.6 ± 93.2	69 ± 29

[a]Relative intake was calculated as a percentage of the minimum recommended intake.
SD, standard deviation.

risk of excessive GWG (aOR: 2.13, 95%CI: 1.27–3.60) compared with those with LNDs.

The mediation analysis demonstrated that the model comprising the independent (excessive GWG), dependent (Mala taste preference), and mediator (HCD) variables was within the acceptable fit (comparative fit index = 1.00, Tucker–Lewis index = 1.04, root mean square error of approximation = 0). As shown in Figure 4, the indirect effect of Mala taste preference on excessive GWG mediated by HCDs was significant ($\beta = 0.138$, $p = 0.019$), while the direct effect was insignificant ($\beta = 0.203$, $p = 0.136$).

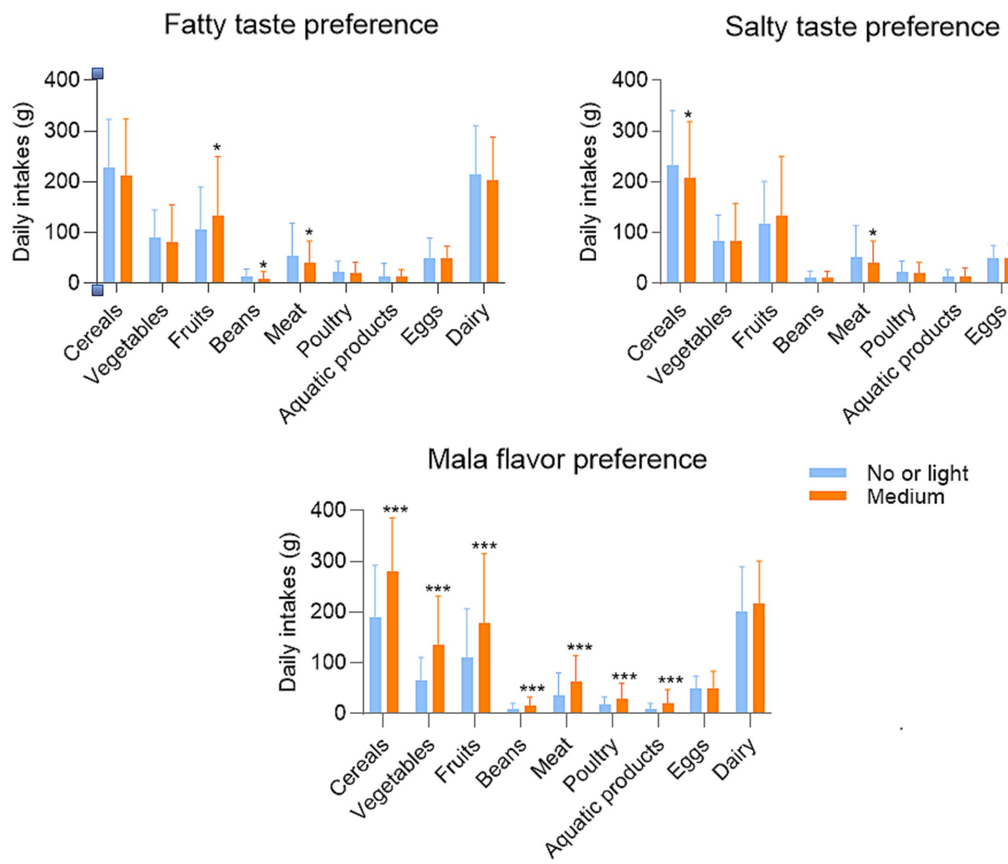

FIGURE 1
Daily food intakes according to different taste preferences, **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

TABLE 3 Fit indices for the latent profile analysis of daily food intakes in pregnant women in Chongqing.

Model	AIC	BIC	aBIC	Entropy	LMRT p	BLRT p	Class probability
2-class	12190.396	12308.124	12219.251	0.983	<0.001	<0.001	0.62/0.38
3-class	11602.113	11761.886	11641.274	0.979	0.0268	<0.001	0.37/0.25/0.38
4-class	11160.996	11362.815	11210.462	0.981	0.4624	<0.001	0.22/0.35/0.07/0.36

AIC, Akaike Information Criterion; BIC, Bayesian Information Criterion; aBIC, Adjusted Bayesian Information Criterion; BLRT, Bootstrap Likelihood Ratio Test; LMRT, Lo–Mendell–Rubin.

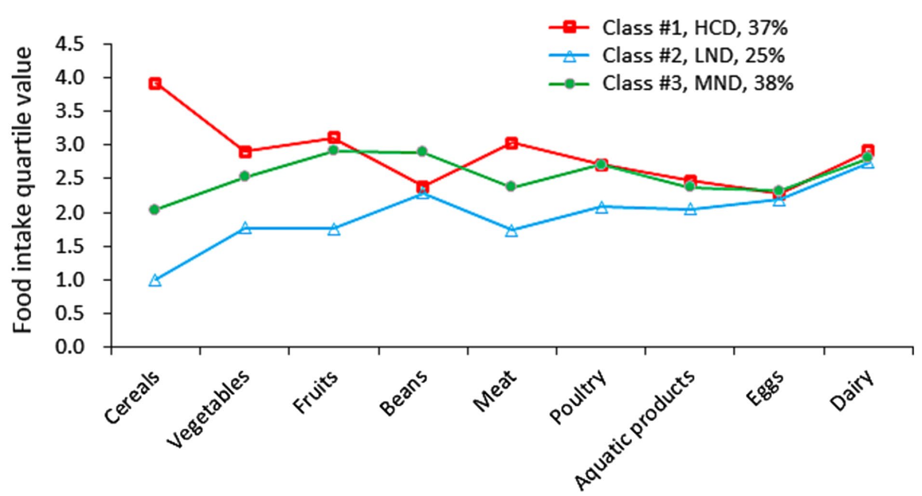

FIGURE 2
Description of the selected LPA profiles of the daily food intakes. HCD, high carbohydrate dietary; LND, low nutrient dietary; MND, moderate nutrient diet.

TABLE 4 Dietary patterns of pregnant women in Chongqing according to different taste preference.

Taste preference	HCD	LND	MND	*p*
Fatty				
No or light	41 (46.6)	14 (15.9)	33 (37.5)	0.041
Medium	141 (34.6)	110 (27.0)	156 (38.3)	
Salty				
No or light	54 (48.6)	22 (19.8)	35 (31.5)	0.013
Medium	128 (33.3)	102 (26.6)	154 (40.1)	
Mala				<0.001
No or light	109 (29.9)	117 (32.1)	139 (38.1)	
Medium	73 (56.2)	7 (5.4)	50 (38.5)	

HCD, high carbohydrate diet; LND, low nutrient diet; MND, moderate nutrient diet.

4 Discussion

GWG surpassing the recommended levels in approximately half of pregnancies is often attributed to unhealthy lifestyles and unbalanced diets (26). Excessive GWG is linked to an increased risk of adverse maternal and neonatal outcomes (27, 28). Data from China indicate that 30–50% of women experience excessive GWG (29). Multiple interventions, including diet, physical activity, and combinations, have been proposed to address this issue (30). A meta-analysis showed that dietary interventions are associated with reduced GWG and exert a more significant effect than physical activity alone does (31). Strategies for dietary interventions in weight management should focus on reducing energy intake and consider dietary patterns related to differences in food accessibility, eating behaviors, taste preferences, and cultural background (32). A comprehensive understanding of regional dietary intake elements is crucial for devising targeted dietary interventions to prevent excessive GWG.

In this study, we evaluated dietary intake and taste preference among pregnant women in Chongqing and their impacts on GWG. Our results showed that food intake during pregnancy was notably inadequate, except for cereals, meats/poultries, and eggs, with less than 70% of the recommended minimum intake based on the CBDP being consumed. This is consistent with the 2018 Chongqing Residents' Health Status report (33). An unbalanced diet heavily laden with carbohydrates has been reported to be associated with weight gain and obesity in Asia (34). This explains why, despite inadequate dietary intake, there are still quite a few cases of excessive GWG in Chongqing (30.3%). We identified three dietary patterns: HCD, LND, and MND by using the LPA method, and found that women adhering to HCD pattern, characterized by a high intake of cereals, had an increased risk of excessive GWG. Our findings align with those of a 2022 Danish study, which demonstrated that a low glycemic index diet was associated with reduced GWG (17). In a similar vein, a 2019 randomized controlled trial established a link between healthy eating practices, including lower carbohydrate intake, and decreased GWG (35). Additionally, a substantial longitudinal study among Korean adults bolsters our conclusions, showing that a diet rich in noodle or rice consumption was inversely related to reductions in waist circumference (36). It is noteworthy that compared to the LND, adhering to a MND pattern did not significantly increase the risk of excessive GWG. This suggests that a balanced diet is a more advantageous approach to ensure the intake of essential nutrients and to manage weight gain during pregnancy effectively.

Taste influences nutritional status and health. A systematic review was carried out in 2023 on the relationship between weight status and the perception of and preference for four common tastes (sweet, salty, fatty, bitter, and sour) by reviewing observational and interventional studies (37). The findings indicated that adults who were overweight and obese exhibited decreased perceptions of the four tastes and that preferences for sweetness and fat increased with weight gain (37). There is no consensus in the literature regarding the effects of food spiciness on obesity. One 2017 prospective study from China suggests that a high intake of spicy foods is positively associated with energy intake but inversely associated with the risk of overweight or obesity (38). A 2023 review of the literature indicated that both pepper extract and capsaicin have shown promising effects in aiding weight reduction (39). However, a meta-analysis of cross-sectional studies in the same year showed that spiciness may adversely affect overweight or obesity (40).

Regarding taste preference during pregnancy, only sugar consumption has been reported in 2019 to contribute to increased GWG and the development of pregnancy complications (41). In the present study, we investigated three taste preferences of pregnant women, namely, fatty, salty, spicy, and Mala flavors, and found that pregnant women who preferred the Mala flavor (but not fatty or salty flavor) had a higher risk of excessive GWG, compared with those who did not. Further analysis showed that the positive effect of consuming foods with a Mala flavor on excessive GWG was mediated by HCD patterns. Unlike the straightforward spiciness found in other regional Chinese cuisines, Sichuan cuisine is distinguished by a unique numbing sensation in its Mala flavor, which is derived from Chinese prickly ash. The numbing compounds in Chinese prickly ash, known as sanshool-based amides, activate sensory neurons in the mouth by targeting TRPV1, a chemically sensitive member of the transient receptor potential (TRP) channels (42, 43). This activation can influence appetite by modulating appetite hormone levels or by regulating gastrointestinal vagal afferent signaling (44). Mala sauce is a staple in Sichuan cooking, used extensively in dishes made with poultry, livestock, fresh fish, beans, and bean products, such as Boiled Meat Slices, Mapo Tofu, Spicy Beef Shreds, Spicy Chicken Slices, and more. Consequently, as our research indicates, the appetite-stimulating effect of Mala flavors lead to increased food intake among pregnant women who prefer this taste, particularly in cereals, and accordingly, a heightened risk of excessive GWG, which is mediated by HCD pattern.

Our study provides an innovative analysis of the effect of preference for the unique Mala taste of Sichuan cuisine on GWG. However, this study has some limitations. First, our FFQ only dealt with food categories, not specific foods, therefore, it was not possible to assess energy and nutrient intake. However, it was effective for collecting the frequency and amount of food category intake and analyzing dietary patterns. Second, the reliability and validity of the FFQ were not evaluated. Nonetheless, this version of the FFQ was an enhancement of the 2014 edition, which had demonstrated good reproducibility and correlations with 24 h dietary recall 2014 (23). And the results of food category intake in our study were consistent with those of the Chongqing Residents' Health Status Report, which reflects the validity of the FFQ to some extent. Moreover, the FFQ showed good reproducibility. The Spearman and intra-class correlation coefficients between the two FFQ measurements 3 months apart ranged from 0.22 to 0.66 and from 0.22 to 0.60, respectively

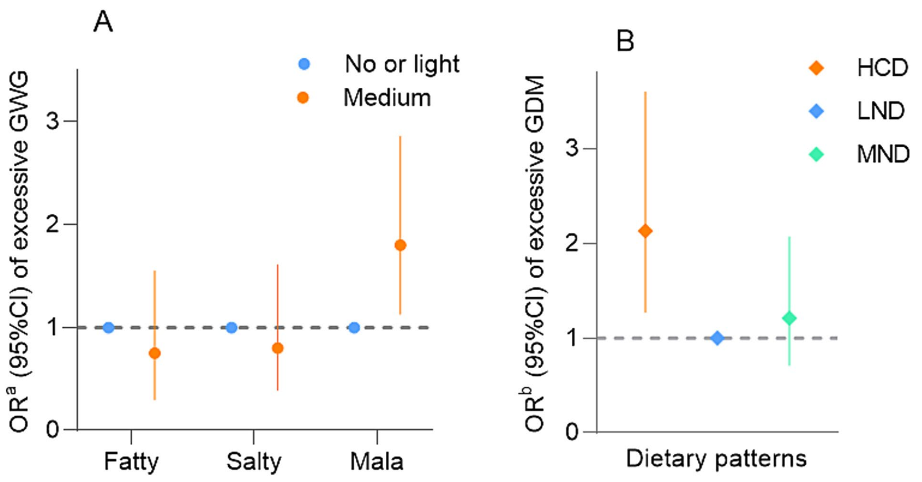

FIGURE 3
(A) The effects of taste preference on excessive gestational weight gain. **(B)** The effects of dietary pattern on excessive GWG. [a]Adjusted for pre-pregnancy BMI and other taste preferences. [b]Adjusted for pre-pregnancy BMI. GWG, gestational weight gain; HCD, high carbohydrate dietary; LND, low nutrient dietary; MND, moderate nutrient diet. The effects of taste preference on excessive gestational weight gain.

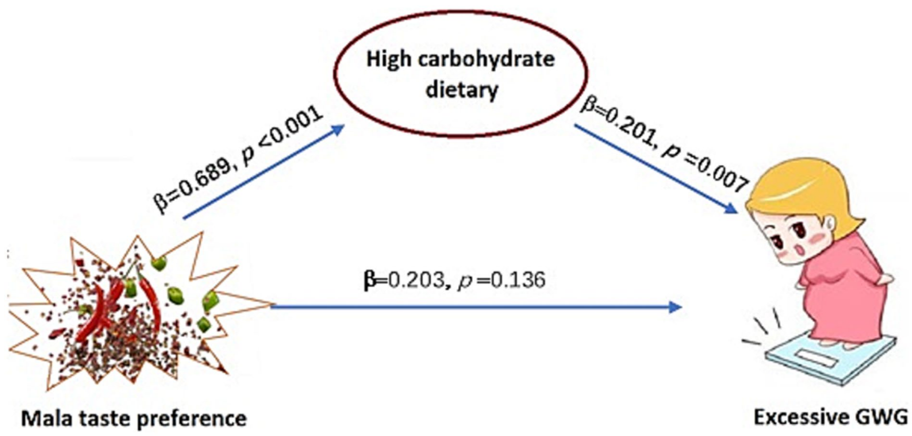

FIGURE 4
Mediating effect of Mala taste preference on excessive GWG. GWG: Gestational weight gain.

(Supplementary Table 1). The proportion of women classified into the same or adjacent quartiles by both FFQ measurements ranged from 72 to 85%, whereas the rate of misclassification into opposite quartiles was <9% (Supplementary Table 2). Third, we did not adjust for food intake when analyzing the relationship between taste preferences and GWG, which could potentially introduce bias into the results. However, in the subsequent mediation analysis, dietary patterns extracted on the basis of food category intake were included and adjusted in the model. Another significant limitation is the absence of external validation for our results, which means we cannot confirm the applicability of our findings to other populations. Consequently, it is imperative to approach the interpretation of our findings with caution.

5 Conclusion

The current study conducted a thorough evaluation of the dietary intake and taste preferences on GWG in the Southwest China region. Our results indicate that a preference for the Mala flavor, a distinctive characteristic of Sichuan cuisine, is positively associated with GWG, with this relationship being mediated by HCD patterns that feature high glycemic indexes cereals. It is recommended that pregnant women in the Chongqing region consider adjusting their preference for Mala flavors and reducing their consumption of high glycemic index cereals to manage GWG effectively and keep it within a healthy range. However, giving the exploratory nature of this study, caution is advised in interpreting these results. Future research with larger sample sizes is essential to validate our findings and to elucidate the underlying mechanisms, potentially incorporating relevant biomarkers into the analysis.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the ethics committee of Chongqing Kaizhou Maternal and Child Health Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JL: Conceptualization, Funding acquisition, Supervision, Writing – review & editing, Writing – original draft. DW: Funding acquisition, Formal analysis, Methodology, Writing – original draft. YM: Data curation, Methodology, Validation, Writing – review & editing. WuZ: Data curation, Investigation, Writing – review & editing. QZ: Supervision, Validation, Writing – review & editing. JL: Funding acquisition, Methodology, Supervision, Writing – review & editing. JD: Project administration, Supervision, Writing – review & editing. WeZ: Conceptualization, Supervision, Writing – review & editing. FW: Conceptualization, Supervision, Validation, Writing – review & editing. ML: Conceptualization, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2024.1464748/full#supplementary-material

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The impact of Pradhan Mantri Matru Vandana Yojna scheme on access to services among mothers and children and their improved health and nutritional outcomes

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KEYWORDS

PMMVY, access to health and nutrition services, impact on maternal and child health, propensity score matching, interrupted time series

1 Introduction and context setting

In developmental programming, more so over the last two decades, there has been an increased interest in and use of cash transfer programs to improve nutrition and health outcomes. There is considerable global evidence on the impact of the cash transfer programs—conditional or unconditional—on food security, dietary diversity, utilization of healthcare services, child cognitive development, and on morbidity, anemia, and anthropometry for both mothers and children (1). This evidence is largely from African, Latin American and American contexts.

In India, conditional cash transfer schemes (CCTs) have been extensively implemented, more so in the context of maternal and child health, and girls' empowerment. One of the earliest schemes was the Muthulakshmi Reddy Maternity Benefit (MRMB) scheme and the Girl Child Protection Scheme implemented in the state of Tamil Nadu in the 1990s (Department of Health and Family Welfare, Government of Tamil Nadu). This was followed by the Janani Suraksha Yojna (JSY), a national scheme introduced in 2005, designed to promote institutional deliveries (Ministry of Health and Family Welfare, Government of India). In 2017, the Government of India launched the Pradhan Mantri Matru Vandana Yojana (PMMVY), which is implemented as per the provisions of the National Food Security Act (NFSA) 2013. The scheme provides financial support to pregnant and lactating mothers to improve the health and nutrition for the mother and child, as well as compensate for wage loss, if any (Ministry of Women and Child Development, Government of India).

While CCTs have been implemented in India for over two decades, evidence on their impact and effectiveness is limited. India specific evidence is largely in the context of the JSY, where evidence indicates an increase in medically supervised births (2–4) and increase in access to Antenatal care (ANC) (3). Challenges with poor coverage of the scheme, and poor service quality were noted. After the JSY, the PMMVY is India's flagship maternity benefit program. Evidence on PMMVY is limited to evaluations done during the program pilot phase and studies done at state and district levels. There are few studies that review the scheme at a national level.

To understand the impact of the PMMVY on maternal and child nutrition and its effectiveness in improving service uptake, we examined the shift in key health and nutrition indicators in India, over time, comparing groups exposed and those not exposed to the scheme, using secondary data from the National Family Health Surveys (NFHS) and the Health Management Information System (5).

This paper first provides a brief about the scheme, followed by a summary of the available evidence of the effectiveness of the scheme. We then present our methods and analysis, and the results of the impact of PMMVY.

1.1 The PMMVY scheme

Launched on January 1, 2017, the PMMVY seeks to provide a cash incentive for partial compensation for the wage loss, so that women can rest before and after delivery of the first child and can consume nutritious food. In effect, the scheme seeks to improve maternal and child health and nutrition. Through conditions associated with the cash transfer, the scheme also seeks to improve health seeking behavior among Pregnant Women and Lactating Mothers (PW & LM). The benefit of the PMMVY is available to the first living child, and the second child, if it is a girl.

A total cash incentive of INR 5,000 is provided to PW & LM, subject to the following conditionalities

- First installment—of INR 3,000, on registration of pregnancy and at least one Ante-natal check-up within 6 months from the last menstrual period date at the Anganwadi Center (AWC) or approved health facilities.
- Second installment—of INR 2,000, provided when childbirth is registered and when the child has received the first cycle of immunization—i.e. Bacillus Calmette Guerin (BCG), Oral Polio Vaccine—(OPV), Diphtheria, Pertussis & Tetanus (DPT), and Hepatitis-B or its equivalent/ substitute.

1.2 The effectiveness and impact of PMMVY—A summary from available literature

One of PMMVYs most reported achievements is a systemic shift in terms of access to and utilization of healthcare services. In an assessment done in 52 pilot districts, it was found that women's interaction with local public health facilities rose by 14% in the 3–5 years following delivery. In the more immediate term, there was a 13% increase in the probability of mothers having met with an Anganwadi worker in the past 3 months (6). In terms of the impact of PMMVY on health and nutrition outcomes and mothers' and children, the same assessment found a 10% decrease in underweight mothers. However, this result was statistically not significant due to large standard errors (7). Similarly, there was a decrease in low birth weight by 4% points and a reduction of underweight in children (1–5 years old) by 4.6% points; the results however were not statistically significant. There were no significant impacts on stunting or anemia. Children eligible for the program were 9% more likely to be fully immunized compared to those in the control group. Significant improvement in Polio-3 vaccination, but no statistically significant effects for individual vaccinations when accounting for multiple inferences were noted (6).

A systematic review by Kumar et al. (8), showed that PMMVY created a positive impact in increasing utilization of key maternal and child health services such as antenatal care visits, institutional deliveries, and timely childhood immunization and vaccinations. It also noted that the evidence on the impact of PMMVY on maternal health outcomes was somewhat mixed and statistically inconclusive, with some studies reporting positive effects while others find no significant improvement.

A review of literature on PMMVY by Behera (9) noted that PMMVY encouraged better utilization of health and nutrition services among PW&LM. In a mixed-methods research study conducted in Gujarat, it was found that 56.62% of the mothers who had received PMMVY cash transfers reported that they spent the money on nutritious food and 25.62% reported spending it on health and medicines. However, at the time of the study, 21.9% of the beneficiary mothers had not yet withdrawn the money. It was also found that there was a lack of awareness among the beneficiaries about the specific purposes for which the money should be used (10).

Some improvements in immunization of children were noted, when PMMVY was implemented, along with the JSY. Four–six percent children were more likely to receive BCG (administered at birth) and DPT vaccines (administered within 2 months of birth) compared to those in districts with no JSY rollout (11).

Aizawa (12) using the data from the pilot phase evaluation of the PMMVY in 52 districts noted a reduction of 8.32% in infant mortality in treatment districts. In the pilot phase of PMMVY, there were 1.53 fewer deaths per 1,000 live births in the treatment districts. The Mamta Scheme, a state-level maternity entitlement scheme in Odisha meant to improve the health of pregnant mothers similar to PMMVY, also led to a positive impact on children's weight-for-height and weight-for-age ratios, significantly reducing child-wasting (13).

The available evidence thus indicates that PMMVY has encouraged health seeking and service utilization among PW& LM. However, evidence on the impact of PMMVY on maternal and child health outcomes, however, is mixed and less conclusive.

The design and implementation of the scheme, riddled with challenges, underscores the interpretation of the effectiveness and impact results. Some of the challenges documented in literature include:

- Poor quality service delivery, because of poor training, excessive workload and poor compensation of Aanganwadi and ASHA workers (14).
- Challenges in scheme implementation—including delays in cash transfers, exclusion of eligible beneficiaries, inadequate monitoring and grievance redressal mechanisms (8). A lengthy and complicated registration process, plagued by administrative delays, cumbersome verification procedures, the requirement of multiple documents at different stages, information asymmetry among beneficiaries, and discrepancies between bank accounts and AADHAR details affecting the cash transfer were noted by Behera (9), Dhariwal et al. (10), and Shruthi et al. (14).
- In terms of the scheme's design, concerns on the inadequacy of the incentive to compensate for out-of-pocket expenses during

pregnancy and childbirth have been documented, forcing women to return to the workforce within a month or so postpartum (14, 15). The autonomy and agency of women to influence fiscal expenditure and decision making on their health, influence the effectiveness of the scheme and use of the incentive, as intended, are also challenges. Dhariwal et al. (10) note that the scheme has not comprehensively addressed the underlying agency and economic pressures of women, which would eventually influence the impact of the PMMVY.

This paper seeks to add to the existing literature on PMMVY, and CCTs by shedding new light on the effectiveness and impact of PMMVY and identifying potential areas of improvement.

2 Study objectives

The objectives of the study are as follows:

- To assess the impact of PMMVY in improved access to and uptake of services—namely, early pregnancy registration, antenatal checkups, and institutional delivery.
- To assess the impact of PMMVY on maternal health and nutritional outcomes—namely, consumption of IFA by mothers, anemia among mothers, and mothers' weight.
- To assess the impact of PMMVY on child health and nutritional outcomes—namely, child weight at birth, hemoglobin and anemia levels among children, and child immunization status. In the context of PMMVY, the reference to child implies the firstborn child.

3 Data

To assess the impact of the PMMVY, we used two publicly available data sources—(i) NFHS, and (ii) the HMIS published by the Indian Ministry of Health and Family Welfare (MoHFW).

The NFHS is a nationally representative household survey that collects information on a series of health indicators including fertility, reproductive health, infant and child mortality, the practice of family planning, maternal and child health, nutrition, anemia, utilization, and quality of health and family planning services. For this study, we used NFHS round 4 (2015–2016) and round 5 (2019–2020) data.

The HMIS is a web-based monitoring and evaluation (M&E) system that publishes data on a wealth of health system indicators, published monthly at the district level from around 2.2 lakh health facilities (MoHFW). For this study, we used HMIS data from 2008 to 2020.

3.1 Key variables

We extracted variables of interest from the two datasets. The variables can be categorized into three groups— (i) process indicators—antenatal care received, and institutional births, (ii) mother-level indicators—mother's weight, mother's anemia status, and (iii) child-level indicators—child's birth weight, child's anemia status, and immunization status.

Data from the NFHS was used to assess the impact of PMMVY on all process, mother-level, and child-level indicators. Data from the HMIS was used to assess the impact of PMMVY on process indicators—antenatal care received, institutional deliveries, and child immunization.

4 Methodology

Using the two datasets, we used two novel methodologies to assess the impact of PMMVY. We used a propensity score to identify matched pairs of treated and untreated households to estimate the impact of PMMVY on the indicators of interest. Using the HMIS data, we used an event study methodology to assess the impact of PMMVY.

4.1 NFHS—Propensity score matching and analysis methodology

Using the NFHS-4 and—5 datasets, we created a dummy variable (PMMVY) which takes a value (=1) if the first child was born on or after January 1, 2017 (the official nationwide rollout date of the scheme), or (=0) if the first child was born before the cutoff date. This resulted in a total of 185,351 eligible households. All households where the first child was born on or after January 1, 2017, form the treatment group, whereas those with the first child born before January 1, 2017, form the control group. To ensure the comparability of these two groups, we used a propensity score-matching (PSM) algorithm. PSM is a statistical technique used to reduce selection bias when estimating the causal effect of a treatment or intervention. Using PSM, we identified households that fall within a common range of propensity scores that overlap between the treatment and control units (also called common support).

We undertook the matching of households pre- and post-introduction of PMMVY using a set of covariates capturing household demographic information, including household size, social group (religion and caste groups), access to basic services like water and toilet, and household wealth index. We matched the

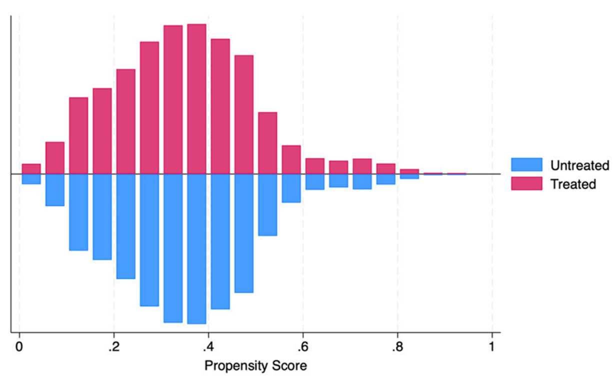

FIGURE 1
PSM common support. Source: figure compiled by authors using NFHS.

TABLE 1 Rosenbaum robustness checks for PSM.

Outcome variable	Gamma	sig+	sig−	t-hat+	t-hat−	CI+	CI−
Mother's weight	1	0.57	0.57	0.00	0.00	−2.00	1.50
	1.1	1.00	0.00	−6.00	5.50	−7.50	7.50
	1.2	1.00	0.00	−11.00	10.50	−12.50	12.50
	1.3	1.00	0.00	−15.50	15.50	−17.50	17.00
	1.4	1.00	0.00	−20.00	20.00	−22.00	21.50
	1.5	1.00	0.00	−24.00	24.00	−26.00	25.50
Mother's hemoglobin	1	0.00	0.00	−0.10	−0.10	−0.10	−0.05
	1.1	0.00	0.68	−0.15	0.00	−0.20	0.05
	1.2	0.00	1.00	−0.25	0.10	−0.30	0.10
	1.3	0.00	1.00	−0.35	0.15	−0.35	0.20
	1.4	0.00	1.00	−0.40	0.25	−0.40	0.25
	1.5	0.00	1.00	−0.45	0.30	−0.50	0.30
Mother's anemia	1	0.00	0.00	0.00	0.00	0.00	0.00
	1.1	0.00	0.00	0.00	0.00	0.00	0.00
	1.2	0.00	0.00	−0.50	0.00	−0.50	0.00
	1.3	0.00	0.00	−0.50	0.00	−0.50	0.00
	1.4	0.00	0.83	−0.50	0.00	−0.50	0.00
	1.5	0.00	1.00	−0.50	0.00	−0.50	0.00
Birth weight	1	0.00	0.00	0.00	0.00	−25.00	0.00
	1.1	0.00	0.91	−50.00	0.00	−50.00	0.00
	1.2	0.00	1.00	−100.00	25.00	−100.00	50.00
	1.3	0.00	1.00	−100.00	50.00	−125.00	75.00
	1.4	0.00	1.00	−150.00	100.00	−150.00	100.00
	1.5	0.00	1.00	−150.00	100.00	−165.00	125.00
Child's current weight	1	0.00	0.00	−15.50	−15.50	−16.00	−15.00
	1.1	0.00	0.00	−17.00	−14.00	−17.50	−13.50
	1.2	0.00	0.00	−18.50	−12.50	−19.00	−12.00
	1.3	0.00	0.00	−20.00	−11.00	−20.50	−10.50
	1.4	0.00	0.00	−21.50	−10.00	−22.00	−9.00
	1.5	0.00	0.00	−22.50	−8.50	−23.00	−8.00
Child's current height	1	0.00	0.00	−74.50	−74.50	−76.50	−72.00
	1.1	0.00	0.00	−81.00	−67.50	−83.00	−65.50
	1.2	0.00	0.00	−87.00	−61.50	−89.00	−59.50
	1.3	0.00	0.00	−92.50	−55.50	−95.00	−53.50
	1.4	0.00	0.00	−98.00	−50.50	−100.00	−48.50
	1.5	0.00	0.00	−102.50	−45.50	−105.00	−43.50
Child hemoglobin	1	0.00	0.00	−0.55	−0.55	−0.60	−0.55
	1.1	0.00	0.00	−0.65	−0.50	−0.70	−0.45
	1.2	0.00	0.00	−0.75	−0.40	−0.75	−0.40
	1.3	0.00	0.00	−0.80	−0.35	−0.85	−0.30
	1.4	0.00	0.00	−0.85	−0.25	−0.90	−0.25

(Continued)

TABLE 1 (Continued)

Outcome variable	Gamma	sig+	sig−	t-hat+	t-hat−	CI+	CI−
	1.5	0.00	0.00	−0.95	−0.20	−0.95	−0.20
Child anemia	1	0.00	0.00	−0.50	−0.50	−0.50	−0.50
	1.1	0.00	0.00	−0.50	−0.50	−0.50	−0.50
	1.2	0.00	0.00	−0.50	0.00	−0.50	0.00
	1.3	0.00	0.00	−0.50	0.00	−0.50	0.00
	1.4	0.00	0.00	−0.50	0.00	−0.50	0.00
	1.5	0.00	0.00	−0.50	0.00	−0.50	0.00

*Gamma–simulated unobservable bias.
Sig^{+} and sig^{-}: upper-bound and lower-bound p-values
**If the value < 0.05, then the results are robust and the outcome variable does not display any unobservable bias.

treated and untreated units with replacement, leading to 1-to-many matches. We retained the pair with the least propensity score (p-score) difference to derive the most effective matching. By doing so, we had 22,984 matched pairs of households (45,968 observations) with a firstborn child, born after and before January 1, 2017.

The Equation 1 for matching is denoted below,

$$M_i = min\,[\,e\,(X_i|Y_i = 1) - \,e\,(X_i|Y_i = 0)] \quad (1)$$

A minimizing function, where M_i is the matched comparison group for a treated household (i). $e(X_i)$ is the propensity for a vector of covariates, Y_i; and denotes the treatment status (whether the child was born before (0) or after (1) the rollout of PMMVY). The equation denotes the pair matching of treated and untreated units (households) based on the lowest propensity score difference. Figure 1 illustrates the common support and the matched pairs.

Using the 22,984 matched pairs of treated and untreated households, we assessed the impact of the PMMVY scheme on the process, mother-level, and child-level indicators relevant to mothers and children in the matched households. We estimated the program's impact using (i) a logistic regression model of binary indicators and (ii) an ordinary least squares (OLS) model for continuous indicators.

For binary indicators (for example, registered pregnancy, institutional childbirth), we used a logistic regression illustrated in Equation 2 below,

$$P\,(Y = 1 \mid X_1,\,X_2,\,X_3,\,\ldots .X_n) = \frac{e^{(\beta_0 +\, \beta_1 X_1 +\, \beta_2 X_2 \ldots \beta_n X_n)}}{1 +\, e^{(\beta_0 +\, \beta_1 X_1 +\, \beta_2 X_2 \ldots \beta_n X_n)}} \quad (2)$$

The equation estimates the predicted probability of ($Y = 1$) lying between 0 and 1. $P\,(Y = 1 \mid\, X_1,\, X_2,\, X_3,\, \ldots .X_n)$ is the probability of the dependent variable $Y = 1$, β_0 is the intercept and β_1 *to* β_n are the coefficients of independent variables X_1*to* X_n, and e is the base of the natural logarithm.

For continuous indicators (for example, mother and child's hemoglobin levels, month when pregnancy registered), we used an OLS model as illustrated in Equation 3 below,

$$Y_i = \beta_0 + \beta_1 PMMVY + \overline{X} + \varepsilon_i \quad (3)$$

where Y_i is the indicator of interest for the mother or child i. β_0 is the intercept and β_1 is the coefficient for PMMVY (0 = pre-January 2017, and 1 = post-January 2017). $\overline{X}$ is the vector of control covariates and ε_i is the error term.

PMMVY's impact on each indicator was estimated using four models, with each subsequent model introducing more control covariates—mother-level controls, demographic controls, and household controls. We can check for model sensitivity to the control covariates through this approach. The standard errors are clustered for the pair of treated and untreated units.

We undertook sensitivity analyses to assess the potential impact of unobserved confounding variables. Following the established framework proposed by Rosenbaum and Rubin (16), these analyses allowed us to estimate the degree to which hidden biases could influence our conclusions. We ran this robustness check for all outcome variables. The results are presented in Table 1. We find that the child-level outcome variables are robust when simulated for 50% higher bias while some mother-related outcomes display unobserved bias.

We acknowledge this unobservable bias as a potential limitation of this paper.

Before the nationwide rollout of PMMVY, a pilot program called the Indira Gandhi Matritva Sahyog Yojana (IGMSY) was implemented in 53 districts. The scheme was introduced in 2010 and was implemented before the national rollout of PMMVY. All the model estimates control for IGMSY pilot districts.

4.2 HMIS—Analysis methodology

Using the HIMS data, we used an interrupted time series (ITS) model to estimate the effect of the PMMVY on process indicators—antenatal care received, institutional deliveries and child immunization. An ITS requires multiple data points before and after the intervention (program) to estimate the program's impact. We extracted monthly data from all districts in India between April 2008 to March 2020. This large dataset allowed us to estimate the short and medium-run effects of the PMMVY program on health and nutrition indicators along with its impact on process indicators.

TABLE 2 Probability of registering pregnancy.

Register pregnancy	(1) Base model	(2) Mother controls	(3) Demographic controls	(4) Household characteristics controls
PMMVY	0.0391***	0.0370***	0.0348***	0.0339***
	(0.00245)	(0.00245)	(0.00238)	(0.00240)
Observations	35,557	35,557	35,451	35,451
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Delta-method standard errors in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.
Source: compiled by authors using NFHS-4 and -5.

TABLE 3 Month when pregnancy is registered.

Pregnancy register month	(1) Base model	(2) Mother controls	(3) Demographic controls	(4) Household characteristics controls
PMMVY	−0.0535***	−0.0558***	−0.0473***	−0.0476***
	(0.0116)	(0.0117)	(0.0138)	(0.0138)
Constant	2.790***	3.124***	2.406***	2.307***
	(0.00883)	(0.0386)	(0.0576)	(0.0641)
Observations	33,468	33,468	33,468	33,468
R-squared	0.001	0.018	0.063	0.069
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Robust standard errors in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.
Source: compiled by authors using NFHS-4 and -5.

TABLE 4 Mother received ANC.

Received ANC	(1) Base model	(2) Mother controls	(3) Demographic controls	(4) Household characteristics controls
PMMVY	0.00443	0.00576*	0.00497*	0.00587**
	(0.00316)	(0.00312)	(0.00271)	(0.00270)
Observations	23,330	23,312	22,998	22,998
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Delta-method standard errors in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.
Source: compiled by authors using NFHS-4 and -5.

A generalized ITS model uses a parameterized linear regression by Huitema and McKean (17) and is illustrated below in Equation 4,

$$Y_t = \beta_0 + \beta_1 t + \beta_2 D_t + \beta_3 [t - T_I] D_t + \varepsilon_t \tag{4}$$

where Y_t is the indicator of interest measured for time-period (t) for N periods, T_I is the interruption in the time series, and D_t a dummy variable = 0 for pre-interruption, and 1 for post-interruption. The model parameters are as follows—β_0–baseline intercept, β_1–slope for the pre-interruption period, β_2–change at the point of interruption, and β_3 change is slope post-interruption.

For all the indicators of interest, we ran a canonical ITS and used a moving averages (MA) model if the indicator exhibited an autocorrelation. Autocorrelation refers to the correlation of the variable with itself over successive time periods. This correlation can lead to model misestimates as the assumption of independence of observations is violated. We used a formal test to detect autocorrelation in the error term using the Durbin-Watson (DW) test (18) for the autocorrelation function (ACF) and partial autocorrelation function (PACF) plots. The DW test estimated the d-statistic. If the d-statistic

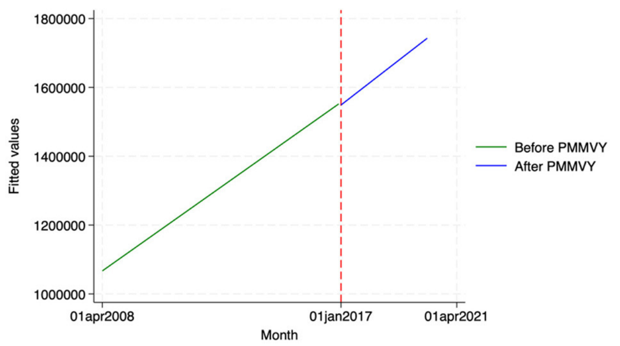

FIGURE 2
ITS—Registered before 1st trimester. Source: figure compiled by authors using HMIS.

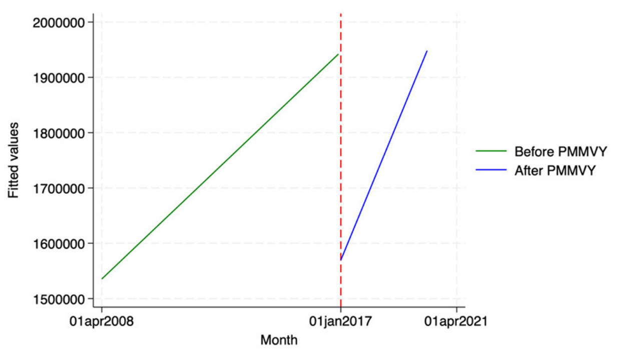

FIGURE 3
ITS—Received 4 or more ANCs. Source: figure compiled by authors using HMIS.

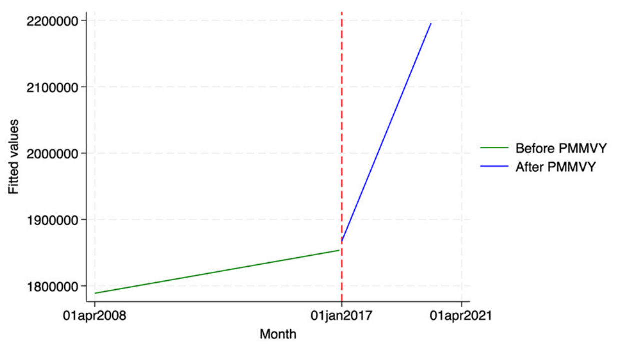

FIGURE 4
ITS—Pregnant women received 180 IFA tablets. Source: figure compiled by authors using HMIS.

TABLE 5 ANC outcomes—OLS.

Variables	(1)	(2)	(3)
	Total ANCs	4 or more ANCs	180 IFA tablets
Time	925.2*	3,911***	621.7
	(515.3)	(432.5)	(754.8)
PMMVY	87,691*	−382,820***	4,784
	(48,220)	(87,324)	(67,019)
Time after intervention	−3,347*	6,064*	8,039***
	(1,836)	(3,228)	(2,426)
Constant	2.289e+06***	1.531e+06***	1.788e+06***
	(34,333)	(30,461)	(56,426)
Observations	144	144	144
R-squared	0.104	0.464	0.225
Autocorrelation	No	No	No
Stationary	N/A	N/A	N/A

Robust standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: table compiled by authors using HMIS.

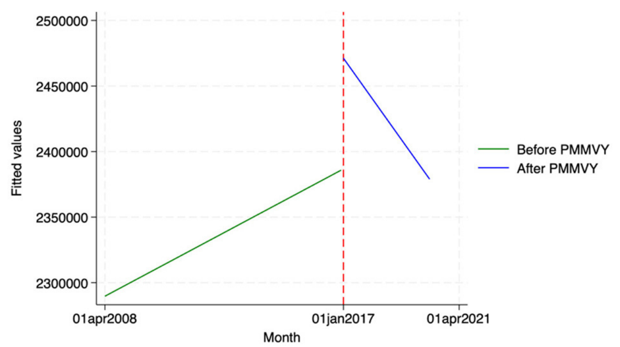

FIGURE 5
ITS—Total ANCs. Source: figure compiled by authors using HMIS.

is between 1 and 3, there is no autocorrelation. If the d-statistic is close to 0 or 4, then there is positive or negative autocorrelation, respectively.

For indicators that displayed autocorrection, we used either (i) an autoregressive moving average (ARMA) or (ii) an autoregressive integrated moving average (ARIMA) model. The difference between the two models is the stationarity of the time series. A time series is stationary if its statistical properties (mean and variance) are constant over time. If a series is non-stationary, it may have a trend or be subject to shocks that don't dissipate over time. We use the Augmented Dickey-Fuller (ADF) test to check the stationarity of the indicator of interest.

One key limitation of using the HMIS data is that it does not contain disaggregated information by birth order.

5 Results

The results are grouped and presented as the impact of PMMVY on three sets of indicators—(i) process indicators, (ii) mother-level indicators, and (iii) child-level indicators.

5.1 Impact of PMMVY on process indicators

5.1.1 Antenatal care

Using NFHS, we found that pregnancies of firstborn children were more likely to be registered post the rollout of PMMVY compared to children born before PMMVY. There was a 3.4% increase in the probability of pregnancy being registered after the introduction of PMMVY. Table 2 shows the marginal effects of PMMVY. Apart from an increased probability of pregnancies being registered, we also found that pregnancies were registered earlier after the introduction of PMMVY. Pregnancies were registered about 4.8% earlier (see Table 3), translating to pregnancies being registered about 12 days earlier than done before.

While there was a statistically significant increase in pregnancy registration, we found a very small (<1%) increase in the probability of mothers having received at least one antenatal care (ANC) visit (Table 4).

We found similar, heterogeneous effects of PMMVY on ANC care, using ITS and the HMIS data. Post the introduction of PMMVY, there was an increase in the number of women having received four or more ANCs (Figures 2, 3) and 180 iron folic acid (IFA) tablets [Figure 4; Table 5 (2) (3)]. An immediate increase in

TABLE 6 ANC outcomes—ARMA/ARIMA.

Variables	(1) ANC registration 1st trimester	(2) Severe anemia treated	(3) Hemoglobin under 7
Time	4,677***	120.3	
	(726.1)	(99.36)	
PMMVY	79,871	−1,952	−742.7
	(81,760)	(15,034)	(39,462)
Time after intervention	−2,195	69.39	2,030
	(2,862)	(430.5)	(587,283)
L.AR	0.781***	0.901***	−0.777
	(0.0922)	(0.0471)	(0.573)
L.MA	−0.212	−0.198**	0.740
	(0.138)	(0.0929)	(0.603)
Constant	1.047e+06***	32,320***	−5.296
	(39,368)	(4,091)	(587,800)
Sigma	74,446***	4,352***	7,013***
	(5,527)	(216.8)	(486.8)
Observations	144	144	143
Autocorrelation	Yes	Yes	Yes
Stationary	Yes	Yes	No

OPG standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p <0.1.
Source: table compiled by authors using HMIS.

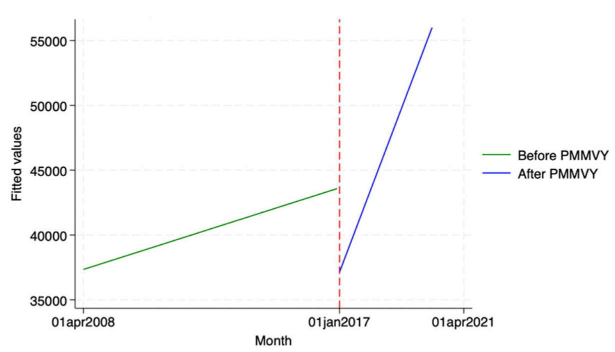

FIGURE 6
ITS—Pregnant women treated for severe anemia. Source: figure compiled by authors using HMIS.

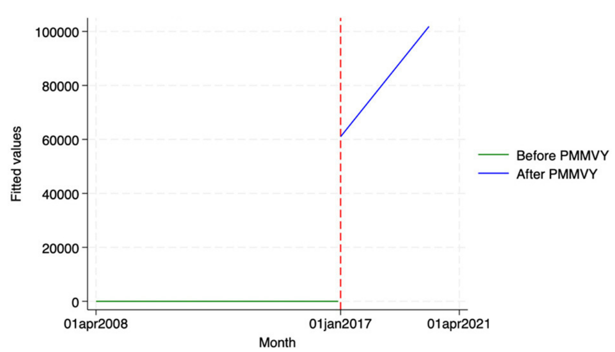

FIGURE 7
ITS—Pregnant women with hemoglobin less than 7. Source: figure compiled by authors using HMIS.

TABLE 7 Institutional delivery.

Institutional delivery	(1) Base model	(2) Mother controls	(3) Demographic controls	(4) Household characteristics controls
PMMVY	0.00505***	0.00406***	0.00293**	0.00622***
	(0.00185)	(0.00156)	(0.00146)	(0.00143)
Observations	45,887	45,887	45,831	45,831
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Delta-method standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: compiled by authors using NFHS-4 and -5.

TABLE 8 Delivery outcomes.

Variables	(1) Institutional Delivery	(2) Discharged within 48 h	(3) Homebirths attended by SBA
Time	2,750**	2,437*	
	(1,370)	(1,409)	
PMMVY	−43,129	7,869	−4,335
	(192,530)	(366,101)	(155,265)
Time after intervention	4,209	−4,897	1,037
	(7,625)	(11,306)	(11,625)
L.AR	0.766***	0.911***	−0.248
	(0.127)	(0.0499)	(0.237)
L.MA	−0.0807	0.0336	151.1
	(0.143)	(0.0939)	(4,956)
Constant	1.206e+06***	377,529***	−1,448
	(84,661)	(75,714)	(1,250)
Sigma	134,422***	56,390***	−88.97
	(7,070)	(3,147)	(2,918)
Observations	144	144	143
Autocorrelation	Yes	Yes	Yes
Stationary	Yes	Yes	No

OPG standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: table compiled by authors using HMIS.

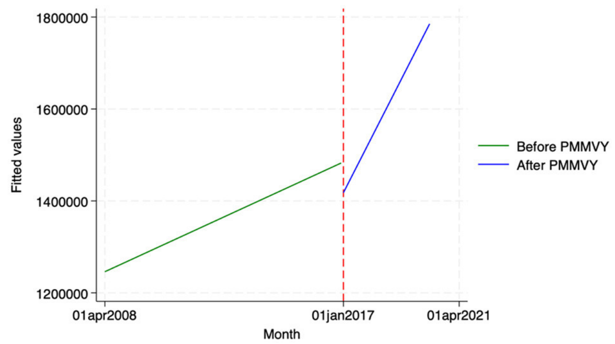

FIGURE 8
ITS—Institutional deliveries. Source: figure compiled by authors using HMIS.

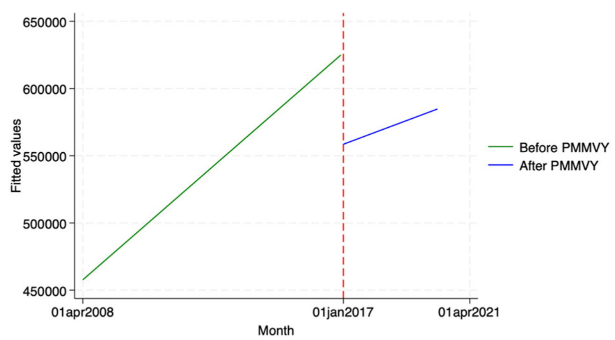

FIGURE 9
ITS—Institutional deliveries discharged within 48 hours. Source: figure compiled by authors using HMIS.

total ANCs completed post the introduction of PMMVY in 2017 was noted (Figure 5); however, there was a net decline in total ANCs over the years (Table 5). Using the HMIS data, we found no significant change in the number of pregnancies registered within the 1st trimester, or the number of pregnant women treated for severe anemia or hemoglobin under 7 g/dl (Table 6) (Figures 6, 7).

5.1.2 Institutional delivery

Using NFHS data, we found a small increase in the probability of institutional delivery post-PMMVY (Table 7).

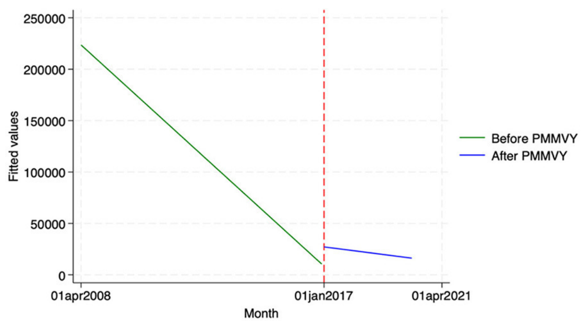

FIGURE 10
ITS—Homebirth attended by Skilled Birth Attendant. Source: figure compiled by authors using HMIS.

Using HIMS data, we estimated the impact of PMMVY on three delivery indicators—(i) the number of institutional deliveries (both public and private), (ii) the number of mother-child discharged within 48 h, and (ii) the number of homebirths attended by skilled birth attendants (Doctor, ANM, nurse).

Across these three indicators, we did not find any statistically significant change after the introduction of PMMVY. While we saw a change in slope or increase over time (as indicated by the coefficient "Time after Intervention"), the change was not statistically significant. In other words, while we did not find a statistically significant change in institutional delivery indicators post the introduction of PMMVY, we did see an overall increase in the absolute count for these indicators' month-on-month (as denoted by the "Time" coefficient in Table 8 and Figures 8–10).

TABLE 9 Mother's current weight.

Mother's current weight	(1) Base model	(2) Mother controls	(3) Demographic controls	(4) Household characteristics controls
PMMVY	0.0320	0.00221	0.0682	0.133
	(0.0954)	(0.0901)	(0.103)	(0.101)
Constant	50.26***	43.30***	50.88***	52.28***
	(0.0680)	(0.230)	(0.404)	(0.453)
Observations	45,968	45,968	45,968	45,968
R-squared	0.000	0.111	0.161	0.186
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Robust standard errors in parentheses.
***$p < 0.01$.
**$p < 0.05$.
* $p<0.1$.
Source: compiled by authors using NFHS-4 and -5.

TABLE 10 Mother's hemoglobin.

Mother's hemoglobin	(1) Base model	(2) Mother controls	(3) Demographic controls	(4) Household characteristics controls
PMMVY	−0.0801***	−0.0817***	−0.0250	−0.0248
	(0.0143)	(0.0142)	(0.0163)	(0.0163)
Constant	11.53***	11.24***	10.85***	10.93***
	(0.0105)	(0.0416)	(0.0737)	(0.0791)
Observations	45,968	45,968	45,968	45,968
R-squared	0.001	0.013	0.042	0.047
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Robust standard errors in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.
Source: compiled by authors using NFHS-4 and -5.

TABLE 11 Mother's anemia status.

Mother's anemia status	(1) Base model	(2) Mother controls	(3) Demographic controls	(4) Household characteristics controls
Severe anemia	0.00592***	0.00583***	0.00299***	0.00267**
	(0.00112)	(0.00106)	(0.00111)	(0.00105)
Moderate anemia	0.110***	0.112***	0.0756***	0.0772***
	(0.00396)	(0.00396)	(0.00464)	(0.00466)
Mild anemia	−0.0827***	−0.0828***	−0.0524***	−0.0528***
	(0.00429)	(0.00431)	(0.00496)	(0.00503)
Not anemic	−0.0336***	−0.0348***	−0.0262***	−0.0270***
	(0.00462)	(0.00464)	(0.00541)	(0.00544)
Observations	45,968	45,968	45,968	45,968
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Delta-method standard errors in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.
Source: compiled by authors using NFHS-4 and -5.

5.2 Impact of PMMVY on mother-level indicators

While we found some improvements in the process indicators, we did not find any statistically significant improvement in (i) the mothers' current weight (Table 9) or (ii) the mothers' hemoglobin levels, post the introduction of PMMVY (Table 10). The same cannot be said about the mothers' anemia status. There was an increase in the probability of first-time mothers being severely or moderately anemic, with the probability of the non-anemic status of mothers being lower for the treatment group (Tables 10, 11) (Figures 6, 7).

5.3 Impact of PMMVY on child-level indicators

5.3.1 Child weight and anemia

Using the NFHS data, we found that child-level indicators (i) the child's birth weight, (ii) hemoglobin levels, and (iii) anemia status were lower for the treatment group (post-2017). The children's birth weight for the treatment group was lower by about 10 g (Table 12) (95% significance levels). While this is a small number, the results are significant.

The hemoglobin levels of children in the treatment group were 0.47 units lower (Table 13), as compared to the control group. This has implications for early childhood development. The treatment group was 13.6% less likely to be non-anemic, with an almost equal increase in the probability of a child being moderately anemic, by 13.2% (Tables 13, 14).

TABLE 12 Child's birth weight.

Child's birth weight	(1) Base model	(2) Demographic controls	(3) Household characteristics controls
PMMVY	−0.0210***	−0.0130**	−0.0125**
	(0.00536)	(0.00596)	(0.00598)
Constant	2.817***	2.409***	2.397***
	(0.00389)	(0.0295)	(0.0321)
Observations	45,968	45,968	45,968
R-squared	0.000	0.043	0.045
Demographic controls	No	Yes	Yes
Household characteristics controls	No	No	Yes

Robust standard errors in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.
Source: compiled by authors using NFHS-4 and -5.

Using the HMIS data, we looked at two indicators—(i) the number of newborns that were weighed at birth, and (ii) the number of newborns who weighed below 2.5 kg. We did not see a statistically significant change in the indicators post-PMMVY. Having said that, we found a general upward trend for newborns weighed (Figure 11; as reported in the "Time" coefficient in Table 15). In other words, there was an increase

TABLE 13 Child's hemoglobin status.

Child's hemoglobin	(1) Base model	(2) Mother controls	(3) Demographic controls	(4) Household characteristics controls
PMMVY	−0.569***	−0.565***	−0.474***	−0.470***
	(0.0141)	(0.0139)	(0.0158)	(0.0158)
Constant	10.64***	9.950***	9.418***	9.448***
	(0.00992)	(0.0397)	(0.0734)	(0.0801)
Observations	45,968	45,968	45,968	45,968
R-squared	0.034	0.049	0.093	0.097
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Robust standard errors in parentheses.
***p < 0.01.
** p < 0.05.
*p < 0.1.
Source: compiled by authors using NFHS-4 and -5.

TABLE 14 Child's anemia status.

Child's anemia status	(2) Base model	(4) Mother controls	(6) Demographic controls	(8) Household characteristics controls
Severe anemia	0.0142***	0.0142***	0.00863***	0.00831***
	(0.00129)	(0.00130)	(0.00100)	(0.000957)
Moderate anemia	0.137***	0.138***	0.123***	0.123***
	(0.00437)	(0.00439)	(0.00509)	(0.00516)
Mild anemia	0.00164	0.00174	0.00370	0.00428
	(0.00421)	(0.00424)	(0.00497)	(0.00502)
Not anemic	−0.153***	−0.154***	−0.135***	−0.136***
	(0.00441)	(0.00443)	(0.00523)	(0.00524)
Observations	45,968	45,968	45,968	45,968
Mother controls	No	Yes	Yes	Yes
Demographic controls	No	No	Yes	Yes
Household characteristics controls	No	No	No	Yes

Delta-method standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: compiled by authors using NFHS-4 and -5.

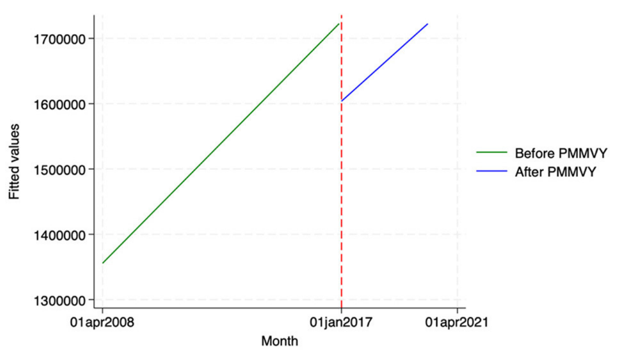

FIGURE 11
ITS—Newborns weighed. Source: figure compiled by authors using HMIS.

in the number of newborns weighed and a decrease in those weighing below 2.5 kg (Figure 12); however, these changes were not statistically significant.

5.3.2 Child immunization

We looked at the effect of the introduction of PMMVY on child immunization. Using NFHS, we grouped the vaccines into two—(i) vaccines that were part of the Universal Immunization Program (UIP) from before 2016, and (ii) vaccines introduced post-2017. To measure the effects of PMMVY on child immunization using HMIS data, we looked at 11 vaccines for which there was data from 2008 to 2020. In the HMIS, data for the newer vaccines introduced post 2017 in the UIP, has been analyzed for the period from 2017–2020 (for which the data was available).

TABLE 15 Newborns weighed.

Variables	(1)	(2)
	Newborns weighed	Newborns weighed <2.5 kg at birth
Time	3,737***	−808.2***
	(1,054)	(206.0)
PMMVY	−81,207	−9,413
	(137,246)	(35,998)
Time after intervention	−2,890	1,310
	(5,335)	(1,332)
L.AR	0.668***	0.576***
	(0.156)	(0.120)
L.MA	−0.0261	0.0190
	(0.179)	(0.146)
Constant	1.333e+06***	285,486***
	(61,323)	(9,624)
Sigma	119,913***	25,336***
	(7,509)	(1,293)
Observations	144	144
Autocorrelation	Yes	Yes
Stationary	Yes	Yes

OPG standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: table compiled by authors using HMIS.

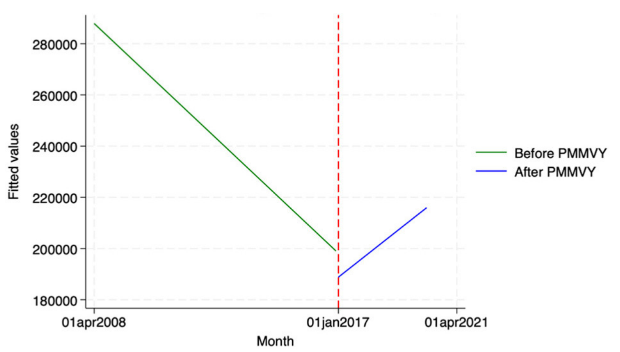

FIGURE 12
ITS—Newborns Weighed under 2.5 Kg. Source: figure compiled by authors using HMIS.

Across both datasets, we found a general increase in child immunization rates. Using the NFHS data, we found a statistical increase in child immunization for BCG, DPT, polio and measles (Tables 16, 17). Using the HMIS data, we did not see a statistically significant change in the number of vaccine doses, barring measles−1 (Table 18), and oral polio vaccine (OPV)-1 and−2 (Table 19).

TABLE 16 Vaccines received by children−1.

Vaccine	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	BCG	DPT-1	Polio-1	DPT-2	Polio-2	DPT-3	Polio-3	Measles-1	Polio-0
PMMVY	0.0206***	0.0284***	0.0111***	0.0446***	0.0265***	0.0778***	0.0959***	−0.119***	0.0769***
	(0.00261)	(0.00306)	(0.00336)	(0.00362)	(0.00401)	(0.00447)	(0.00545)	(0.00596)	(0.00482)
Observations	35,472	35,421	35,479	35,421	35,479	35,421	35,479	35,324	35,479

Delta-method standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: compiled by authors using NFHS-4 and -5.

TABLE 17 Vaccines received by children—2.

Vaccine	(1) Pentavalent-1	(2) Pentavalent-2	(3) Pentavalent-3	(4) Rotavirus-1	(5) Rotavirus-2	(6) Rotavirus-3	(7) Hepatitis-1	(8) Hepatitis-2	(9) Hepatitis-3	(10) Hepatitis at Birth
PMMVY	0.0292**	0.0216	0.0157	0.112***	0.102***	0.0894***	0.0188*	0.0105	0.00355	0.0543***
	(0.0129)	(0.0135)	(0.0147)	(0.0348)	(0.0326)	(0.0294)	(0.0111)	(0.0118)	(0.0131)	(0.0198)
Observations	20,121	20,121	20,121	20,056	20,056	19,979	20,067	20,157	20,157	20,080

Delta-method standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: compiled by authors using NFHS-5.

6 Conclusion and discussion

The PMMVY scheme was launched to enable wage compensation for pregnant women, enabling them rest and better nutrition during pregnancy and childbirth. The conditional cash transfer scheme linked the payment of cash installments to specific conditions of service access. Thus, the PMMVY sought to improve access to services and eventually, health and nutrition outcomes for women and children.

The results indicate that the scheme has had some impact on process indicators—i.e. access to health services. We saw an increase in registration and early registration of pregnancies, we also saw an increase in women accessing four ANC visits and in consumption of IFA tablets. Institutional deliveries showed an upward (increasing) trend, though not statistically significant. The same holds true for child immunization; an upward trend in immunization access was noted, with statistically significant effects for the oral polio vaccine.

There has, however, been no impact of PMMVY on mothers' weight and anemia status. The results noted an increase in the probability of first-time mothers being moderately or severely anemic. The same was true for child weight at birth and anemia—with lower birth weights and hemoglobin levels among children, post-2017.

These results are consistent with earlier published literature on the PMMVY. While earlier literature was limited largely to the pilot districts, or regional studies and reports, this paper with analysis at a national level corroborates the available evidence. Data from NFHS 5, which shows an overall increase in maternal and child anemia levels across the country, is an important factor to consider in interpreting these results. Analyses and interpretation of NFHS 5 data indicate several factors that could influence the increased anemia levels among women and children—including the burden of diseases such as malaria, the inability of poor households to enable adequate nutrition for women and children, mother's educational levels, climate change events, affecting local availability of food, overdependence on rice and wheat, and possibly the impact of the COVID-19 pandemic, among other factors (19).

For PMMVY to enable improvement in maternal and child health and nutritional outcomes, there is a need to address the contextual factors influencing maternal and child health. There is a need for a greater focus on dietary diversity, with the inclusion of locally available nutritious foods. The need to improve maternal education is critical. Building food security, with an increased focus on climate events would be critical in the future. The supplementary nutrition program could also be used as an opportunity to enable nutrition-dense foods, supported by better implementation of the kitchen garden scheme. The implementation challenges of the PMMVY also need to be addressed—ensuring timely disbursement of the installments, coupled with easier paperwork. Information provision and building agency among women, to enable them to use the cash installments is important.

There is a need for future research that leverages alternative causal inference methods, such as instrumental variable approaches or structural equation modeling, to better account for unobserved confounding and use a large household-level panel to further these findings.

TABLE 18 Child vaccination.

Variables	(1) BCG	(2) DPT-1	(3) DPT-2	(4) DPT-3	(5) Hepatitis—birth dose	(6) Hepatitis-1	(7) Measles-1
Time	−1,070						
	(1,268)						
PMMVY	−43,811	5,018	1,035	−5,794	−58,071	−876.5	144,548
	(191,245)	(3.015e+07)	(1.698e+07)	(9.835e+06)	(326,670)	(1.475e+07)	(211,176)
Time after intervention	2,832	16,815	17,668	16,676	−9,535	4,466	−43,682***
	(7,272)	(1.128e+06)	(1.345e+06)	(1.145e+06)	(11,028)	(598,840)	(14,417)
L.AR	0.565***	−0.204	0.494***	0.414*	−0.992***	−0.527	0.712***
	(0.150)	(0.249)	(0.176)	(0.241)	(0.0518)	(0.368)	(0.0609)
L.MA	−141.1	−0.0915	−1.314***	−1.334***	0.966***	0.418	−1.000
	(3,748)	(0.229)	(0.251)	(0.336)	(0.0880)	(0.384)	(89.05)
Constant	2.091e+06***	−17,176	−17,929*	−17,123*	11,021	−4,825	−3,415
	(55,747)	(14,059)	(9,446)	(9,621)	(8,667)	(9,764)	(2,830)
Sigma (constant)	1,206	171,821***	126,235***	135,962***	64,480***	110,571***	222,615
	(32,061)	(6,661)	(23,330)	(32,342)	(3,710)	(4,065)	(9.911e+06)
Observations	144	143	143	143	143	143	143
Autocorrelation	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stationary	Yes	No	No	No	No	No	No

OPG standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: table compiled by authors using HMIS.

TABLE 19 Child vaccination—2.

Variables	(1) OPV—birth dose	(2) OPV-1	(3) OPV-2	(4) OPV-3
Time	3,645***	−1,463**	−1,213*	−1,460**
	(946.6)	(698.4)	(683.5)	(695.1)
PMMVY	−89,060	18,208	27,995	55,047
	(54,913)	(66,635)	(67,598)	(64,672)
Time after intervention	−267.8	5,283**	4,289*	3,984
	(2,158)	(2,514)	(2,527)	(2,446)
Constant	1.142e+06***	2.060e+06***	1.994e+06***	1.994e+06***
	(72,309)	(48,194)	(48,133)	(49,828)
Observations	144	144	144	144
R-squared	0.212	0.053	0.039	0.051
Autocorrelation	No	No	No	No
Stationary	N/A	N/A	N/A	N/A

Robust standard errors in parentheses.
***p < 0.01.
**p < 0.05.
*p < 0.1.
Source: table compiled by authors using HMIS.
In both the analysis strategies, we saw a large reduction in the measles-1 vaccine because of the Government of India's (GoI) decision to move away from only measles vaccines to the measles, mumps, rubella (MMR) combination vaccine in 2017 (https://mohfw.gov.in/sites/default/files/Measles%20rubella%20vaccine%20operational%20guidelines.pdf).

Thus, while conditional cash transfer schemes such as the PMMVY have the potential to improve service uptake, maternal and child health, and nutrition; they need to be coupled with local contextual programs and solutions, behavior change interventions, and effective and efficient scheme implementation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

RJ: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft. VC: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing.

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Conflict of interest

RJ and VC were employed by company Development Solutions.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Trends and determinants of exclusive and predominant breastfeeding practices for two decades (2000–2019) in Ethiopia

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Background: Ethiopia has had a long-standing national commitment to improving child health. However, evidence on trends in breastfeeding has remained fragmented, and there is a paucity of information on the impacts of breastfeeding policy on breast feeding practices and associated factors influencing it. This study examined trends and determinants of exclusive and predominant breastfeeding in the last two decades.

Methods: The study employed a retrospective observational design using Ethiopian Demographic and Health Surveys (EDHS2000-2019) dataset for children aged <6 months and their mothers. Data analyses were performed via SPSS version 25. Trend analysis and multivariable logistic regression analysis were used.

Results: Exclusive and predominant breastfeeding practices have fluctuated inconsistently over the past two decades. Exclusive breastfeeding increased from 59.96% in 2000 to 66.01% in 2016 and then decreased to 59.86% in 2019. Predominant breastfeeding decreased from 40.04% in 2000 to 32.95% in 2016 and increased to 39.43% in 2019. Regional state, place of residence, and religion were significantly ($p < 0.001$) associated with the likelihood of practicing exclusive or predominant breastfeeding.

Conclusion: These inconsistent trends and the complex interplay of various factors suggest the limited success of previous policies and strategies and highlight the need for further investigation and revisiting current policies for a more nuanced and targeted approach in future interventions.

KEYWORDS

exclusive breastfeeding, predominant breastfeeding, disparities, trend analysis, Ethiopia

1 Introduction

Breastfeeding is a cornerstone of child health, offering essential nutrients and immune system support for optimal growth and development (1). Breast milk provides bioactive nutrients and antibodies that bolster a child's immune system and growth (2, 3), promote growth, and facilitate tissue repair (3). Breastfeeding also contributes to preventing infectious diseases, gastroenteritis, respiratory disease, childhood diabetes, obesity, and dental disease in children (4). It positively affects the intelligence quotient (IQ) and educational and behavioral outcomes of children (5). Breastfeeding mothers benefit from decreased risks of breast and ovarian cancer and diabetes (6). Compared with non-breastfed children, breastfed children have a reduced risk of acute and chronic illness and improved cognitive outcomes (5), resulting in greater educational achievement and earning potential. Hence, breastfeeding is a critical component of infant and child health, even for mothers (7). The World Health Organization and UNICEF recommend starting breastfeeding within an hour of birth, exclusively nursing for the first 6 months, and continuing breastfeeding for at least 2 years (8) However, challenges persist, particularly in ensuring consistent and equitable breastfeeding, early breastfeeding initiation, exclusive breastfeeding and predominant breastfeeding (9). Exclusive breastfeeding refers to infants receiving only breast milk with no other liquids or solids, while predominant breastfeeding means breast milk is the primary source of nutrition for infants under 6 months (10, 11). Disparities have continued for these practices despite global, national, and local efforts and interventions (12, 13).

For the last five decades, Ethiopia has actively promoted optimal breastfeeding practices (13–17). This dedication reflects a long-standing national commitment to improving child health. Improved access to and use of healthcare has contributed to a rapid decline in under-five mortality rates in Ethiopia (18). A recent study found that the prevalence of under-five mortality in the country was 5.9% (59 deaths per 1,000 live births) (19). This represents significant progress in addressing child health challenges in Ethiopia. The roots of this focus likely lie in the late 1970s and 1980s (20). During this period, a global movement to improve infant and young child feeding practices, including breastfeeding promotion, gained momentum. Ethiopia, which is a significant challenge with respect to childhood mortality rates, highlights the well-documented health benefits of breastfeeding as a potential solution (13–17). This recognition likely sets the stage for the ongoing national commitment to promoting these practices reflected in various national policies and strategies (9, 21, 22). The National Strategy for Infant and Young Child Feeding in Ethiopia aims to improve children's health through better feeding practices (21). It sets national standards for breastfeeding and complementary feeding, emphasizing early breastfeeding initiation and exclusive and predominant breastfeeding for the first 6 months. The National Adolescents, Maternal, Infant, and Young Child Nutrition Guideline (2016–2020) is another policy document in Ethiopia focused on improving nutrition, including breastfeeding (9). Recently, the National Infant and Young Child Feeding in Emergency (IYCF-E) guidelines were released, providing practical guidance for ensuring appropriate infant and young child feeding in emergency response (22).

Multiple factors influence breastfeeding practices beyond a mother's control (12). Exclusive and predominant breastfeeding at the population level can be improved rapidly through multilevel and multicomponent interventions across the socioecological model and settings (1). Such interventions must be guided by research findings for well-informed policies, strategies and initiatives. One such approach is the World Health Organization (WHO) and UNICEF's Baby-Friendly Hospital Initiative (BFHI), which promotes optimal breastfeeding practices by encouraging facilities to implement the Ten Steps to Successful Breastfeeding (23). Ethiopia is implementing the Baby-Friendly Hospital Initiative (BFHI) as part of its multisector National Nutrition Programs to improve child nutrition (8, 24). While positive developments in tackling malnutrition have occurred over the last 10 years, the initial levels were so severe that the country required substantial investment in nutritional programs (24).

Ethiopia's diverse sociocultural landscape and variations in healthcare access necessitate a nuanced examination of exclusive and predominant breastfeeding (24). The country has made notable strides in terms of maternal and child health (25). For instance, the Under-five mortality in Ethiopia decreased by 60% from 2000 to 2016, falling from 166 to 67 deaths per 1,000 live births (19). While previous studies have explored exclusive and predominant breastfeeding, a comprehensive analysis of time trends and determinants over an extended period, mainly using EDHS data in the Ethiopian context, remains limited (9, 15, 16, 26, 27). As far as the researcher knowledge, there has been no recent study on time series data to understand trends in exclusive and predominant breastfeeding practices. Previous studies have been fragmented, and there is a paucity of holistic evidence on the extent of the impacts of policy and implementation strategies. This lack of clarity is particularly concerning when considering potential disparities in exclusive and predominant breastfeeding across different regions and sociodemographic groups within the country. Investigating prevalence trends and disparities will offer insights into the effectiveness of interventions and guide the development of targeted strategies to improve exclusive and predominant breastfeeding practices. It is also crucial for policymakers, healthcare providers, and organizations working to improve child health in Ethiopia.

This study analyzed data from five Ethiopian demographic and health surveys (EDHSs) (2000–2019) (28–32). Therefore, this study aims to fill this gap by examining time trends, and determinants of exclusive and predominant breastfeeding practices (<6 months) across regions and urban/rural areas over the past two decades.

2 Materials and methods

2.1 Study design and source of data

The present study employed a retrospective observational design using nationally representative Ethiopian Demographic and Health Survey (EDHS) datasets (28–32). Despite, the limitations of the retrospective observational design, as it does not allow for manipulation of variables or random assignment of participants, such a large nationally representative dataset allows for a robust analysis of trends and patterns in exclusive and predominant breastfeeding practices over time. The data for this study were obtained from the Ethiopian Demographic and Health Survey (EDHS) program, a nationally representative cross-sectional survey conducted periodically by the Ethiopian Central Statistical Agency (CSA) and ICF International with financial support from USAID, UKAID, UNICEF, and other donors (28–32).

The EDHS uses a stratified two-stage cluster sampling design to ensure a representative sample of women aged 15–49 across urban and rural areas of Ethiopia. The most recent survey was conducted in 2019, and previous surveys were completed in 2000, 2005, 2011, and 2016. The DHS interviews women in their households, collecting data on a wide range of topics, including demographics, health, and family planning. The specific modules used for collecting breastfeeding data may vary slightly across survey years, but all EDHS surveys adhere to standardized questionnaires and data collection methods to ensure comparability across time periods. By utilizing data from five consecutive DHS datasets (2000–2019), this study provides a valuable opportunity to examine trends and changes in exclusive and predominant breastfeeding practices in Ethiopia over the last two decades. The population base of the study was children living with their mothers, born at least 6 months of age, and the time immediately before the survey was considered.

2.2 Study variables and operational definitions

This paper focused on the prevalence trends and disparities of exclusive breastfeeding and predominant breastfeeding, emphasizing disparities in sociodemographic factors across geographical areas and over time. The prevalence in this study context is the proportion of exclusive breastfeeding and predominant breastfeeding practices among mothers of children aged <6 months in Ethiopia from 2000 to 2019 for each EDHS phase, which is calculated by dividing the number of breastfeeding children aged <6 months by the total number of children aged <6 months who lived with their mothers. The prevalence trend is the change in the prevalence of exclusive breastfeeding and predominant breastfeeding among children aged <6 months from 2000 to 2019. Disparities refer to how exclusive breastfeeding and predominant breastfeeding among children aged <6 months are distributed in a population described by independent variables, mainly time factors every 5 years for 20 years, regional state, place of residence, and other maternal and child sociodemographic variables. Hence, the study included exclusive breastfeeding and predominant breastfeeding (dependent variables) and the characteristics of mothers and their children (independent variables).

2.3 Outcome variables

The variables related to breastfeeding practices analyzed in the present study focused on the following:

1. *Exclusive breastfeeding* is the prevalence of children aged <6 months who were still breastfeeding at the time of the survey (status quo) and who did not report introducing other foods or liquids before 6 months of age (whether the mother exclusively breastfed for the first 6 months of the child's life by the recall of the mother).
2. *Predominant breastfeeding* is the prevalence of children aged <6 months who are still breastfeeding and who consume only nonnutritive liquids, such as water and sugar-free drinks, in addition to breast milk, but not other foods or liquids.

2.3 The independent variables

The sociodemographic characteristics mainly focused on mothers and their children aged < 6 months in Ethiopia. The survey year (time), mother age group, regional state, place of residence, mother's current marital status, mother's education level, religion, mother's employment status, current pregnancy status, place of delivery, antenatal care utilization, postnatal care utilization and number of household members or family size were characteristics considered as independent variables.

2.4 Data acquisition and extraction

The data for this study were acquired from the Ethiopian Demographic and Health Survey (EDHS) datasets covering the period from 2000 to 2019 in Ethiopia, which were obtained following formal application to the program Data Archivist (28–32). The EDHS surveys employed rigorous sampling methodologies to ensure national representativeness, and the data were collected through standardized interviews, questionnaires, and measurements. Ethical considerations are paramount in the EDHS data collection process. Hence, the utilization of these datasets for the current research follows the terms and conditions specified by the Demographic and Health Survey Program.

The samples of the analysis were performed from the five consecutive surveys stratifying and extracting the exclusive and predominant breastfeeding practices and the presumed independent variables for children aged <6 months (Figure 1). The first datasets for all infants and young children, including children who died, were taken, and then young children living with their mothers were identified. Next, children aged <6 months and living with their mothers and those who practice exclusive and predominant breastfeeding were identified. Finally, infants and young children living with their mothers, who practice exclusive and predominant breastfeeding, were filtered consecutively (Figure 1).

2.5 Data analysis

Data analysis was performed via the Statistical Package for Social Sciences (SPSS) software version 25. Data were weighted for the survey year and mothers' characteristics. The study utilized descriptive statistics to examine the overall prevalence of exclusive and predominant breastfeeding practices over the last five consecutive surveys. Time series analysis was employed to discern temporal patterns and changes (trends) in exclusive and predominant breastfeeding practices. Multivariate logistic regression models were used to identify the factors associated with exclusive and predominant breastfeeding practices, with $p \leq 0.05$ at the 95% confidence interval. Throughout the analysis, potential confounders were controlled by stratification, restriction, and statistical approaches. The analysis was based on the assumptions of sufficient data, linear relationships between variables (after transformation), the absence of multicollinearity (independent variables are not highly correlated), and the absence of outliers.

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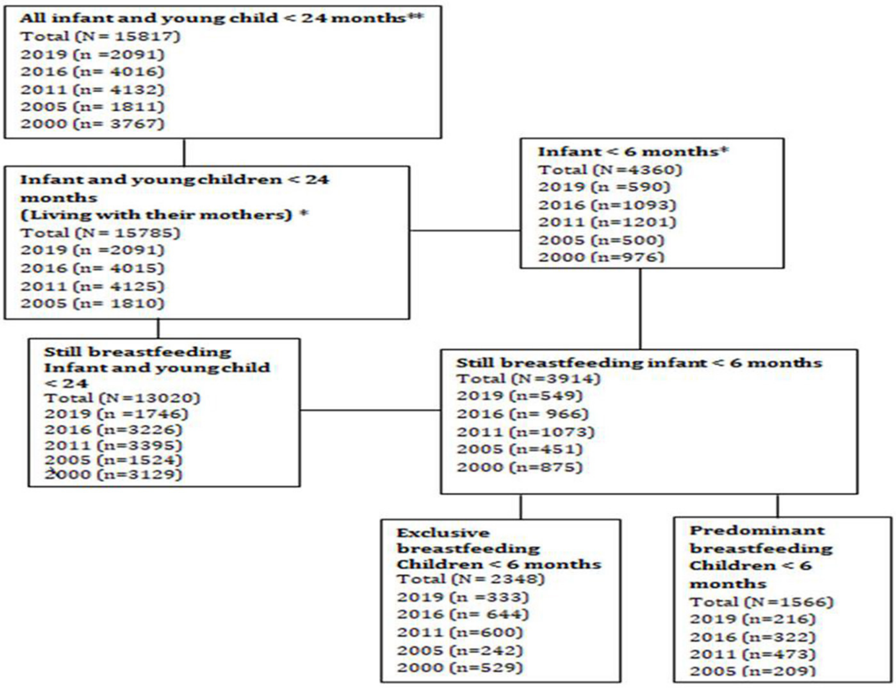

FIGURE 1
Flow diagram of the extraction of study samples for the analysis of exclusive and predominant breastfeeding practices, Ethiopia 2000–2019. **All infants and young children, including those who died. *All infants and young children living with their mothers, including those who died.

3 Results

3.1 Characteristics of study participants

According to the results of the Pearson chi-square test, children aged <6 months and their mothers were distributed differently across the indicated sociodemographic and related characteristics ($p < 0.001$), with the exception of the mothers' age group ($p = 0.66$) and family size ($p = 0.467$) (Table 1). Approximately 3.59% of the children aged <6 months during the data collection period died. The sociodemographic characteristics of mothers and their children in the five surveys differed significantly (EDHS 2000–2019) (Table 1). The majority of mothers (73.89%) were 20–34 years old, and 94.50% of the mothers surveyed were married during the survey. Proportionally, approximately 58.20% of mothers and their children lived in the four populated regional states, namely, Oromia, Amhara, Tigray, and the former Southern Nations and Nationalities and Peoples (SNNP). Most mothers and their children resided in rural areas, which declined slightly across the five survey years, from 84.13% in 2000 to 78.52% in 2019. Most mothers were uneducated, which declined from 79.46% in 2000 to 48.56% in 2019, and a significant number of mothers did not complete primary education, with the proportion decreasing across the survey years (Table 1).

The proportion of home births in Ethiopia has steadily declined, dropping from 88.20% in 2000 to 45.23% in 2019. The proportion of mothers who did not receive antenatal care declined from 67.64% in 2000 to 26.17% in 2019. Most mothers did not utilize postnatal care. Most of the mothers and their children lived in a family of five or more household members (Table 1).

3.2 Trends in exclusive breastfeeding and predominant breastfeeding in Ethiopia

According to the visualization of multiseries line graphs, the pattern of prevalence and trends of exclusive breastfeeding and predominant breastfeeding has fluctuated inconsistently and changed in the last 20 years across states/regions and urban, rural, and countrywide levels (Figure 2). Exclusive breastfeeding increased from 59.96% in 2000 to 66.01% in 2016. However, it then slightly decreased to 59.86% in 2019. Predominant breastfeeding decreased from 40.04% in 2000 to 32.95% in 2016 and slightly increased to 39.43% in 2019, generally declining over the past two decades (Figure 2). These estimates of exclusive breastfeeding and predominant breastfeeding prevalence and changes over time revealed disparities across states/regions, urban areas, rural areas, and countrywide levels.

Children from rural areas were more likely to practice exclusive breastfeeding than those from urban areas were, which declined in 2005 and then increased until 2016 (Figure 2A). Compared with those in rural areas, children in urban areas are more likely to practice predominant breastfeeding, which has continued to decline in both areas since the survey year of 2005 and has slightly increased since 2016 (Figure 2C). In general, the pattern of the

TABLE 1 Characteristics of mothers and their children aged < 6 months in Ethiopia.

Respondents Characteristics	Survey year (2000–2019)					Pearson chi-square *P* values
	2000	2005	2011	2016	2019	
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	
	964 (22.94)	594 (11.75)	1158 (27.55)	1033 (24.58)	554 (13.18)	
Mothers age in 5 years group						
15–19	96 (9.96)	53 (10.73)	111 (9.59)	88 (8.52)	65 (11.73)	0.066
20–24	257 (26.66)	131 (26.52)	288 (24.87)	262 (25.36)	130 (23.47)	
25–29	259 (26.87)	145 (29.35)	358 (30.92)	294 (28.46)	161 (29.06)	
30–34	190 (19.71)	89 (18.02)	189 (16.32)	213 (20.62)	117 (21.12)	
35–39	124 (12.86)	52 (10.53)	154 (13.30)	143 (13.84)	56 (10.11)	
40–44	35 (3.63)	18 (3.64)	50 (4.32)	30 (2.90)	24 (4.33)	
45–49	3 (0.31)	6 (1.21)	8 (0.69)	3 (0.29)	1 (0.18)	
Regional states						
Tigray	98 (10.17)	42 (8.50)	100 (8.64)	115 (11.13)	56 (10.11)	<0.001
Afar	49 (5.08)	33 (6.68)	118 (10.19)	99 (9.58)	64 (11.55)	
Amhara	136 (14.11)	79 (15.99)	116 (10.02)	99 (9.58)	43 (7.76)	
Oromia	179 (18.57)	92 (18.62)	199 (17.18)	164 (15.88)	72 (13.00)	
Somali	51 (5.29)	28 (5.67)	117 (10.10)	140 (13.55)	58 (10.47)	
Ben-Gumz	92 (9.54)	35 (7.09)	97 (8.38)	86 (8.33)	49 (8.84)	
Former SNNP	148 (15.35)	95 (19.23)	162 (13.99)	115 (11.13)	55 (9.93)	
Gambela	51 (5.29)	25 (5.06)	93 (8.03)	60 (5.81)	49 (8.84)	
Harari	52 (5.39)	32 (6.48)	53 (4.58)	58 (5.61)	43 (7.76)	
Addis Ababa	53 (5.50)	15 (3.04)	36 (3.11)	49 (4.74)	24 (4.33)	
Dire Dawa	55 (5.71)	18 (3.64)	67 (5.79)	48 (4.65)	41 (7.40)	
Place of residence						
Urban	153 (15.87)	69 (13.97)	174 (15.03)	202 (19.55)	119 (21.48)	<0.001
Rural	811 (84.13)	425 (86.03)	984 (84.97)	831 (80.45)	435 (78.52)	
Mother's current marital status						
Never married	10 (1.04)	6 (1.21)	6 (0.52)	7 (0.68)	8 (1.44)	<0.001
Married	911 (94.50)	463 (93.72)	1,047 (90.41)	987 (95.55)	525 (94.77)	
Living together	11 (1.14)	13 (2.63)	57 (4.92)	12 (1.16)	6 (1.08)	
Widowed	8 (0.83)	2 (0.40)	10 (0.86)	3 (0.29)	2 (0.36)	
Divorced	12 (1.24)	5 (1.01)	20 (1.73)	14 (1.36)	7 (1.26)	
Not living together	12 (1.24)	5 (1.01)	18 (1.55)	10 (0.97)	6 (1.08)	
Mother education attainment						
No education	766 (79.46)	370 (74.90)	769 (66.41)	601 (58.18)	269 (48.56)	<0.001
Incomplete primary	106 (11.00)	81 (16.40)	300 (25.91)	263 (25.46)	159 (28.70)	
Complete primary	13 (1.35)	7 (1.42)	21 (1.81)	25 (2.42)	31 (5.60)	
Incomplete Secondary	53 (5.50)	23 (4.66)	42 (3.63)	97 (9.39)	57 (10.29)	
Complete secondary	23 (2.39)	5 (1.01)	7 (0.60)	8 (0.77)	7 (1.26)	
Higher	3 (0.31)	8 (1.62)	19 (1.64)	39 (3.78)	31 (5.60)	

(Continued)

TABLE 1 (Continued)

Respondents Characteristics	Survey year (2000–2019)					Pearson chi-square *P* values
	2000	2005	2011	2016	2019	
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	
Religion						
Muslim	370 (38.38)	183 (37.04)	574 (49.57)	523 (50.63)	296 (53.43)	
Orthodox	422 (43.78)	184 (37.25)	323 (27.89)	316 (30.59)	154 (27.80)	<0.001
Protestant	139 (14.42)	116 (23.48)	226 (19.52)	170 (16.46)	99 (17.87)	
Catholic	5 (0.52)	2 (0.40)	10 (0.86)	3 (0.29)	2 (0.36)	
Traditional	28 (2.90)	9 (1.82)	11 (0.95)	9 (0.87)	3 (0.54)	
Place of delivery						
Home	837 (88.20)	439 (88.69)	992 (85.81)	591 (57.05)	251 (45.23)	<0.001
Government/public health facilities	104 (10.96)	48 (9.70)	135 (11.68)	398 (38.42)	285 (51.35)	
Private/NGO health facilities	8 (0.84)	8 (1.62)	29 (2.51)	47 (4.54)	19 (3.42)	
Antenatal care utilization						
No antenatal visits	648 (67.64)	346 (70.76)	674 (58.20)	330 (31.95)	145 (26.17)	<0.001
1- or 2-times antenatal visits	149 (15.55)	46 (9.41)	162 (13.99)	179 (17.33)	69 (12.45)	
At least 3-time antenatal visits	161 (16.81)	97 (19.84)	322 (27.81)	524 (50.73)	340 (61.37)	
Postnatal care utilization						
No	-	253 (95.47)	960 (96.48)	949 (91.87)	500 (90.25)	<0.001
Yes	-	12 (4.53)	35 (3.52)	84 (8.13)	54 (9.75)	
Number of household members/family size						
1–2	7 (0.73)	1 (0.20)	15 (1.28)	12 (1.15)	3 (0.54)	0.467
3–4	241 (25.00)	134 (27.07)	274 (23.46)	279 (26.72)	145 (25.99)	
5–6	305 (31.64)	163 (32.93)	380 (32.53)	332 (31.80)	186 (33.33)	
7+	411 (42.63)	197 (39.80)	499 (42.72)	421 (40.33)	224 (40.14)	

prevalence of exclusive breastfeeding (Figure 2B), and predominant breastfeeding was similar across regional states, except for the pattern for Gambella from 2000 to 2011 (Figure 2C).

3.3 Factors associated with exclusive and predominant breastfeeding in Ethiopia

A multicollinearity test was performed to assess the degree of correlation among the independent variables to ensure the reliability and interpretability of the model, checking that the variables were not highly correlated. The variance inflation factor (VIF) ranged from 1.286 to 3.704, which was within the acceptable limit. Year of the survey, mothers' age group, regional state, place of residence, marital status, educational attainment, religion, mothers' current working status, delivery location, antenatal and postnatal care utilization, and family size—were examined.

While there seems to be a fluctuation in the prevalence of exclusive and predominant breastfeeding in Ethiopia from 2000 to 2019 across the years, the present study does not show significant associations between exclusive breastfeeding or predominant breastfeeding and the year of the survey using AORs. The study revealed that regional state, place of residence, and maternal religion were significantly ($p < 0.001$) associated with the likelihood of exclusively breastfeeding. Mothers residing in Amhara (AOR: 5.036), Oromia (AOR: 4.418), Tigray (AOR: 2.574), Benishangul-Gumz (AOR: 2.149), former SNNP (AOR: 3.997), Harari (AOR: 1.740), Addis Ababa (AOR: 2.535), and Dire Dawa (AOR: 2.117) have a much greater likelihood of practicing exclusively than mothers in the Somali region ($p < 0.001$).

Similarly, the study revealed a statistically significant association between a regional state and the likelihood of practicing predominant breastfeeding. Mothers residing in Amhara (AOR: 4.479), Oromia (AOR: 4.418), Tigray (AOR: 2.452), Benishangul-Gumz (AOR: 2.020), former SNNP (AOR: 3.204), Harari (AOR: 1.440), Addis Ababa (AOR: 1.593), and Dire Dawa (AOR: 1.559) have a much greater likelihood of practicing predominant breastfeeding than mothers in the Somali region

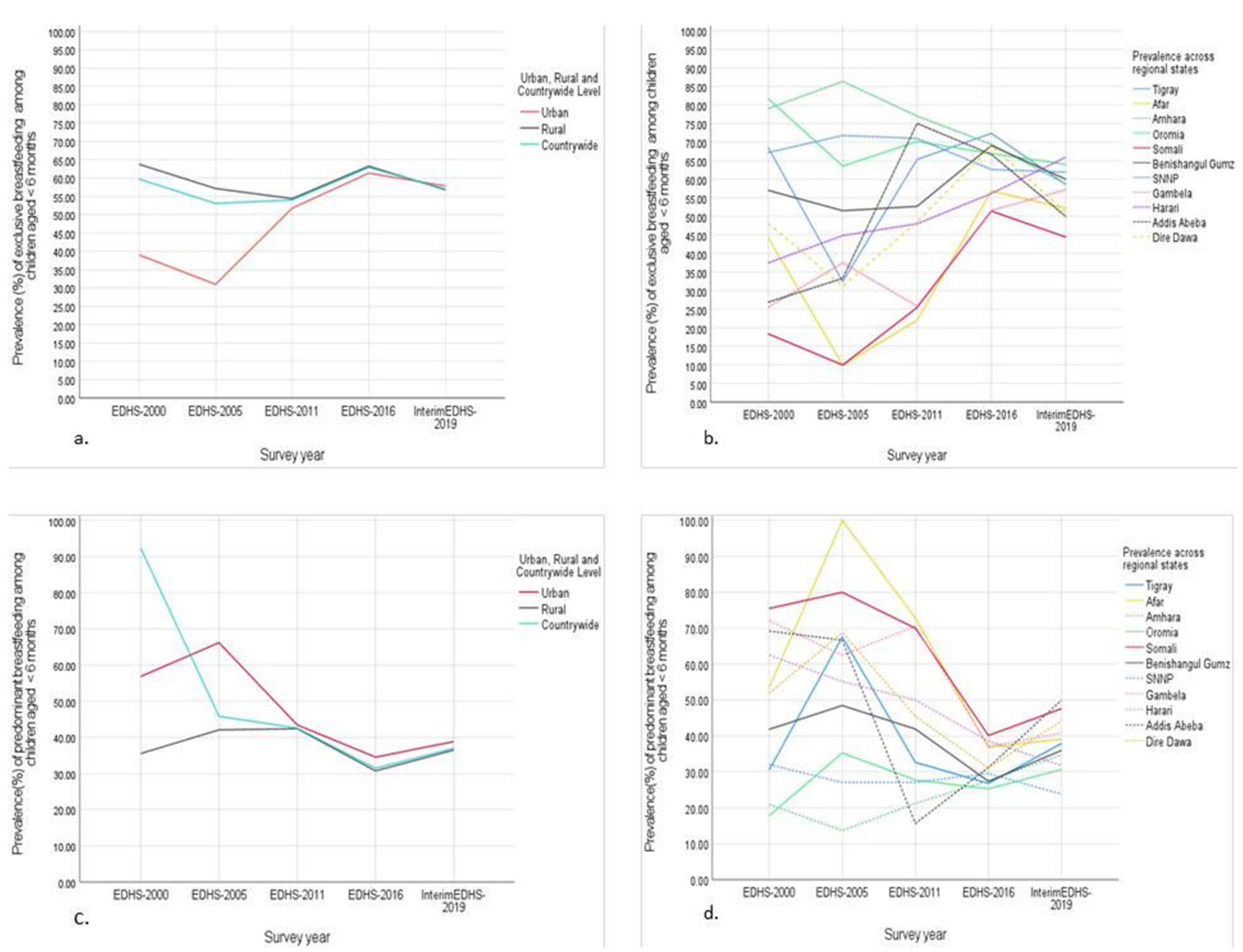

FIGURE 2
The prevalence trends and disparities of **(A)** exclusive breastfeeding in urban, rural and countrywide level, **(B)** exclusive breastfeeding across regional states level **(C)** predominant breastfeeding in urban, rural and countrywide level and **(D)** predominant breastfeeding across regional states level among Ethiopian children (<6 months) (EDHS, Ethiopian Demographic and Health Survey).

($p < 0.01$) (Table 2). Mothers between 25 and 29 years old were significantly associated with exclusive breastfeeding; these mothers were somewhat less likely to practice exclusive breastfeeding (AOR: 0.752, $p = 0.013$) and predominant breastfeeding (AOR: 0.778, $p = 0.03$) than mothers aged 15–19 years were. However, there was no statistically significant association for the other age groups. Mothers living in rural areas are significantly more likely to practice exclusive breastfeeding (AOR: 1.407) and predominant breastfeeding (AOR: 1.406) than mothers in urban areas are ($p < 0.001$) (Table 2).

Statistically significant associations were observed between a mother's religion and the likelihood of practicing exclusive breastfeeding (EBF) and predominantly breastfeeding (Table 2). Compared with Muslim mothers, Protestant mothers (AOR: 1.303, $p = 0.002$) and Orthodox mothers (AOR: 1.868, $p < 0.001$) are significantly more likely to practice EBF. Similarly, protestant (AOR: 1.253, $p = 0.009$) and Orthodox mothers (AOR: 1.727, $p < 0.001$) are significantly more likely to practice predominant breastfeeding than Muslim mothers are. Compared with mothers with no education, mothers with complete secondary education had a significantly lower prevalence of EBF and predominantly breastfeeding (AOR: 0.490, $p = 0.012$). While the present study did not show statistically significant associations with other factors via AORs, there was evidence of disparities across these factors (Table 2).

4 Discussion

In the present study, children aged <6 months and their mothers were distributed unevenly across the majority of sociodemographic characteristics, implying that these factors are likely associated with exclusive and predominant breastfeeding practices. The number of home births in Ethiopia has shown a positive trend, declining significantly from 88.20% in 2000 to 45.23% in 2019, implying increased literacy and improved access to and utilization of maternal healthcare services, as depicted in other studies (33, 34). Similarly, the decline in the proportion of mothers who did not utilize antenatal care (ANC) from 67.64% in 2000 to 26.17% in 2019 is a

TABLE 2 Prevalence and associated factors of exclusive and predominant breastfeeding (children<6 months).

Independent variables	Dependent variables					
	Exclusive breastfeeding (children < 6 months)			Predominant breastfeeding (children < 6 months)		
	Prevalence (95%CI)	AOR (95%CI)	*P* value	Prevalence (95%CI)	AOR (95%CI)	*P* value
Survey year						
2000	59.96 (56.84–63.02)	Ref.		40.04 (36.98–43.16)	Ref.	
2005	54.75 (50.35–59.09)	0.815 (0.656–1.013)	0.065	45.05 (40.71–49.45)	0.813 (0.653–1.011)	0.062
2011	55.22 (52.36–58.06)	0.799 (0.673–0.948)**	0.010	43.92 (41.09–46.78)	0.877 (0.739–1.042)	0.136
2016	66.00 (63.08–68.82)	1.174 (0.984–1.402)	0.075	32.95 (30.15–35.85)	1.424 (1.189–1.707)	0.081
2019	59.86 (55.75–63.86)	0.898 (0.730–1.105)	0.310	39.43 (35.43–43.53)	1.100 (0.891–1.358)	0.373
Mothers age group						
15–19	62.47 (57.73–67.04)	Ref.		37.53 (32.96–42.27)	Ref.	
20–24	62.43 (59.50–65.30)	0.992 (0.789–1.247)	0.943	37.38 (34.52–40.31)	1.010 (0.801–1.275)	0.931
25–29	55.60 (52.81–58.37)	0.752 (0.601–0.941)*	0.013	43.91 (41.14–46.70)	0.778 (0.620–0.976)*	0.030
30–34	60.52 (57.12–63.85)	0.931 (0.733–1.182)	0.557	38.24 (34.94–41.63)	0.966 (0.758–1.231)	0.780
35–39	60.30 (56.10–64.38)	0.914 (0.706–1.183)	0.496	38.76 (34.70–42.95)	0.951 (0.732–1.236)	0.709
40–44	56.25 (48.51–63.77)	0.787 (0.547–1.133)	0.198	41.88 (34.43–49.61)	0.831 (0.575–1.202)	0.325
45–49	47.62 (27.73–68.12)	0.498 (0.213–1.162)	0.107	52.38 (31.88–72.27)	0.626 (0.270–1.453)	0.276
Regional state						
Somali	39.39 (34.67–44.27)	Ref.		60.10 (55.22–64.84)	Ref.	
Afar	40.55 (35.60–45.64)	1.031 (0.745–1.425)	0.856	58.90 (53.80–63.86)	1.011 (0.765–1.336)	0.940
Amhara	76.68 (72.73–80.31)	5.036 (3.473–7.301)***	<0.001	22.69 (19.10–26.61)	4.479 (3.359–5.973)***	<0.001
Oromiya	72.29 (68.92–75.49)	4.418 (3.282–5.947)***	<0.001	27.00 (23.84–30.36)	3.631 (2.819–4.678)***	<0.001
Tigray	64.81 (60.10–69.30)	2.574 (1.760–3.765)***	<0.001	34.95 (30.47–39.65)	2.452 (1.855–3.241)***	<0.001
Benshangul–Gumz	58.84 (53.72–63.82)	2.149 (1.541–2.996) ***	<0.001	40.33 (35.37–45.45)	2.020 (1.522–2.681)***	<0.001
Former SNNP	69.72 (65.89–73.36)	3.997 (2.801–5.704)***	<0.001	29.76 (26.14–33.58)	3.204 (2.467–4.161)***	<0.001
Gambela	39.22 (33.67–45.00)	1.028 (0.672–1.573)	0.897	59.01 (53.21–64.63)	0.960 (0.710–1.299)	0.793
Harari	51.46 (45.14–57.75)	1.740 (1.209–2.503)**	0.003	48.12 (41.84–54.44)	1.440 (1.049–1.977)*	0.024
Addis Ababa	53.67 (46.32–60.91)	2.535 (1.584–4.057) ***	<0.001	46.33 (39.09–53.68)	1.593 (1.124–2.259)**	0.009
Dire Dawa	53.04 (46.59–59.42)	2.117 (1.465–3.060)***	<0.001	46.52 (40.15–52.98)	1.559 (1.132–2.149)**	0.007
Place of residence						
Urban	52.57 (48.92–56.21)	Ref.		47.15 (43.52–50.80)	Ref.	
Rural	60.94 (59.32–62.54)	1.407 (1.201–1.648)***	<0.001	38.38 (36.78–39.99)	1.406 (1.199–1.648)***	<0.001
Mother current marital status						
Never married	62.16 (46.10–76.40)	Ref.		37.84 (23.60–53.90)	Ref.	
Married	59.47 (57.93–60.99)	1.068 (0.575–1.986)	0.835	39.97 (38.46–41.51)	0.818 (0.428–1.565)	0.544
Living together	62.63 (52.84–71.68)	1.213 (0.582–2.527)	0.606	37.37 (28.32–47.16)	0.911 (0.425–1.950)	0.810
Widowed	56.00 (36.78–73.91)	0.913 (0.340–2.451)	0.857	44.00 (26.09–63.22)	0.707 (0.257–1.943)	0.502
Divorced	62.30 (49.79–73.66)	1.239 (0.556–2.760)	0.600	32.79 (22.01–45.15)	1.089 (0.472–2.514)	0.842
Not living together	53.85 (40.40–66.88)	0.843 (0.373–1.905)	0.681	44.23 (31.35–57.74)	0.699 (0.301–1.621)	0.404
Mother education attainment						
No education	59.08 (57.24–60.89)	Ref.		40.28 (38.47–42.11)	Ref.	
Incomplete primary	62.14 (58.97–65.25)	1.129 (0.972–1.311)	0.113	37.31 (34.22–40.48)	1.132 (0.972–1.318)	0.112

(Continued)

TABLE 2 (Continued)

Independent variables	Dependent variables					
	Exclusive breastfeeding (children < 6 months)			Predominant breastfeeding (children < 6 months)		
	Prevalence (95%CI)	AOR (95%CI)	*P* value	Prevalence (95%CI)	AOR (95%CI)	*P* value
Complete primary	61.86 (51.96–71.06)	1.150 (0.763–1.732)	0.505	38.14 (28.94–48.04)	1.072 (0.709–1.622)	0.741
Incomplete secondary	55.31 (49.38–61.13)	0.888 (0.694–1.138)	0.349	44.32 (38.52–50.25)	0.830 (0.648–1.065)	0.143
Complete secondary	42.00 (29.09–55.81)	0.490 (0.281–0.855) *	0.012	58.00 (44.19–70.91)	0.530 (0.307–0.914)*	0.023
Higher	65.69 (56.14–74.36)	1.391 (0.921–2.099)	0.116	32.35 (23.87–41.83)	1.357 (0.891–2.067)	0.154
Religion of mothers						
Muslim	53.65 (51.44–55.86)	Ref.		45.78 (43.58–48.00)	Ref.	
Catholic	52.17 (32.52–71.31)	1.028 (0.451–2.339)	0.948	43.48 (24.99–63.50)	1.019 (0.445–2.335)	0.964
Protestant	59.74 (56.21–63.19)	1.303 (1.103–1.540) **	0.002	39.60 (36.16–43.13)	1.253 (1.058–1.484) **	0.009
Orthodox	67.71 (65.23–70.12)	1.868 (1.624–2.149)***	<0.001	31.79 (29.40–34.26)	1.727 (1.499–1.991)***	<0.001
Traditional and others	57.89 (44.95–70.06)	1.243 (0.734–2.106)	0.418	38.60 (26.78–51.54)	1.283 (0.749–2.196)	0.364
Mothers currently working						
No	59.06 (57.18–60.93)	Ref.		40.37 (38.51–42.25)	Ref.	
Yes	60.53 (57.50–63.49)	1.093 (0.946–1.264)	0.228	38.79 (35.83–41.80)	1.046 (0.903–1.211)	0.552
Delivery place						
Home	59.29 (57.56–61.01)	Ref.		40.13 (38.42–41.86)	Ref.	
Public Health Facilities	60.00 (56.89–63.05)	1.019 (0.882–1.176)	0.799	39.28 (36.24–42.38)	1.042 (0.901–1.206)	0.579
Private/NGO Facilities	64.86 (55.69–73.27)	1.206 (0.823–1.766)	0.336	34.23 (25.90–43.38)	1.310 (0.883–1.943)	0.179
Antenatal care utilization						
No antenatal visits	59.03 (56.94–61.10)	Ref.		40.97 (38.90–43.06)	Ref.	
1 or 2 times antenatal visits	61.32 (57.40–65.14)	1.099 (0.917–1.316)	0.308	38.51 (34.70–42.44)	1.104 (0.919–1.326)	0.289
At least 3 time antenatal visits	60.60 (58.06–63.09)	1.067 (0.934–1.219)	0.341	39.40 (36.91–41.94)	1.064 (0.930–1.218)	0.366
Postnatal care utilization with 2 months						
No	60.33 (58.46–62.18)	Ref.		39.67 (37.82–41.54)	Ref.	
Yes	57.30 (50.10–64.27)	0.955 (0.707–1.288)	0.761	42.70 (35.73–49.90)	0.838 (0.620–1.132)	0.249
Number of household members/family size						
1–2	47.37 (32.17–62.95)	Ref.		52.63 (37.05–67.83)	Ref.	
3–4	59.27 (56.31–62.18)	1.579 (0.832–2.996)	0.162	40.63 (37.72–43.59)	1.618 (0.853–3.066)	0.140
5–6	61.49 (58.89–64.05)	1.738 (0.918–3.290)	0.090	37.99 (35.45–40.59)	1.795 (0.949–3.394)	0.072
7+	58.39 (56.07–60.68)	1.515 (0.802–2.862)	0.201	40.58 (38.30–42.90)	1.629 (0.863–3.073)	0.132

*p < 0.05, **p < 0.01, ***p< 0.001, Ref., reference category.

positive development, as other studies confirmed that the utilization of maternal healthcare services in Ethiopia is improving (16, 35). However, a significant concern is that most mothers do not utilize postnatal care. Most of the mothers and their children in Ethiopia lived in families of five or more members.

The WHO and UNICEF recommend that children should only receive breast milk for the first 6 months of life (exclusive breastfeeding) or that they may also receive small amounts of water, oral rehydration solutions (ORSs), or medicines (predominantly breastfeeding) (36, 37). This nationwide population-based study investigated exclusive and predominant breastfeeding practices over the last two decades, indicating the impact of policies and strategies (9, 21, 22). Previous studies were fragmented and focused on specific populations and timeframes, hindering a complete understanding of national prevalence trends through time and disparities (9). The time series analysis revealed that the trends of exclusive and predominant breastfeeding in Ethiopia were inconsistent and fluctuated across different regions over the last 20 years.

The observed trend in exclusive breastfeeding rates—an increase from 2000 to 2016 followed by a decline in 2019—is a complex issue with multiple potential causes (Figure 2). These findings align with a previous study on breastfeeding practices, particularly, showing a decline in ever-breastfeeding and inconsistent trends in early initiation (38). The possible reasons might be demographic changes, dietary pattern changes and an increase in access to formula milk. Another possible explanation might be that public health interventions might have declined in intensity or quality after 2016, which could have contributed to the subsequent drop in exclusive or predominant breastfeeding practices (21, 39). However, predominant breastfeeding declined from 2000 to 2016 and subsequently increased in 2019. The study revealed no significant associations between these rates and the year of the survey, despite these fluctuations suggesting that these breastfeeding practices are not improving. These findings contrast with a study that concluded that breastfeeding practices improved in LMICs over the past decade despite regional variation (40). A possible explanation might be reflected in dietary pattern changes, increased access to formula milk, and demographic changes in recent years.

Except for the Gambella regional state of Ethiopia, which showed a different trend, the rates of exclusive and predominant breastfeeding across most Ethiopian regions fluctuated in a similar pattern from 2000 to 2019 (Figure 2). A possible explanation might be that mothers from Gambella might receive interventions of different intensities or qualities than mothers from other regions. Exclusive breastfeeding was higher in rural areas than in urban areas and declined ~2005, followed by an increase in 2016 and a decline again which is consistent with a systematic review and meta-analysis findings from Ghana (41). Higher exclusive breastfeeding rates in rural areas of Ethiopia compared to urban areas may be attributed to factors such as traditional postpartum care practices, limited access to commercial formula milk products, and lower socioeconomic status among rural mothers (41, 42). Similarly, higher predominant breastfeeding rates were observed in urban areas than in rural areas, where mothers who reside in urban areas could access formula milk and prefer complementary feeding earlier (43). To understand this, we need to consider various factors influencing breastfeeding practices in these settings.

The disparities in exclusive and predominant breastfeeding rates across different geographical and demographic groups in Ethiopia are consistent with global trends (40). These disparities highlight the complex interplay of factors influencing breastfeeding practices (39). Regional state, residence, and maternal religion were significantly associated with the likelihood of practicing exclusive and predominant breastfeeding ($p < 0.01$) (Table 2). For example, mothers residing in Amhara (AOR: 5.036), Oromia (AOR: 4.418), and former SNNP (AOR: 3.997) have significantly higher rates of exclusive breastfeeding than mothers residing in Somali, which is consistent with previous studies (44). These findings also reflected the rural-to-urban disparities. Higher rates of exclusive and predominant breastfeeding were observed among rural mothers than among urban mothers. These findings were consistent with previous findings (25, 44). These differences might be attributed to differences in socioeconomic status, stronger cultural norms supporting breastfeeding, and limited access to formula in rural areas (41, 42). Additionally, rural areas might have more entrenched cultural beliefs and practices supporting breastfeeding with extended family living arrangements, and larger families could provide more support for breastfeeding mothers (45). Another factor might be that the lower availability of formula in rural areas might encourage exclusive breastfeeding.

Mothers aged 25–29 years are less likely to exclusively or predominantly breastfeed than younger mothers aged 15–19 years are ($p < 0.05$). While specific studies focusing on this age group might be limited, general trends in breastfeeding and maternal age in which maternal age is significantly associated with exclusive breastfeeding have been explored in the literature (46). The possible explanations might be a greater likelihood of employment at the age of 25–29 years compared with younger mothers and lower family living arrangements and support from family. Differences in exclusive and predominant breastfeeding practices were observed among different religious groups. For example, Protestant and Orthodox mothers in Ethiopia have significantly higher rates of exclusive and predominant breastfeeding than Muslim mothers do ($p < 0.001$). Several studies have revealed that regions influence various health behaviors and breastfeeding practices (47–49). Potential reasons for religious differences in exclusive and predominant breastfeeding practices might be associated with religious beliefs and practices and the spatial residence of mothers. However, this highlights the need for additional qualitative studies.

The effect of a mother's education level on the likelihood of exclusive and predominant breastfeeding is not clear. Mothers with complete secondary education have a significantly lower prevalence of exclusive and predominant breastfeeding than mothers with no education, which seems counterintuitive. Educational attainment is among the predictors of breastfeeding (47). Conversely, some studies have reported lower breastfeeding rates among educated women, particularly in urban setting (17, 50). For example, analysis of the PMA2023 panel survey data (2021–2023) showed that less educated women in Ethiopia had higher rates of exclusive breastfeeding (50). The possible explanations might be that educated women are more likely to be employed, which can interfere with exclusive breastfeeding and have greater exposure to infant formula marketing.

In contrast to our hypotheses and those of previous studies, marital status (51, 52), employment (25), place of delivery (16, 44), antenatal care utilization (25, 44, 53) and postnatal care utilization (44, 53), and family size (25) were not significantly associated with the likelihood of exclusive and predominant breastfeeding. There might be possible explanations for these counterintuitive findings. The present study used nationally representative data combined from EDHS 2000–2019, whereas other studies were fragmented into different geographical locations. These differences might be due to the study design (sample size, data collection methods, and study period) and the unique characteristics of the national context.

4.1 The strengths and limitations of the study

The study used data from the Demographic and Health Surveys (EDHS) for Ethiopia from 2000 to 2019. The EDHS is a large-scale household survey that collects data on a variety of topics, including breastfeeding practices. This provides a strong foundation for the study. The study used a variety of statistical methods, including pooled multivariate logistic regression analysis, and prevalence odds ratios. This demonstrates a strong understanding of statistical methods and the ability to apply them to complex data.

This study has several considerable limitations. It is based on data from the EDHS, which is a cross-sectional survey. This means that the data can only show associations between factors and cannot be used to establish causality. The study did not control for some potential confounding factors, such as the wealth index, due to a lack of availability of data in all the EDHS datasets. The study did not include variables related to other potential factors that could influence breastfeeding practices, such as social support. Future research should address these limitations by using longitudinal data and collecting data that are more comprehensive on potential confounding factors.

5 Conclusion

Exclusive and predominant breastfeeding rates have varied across children aged <6 months in Ethiopia and have fluctuated inconsistently over the past two decades. These inconsistent trends in exclusive and predominant breastfeeding and a complex interplay of various factors suggest that previous policies and strategies have had limited success in achieving sustained improvements. The significant influence of regional, residential, and religious factors on the likelihood of these breastfeeding practices highlights the need for targeted and tailored public health interventions about exclusive and predominant breastfeeding. These findings suggest a need for further investigation and revisiting the current policies and implementation strategies for a more nuanced and targeted approach in future interventions. The policy and intervention strategies need to be revised through regular assessments and evaluation research that considers regional differences and sociocultural settings for equitable and sustained improvements in breastfeeding in Ethiopia. Further study is needed to explore the interplay between maternal age, employment status, and breastfeeding practices in more detail, investigating social support networks and childcare arrangements and the knowledge, attitudes, and beliefs about breastfeeding among different age groups of mothers to develop targeted interventions.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: http://www.dhsprogram.com/.

Author contributions

HH: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing.

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The necessity of gestational vitamin D supplementation depends on ambient temperature: concern for infant vitamin D status

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Background: Given the ease of access to ambient temperature, it may be a more practical guide than the UVB index. However, the association between gestational temperature and vitamin D level in newborns remains unclear. Our study aims to explore this association and the necessity of maternal vitamin D supplementation when ambient temperature is less than a specific value.

Methods: Based on a birth cohort study, we measured cord blood concentrations of 25(OH)D in 1419 neonates from January to September 2008 in Hefei, a new first-tier city in China. The daily mean temperature of Hefei was obtained from the China Meteorological Data Sharing Service System. Individual information on sociodemographic characteristics, perinatal health status, lifestyle, and birth outcomes was collected prospectively.

Results: The best-fit relationship was observed in the regression model using a quadratic function to describe the association between the ambient temperature of the eighth gestational month (29–32 gestational weeks) and cord blood 25(OH)D concentrations (R^2 = 0.358, p < 0.001). Ambient temperatures of 10 and 24.5°C were linked to the cutoff of vitamin D inadequacy (<50 nmol/L) and deficiency (<30 nmol/L) in cord blood, respectively. For maternal exposure to an ambient temperature of ≥24.5°C in the eighth gestational month, vitamin D supplementation during pregnancy failed to significantly enhance neonatal vitamin D concentrations. In contrast, for maternal exposure to ambient temperature of <10°C, maternal vitamin D supplementation was significantly associated with elevated 25(OH)D concentrations in cord blood.

Conclusion: Gestational ambient temperature may be an ideal predictor for infant vitamin D status screening. Maternal exposure to an ambient temperature of less than 10°C is a critical index in the eighth gestational month, which may determine the onset of vitamin D supplementation.

KEYWORDS

pregnant women, vitamin D supplementation, vitamin D, ambient temperature, neonate

Introduction

Vitamin D deficiency during pregnancy and the neonatal period is a common global health concern (1, 2). Studies on pregnant women have reported a high prevalence of vitamin D deficiency in Colombia (23.9%) (3), France (41.5%) (4), and China (76.4%) (5). It has been confirmed that 25-hydroxyvitamin D [25(OH)D], the major circulating form of vitamin D, could readily traverse the hemochorial placenta (6). Fetal vitamin D concentrations are largely dependent on maternal vitamin D status (7). To date, guidelines concerning vitamin D screening in pregnant women have been conflicting (8–13). The Committee Opinion of the American College of Obstetricians and Gynecologists (8) and Australian Government antenatal care clinical practice guidelines (10) recommend screening only women at increased risk of vitamin D deficiency, including vegetarians, women with limited sun exposure, and women with darker skin (14). Hence, identifying pregnant women at increased risk of vitamin D deficiency is an important public health strategy.

The main source of vitamin D in most humans is the synthesis of 7-dehydrocholesterol in the skin upon exposure to ultraviolet B (UVB) solar radiation and its conversion to a measurable circulating metabolite, 25(OH)D, in the liver (15), which is used to determine individual vitamin D status (16). Thus, limited sunlight exposure may influence skin production of vitamin D, resulting in vitamin D deficiency. However, several factors influence the intensity and duration of exposure to UVB radiation, including geographic location, season, atmospheric conditions, and time spent outdoors (17). Notably, the ambient temperature is usually associated with both UVB radiation and its influencing factors. Although there is no direct causality between ambient temperature and vitamin D, given the access to ambient temperature, it may be a better practical predictor of individual vitamin D concentrations. However, to the best of our knowledge, the relationship between ambient temperature and individual vitamin D concentration has not been well established.

We hypothesized that maternal exposure to ambient temperature might be positively associated with fetal vitamin D concentrations and that cutaneous synthesis of previtamin D could be unavailable when the ambient temperature is greatly reduced (i.e., when the amount of solar ultraviolet radiation that reaches the earth's surface is substantially reduced). This leaves the individual uniquely dependent on supplemental sources of vitamin D during periods when ambient temperature is below the threshold value. This study aimed to determine the implications of gestational ambient temperature on infant vitamin D status and to establish the necessity of maternal vitamin D supplementation when the ambient temperature is less than a threshold value. The significance of this study lies in its ability to reveal the effects of ambient temperature on vitamin D supplementation during pregnancy. If ambient temperature is shown to be a reliable predictor of vitamin D deficiency or supplementation needs, it could significantly impact public health strategies, especially in regions with seasonal temperature variations. The findings of this study provide new insights into how environmental factors, particularly temperature, should be considered when developing pregnancy-care guidelines. This could lead to more individualized recommendations for vitamin D supplementation based on the local climate, particularly during colder months when vitamin D synthesis is impaired owing to reduced UVB exposure. Furthermore, this study could lay the foundation for future research on the relationship between environmental factors and maternal vitamin D status, ultimately guiding more effective prenatal care policies to improve maternal and fetal health outcomes.

Abbreviations: 25(OH)D, 25-hydroxyvitamin D; BMI, body mass index; CI, confidence interval; GDM, gestational diabetes mellitus; GM, gestational month; GWG, gestational weight gain; IOM, Institute of Medicine; OR, odds ratio; SGA, small for gestational age; UVB, ultraviolet B.

Subjects and methods

Study design

A total of 2,552 pregnant women with gestational ages between 30 and 34 weeks were recruited at the Hefei Maternal and Child Health Hospital (32°N latitude) between January and September 2008. The inclusion criteria for this study were age ≥ 18 years, absence of communication problems, and residents of Hefei city. The participants completed a structured questionnaire that included questions on their demographic characteristics and perinatal lifestyle through face-to-face interviews. After delivery, well-trained nurses collected the infant anthropometric details and cord blood samples. In this study, we restricted the study sample to full-term births. Women with premature births, stillbirths, birth defects, pregnancies with assisted reproductive technology, or multiple gestations were excluded to avoid confounding factors. Finally, we obtained available data from 1,419 mother-infant pairs with cord blood samples. Informed consent was obtained from each participant. The research protocol was approved by the Ethics Committee of Anhui Medical University (Approval Number: 2008020).

Ambient temperature exposure

The daily mean temperature of Hefei was obtained from the China Meteorological Data Sharing Service System[1]. This system provides publicly available temperature data, including the daily average temperature of Hefei based on measurements collected from several meteorological stations across the city. These measurements were taken at a standard height of 2 meters above ground level, which is the standard method for collecting ambient temperature data. The daily mean temperature reflects the average temperature for each 24-h period. To estimate the ambient temperature exposure of each participant, we used the last menstrual period (LMP) date of each woman to calculate their gestational months (GM). The LMP was used to estimate gestational age as it provides a reliable reference point for determining the timing of pregnancy stages. For each participant, gestational months were divided into four-week intervals, with each GM consisting of approximately 4 weeks. Once gestational months were identified, we calculated the mean ambient temperature for each specific GM during pregnancy. This involved averaging daily temperature readings from the China Meteorological Data Sharing Service System for the corresponding weeks of each participant's

1 http://data.cma.cn/

pregnancy. Daily temperature data were averaged over each gestational month to provide an estimate of the mean temperature for that month. In addition, ambient temperatures were categorized into three distinct ranges based on their potential impact on UVB radiation exposure and fetal vitamin D synthesis: <10°C, 10–24.4°C, and ≥24.5°C.

Vitamin D supplementation assessment

When pregnant women first underwent prenatal checkups in obstetric clinics, they were advised to take 600 IU/d of vitamin D3 supplements during the second and third trimesters, according to the guidelines of the Institute of Medicine (IOM) (11). In the interview conducted between 32 and 34 gestational weeks, each participant was invited to respond to the two questions: "How long have you taken vitamin D during pregnancy?" and "What's the daily dose of vitamin D supplementation you have taken during pregnancy?" However, most pregnant women are unable to report the exact dose of vitamin D supplementation. By collecting information on the brands of vitamin D supplements and their frequency of use, we found that the majority of pregnant women were taking commercial vitamin D at doses ranging from 300 IU to 600 IU per day. For analytical purposes, the duration of vitamin D supplementation was selected as the index of vitamin D supplementation and categorized as per the following prioritization: <2 months and ≥2 months.

Cord blood 25(OH)D measurement

Cord blood samples were collected immediately after delivery. Plasma samples were centrifuged and promptly refrigerated at −4°C and then transferred to −80°C freezers within 12 h for long-term storage. Cord blood 25(OH)D concentrations were measured using commercial radioimmunoassay kits (DiaSorin Stillwater, MN, United States) by well-trained researchers at the Anhui Provincial Key Laboratory of Population Health and Aristogenics (5). The intra- and interassay coefficients of variation were 8.8 and 11.1%, respectively. According to the IOM classification (18), vitamin D status was defined as deficient [25(OH)D < 30 nmol/L] or inadequate [30 nmol/L ≤ 25(OH)D < 50 nmol/L].

Covariates

Information on essential potential confounders was collected from medical records or interviews in this study. Maternal sociodemographic characteristics included age, education (≤9 and >9 years of completed schooling), and household income (<2000 and ≥2000 Yuan RMB/month). Perinatal health status included pre-pregnancy body mass index (BMI), gestational weight gain (GWG), pregnancy complications (including moderate or severe anemia, hypertension, diabetes mellitus, glandula thyreoidea disease, abnormal heart function, and intrahepatic cholestasis of pregnancy), and parity (nullipara or multipara). The pre-pregnancy lifestyle included daily outdoor time (<1 h/d vs. ≥1 h/d), maternal alcohol consumption, paternal smoking, and alcohol consumption for up to 6 months before pregnancy. The birth outcomes included gestational age, birth weight, and infant sex. Small for gestational age (SGA) was defined as birth weight < 10th percentiles of distribution for gestational age and infant gender (19). The birth seasons were designated as follows: spring (March, April, and May), summer (June, July, and August), fall (September, October, and November), and winter (December, January, and February).

Statistical analysis

Associations between the characteristics of mother-infant pairs and cord blood 25(OH)D levels were examined to determine potential covariates in subsequent analyses (Table 1). The trend in cord blood 25(OH)D concentrations across birth seasons was estimated using a sinusoidal model, and infant vitamin D status across birth seasons was examined using the chi-square test (Figure 1).

To confirm the critical time when maternal exposure to ambient temperature influences cord blood 25(OH)D concentrations, linear and non-linear regression models (quadratic and cubic) were used to assess the relationships between the ambient temperature of each GM and cord blood 25(OH)D concentration, respectively. The best-fit relationship was observed in the eighth GM, with a quadratic function (Table 2). Consequently, the eighth GM was considered a critical time when maternal exposure to ambient temperature influenced cord blood 25(OH)D concentration in subsequent analyses. The regression model with the quadratic function suggested that ambient temperatures of 10°C and 24.5°C in the eighth GM were linked to the cutoff of vitamin D inadequacy and vitamin D deficiency in cord blood, respectively (Figure 2). Odds ratios (*OR*) and 95% confidence intervals (CI) of vitamin D deficiency and vitamin D inadequacy for maternal exposure to 10–24.4°C and <10°C in the eighth GM were generated using a multiple logistic regression model (Table 3).

Stratified by the ambient temperature of the eighth GM, hierarchical multiple regression analyses were conducted to assess the relative contributions of ambient temperature and vitamin D supplementation during pregnancy to cord blood 25(OH)D concentration. For these analyses, we allowed potential covariates to enter the first blocks in a stepwise fashion, then forced the ambient temperature of the eighth GM into the equation and entered vitamin D supplementation (Table 4). All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) statistical software (version 21.0).

Results

Effect of temperature on vitamin D supplementation

Attrition analyses revealed no significant difference in the distributions of demographic characteristics, perinatal health status, lifestyle, and birth outcomes between participants and non-participants. Table 1 shows the characteristics of mother-infant pairs in this study and their association with cord blood 25(OH)D concentrations. Cord blood 25(OH)D concentrations were suggested to be significantly related to GWG, pregnancy complications, paternal alcohol consumption, daily outdoor time, and infant sex, which were considered potential covariates in subsequent analyses.

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TABLE 1 Characteristics of pregnant women in relation to cord blood 25(OH)D.

Characteristics	Classify	Mean (SD) or *n* (%)	*β* (95% CI)	*p*-value
Sociodemographic characteristics				
Maternal age, y		27.68 (3.61)	0.04 (−0.25, 0.33)	0.796
Maternal education	<9 years	282 (19.9)	−0.71 (−3.35, 1.94)	0.600
	≥9 years	1,137 (80.1)	Ref	
Maternal income	<2000 yuan	207 (14.6)	−0.99 (−3.97, 2.00)	0.516
	≥ 2000 yuan	1,212 (85.4)	Ref	
Perinatal health status				
Pre-pregnancy BMI, kg/m^2		20.15 (2.40)	−0.19 (−0.63, 0.25)	0.394
GWG, kg		16.90 (4.84)	−0.36 (−0.57, −0.14)	0.001
Multipara	Primipara	1,234 (87.0)	Ref	
	Multipara	185 (13.0)	−0.47 (−3.60, 2.66)	0.768
Pregnancy complications[1]	Yes	211 (14.9)	−3.27 (−6.23, −0.32)	0.030
	No	1,208 (85.1)	Ref	
Perinatal lifestyle[2]				
Maternal alcohol consumption	Any	216 (15.2)	−1.60 (−4.54, 1.33)	0.284
	No	1,203 (84.8)	Ref	
Paternal alcohol consumption	Any	1,137 (80.1)	3.42 (0.79, 6.06)	0.011
	No	282 (19.9)	Ref	
Paternal smoking[3]	Yes	317 (22.3)	0.75 (−1.78, 3.28)	0.561
	No	1,102 (77.7)	Ref	
Daily outdoor time	≥1 h/d	486 (34.2)	2.62 (0.44, 4.79)	0.018
	<1 h/d	933 (65.8)	Ref	
Vitamin D supplementation	≥2 months	691 (48.7)	2.66 (0.56, 4.77)	0.013
	<2 months	728 (51.3)	Ref	
Birth outcomes				
Infant gender	Female	667 (47.0)	−2.23 (−4.34, −0.13)	0.038
	Male	752 (53.0)	Ref	
Birth weight, g		3,420 (419)	0.001 (−0.003, 0.002)	0.801
SGA	Yes	122 (8.6)	−1.92 (−5.68, 1.84)	0.317
	No	1,297 (91.4)	Ref	

25(OH)D, 25-hydroxyvitamin D; BMI, body mass index; GWG, gestational weight gain; SGA, small for gestational age.
[1]Complications of pregnancy included diabetes mellitus, hypertension, abnormal heart function, glandula thyreoidea disease, intrahepatic cholestasis of pregnancy, and moderate and severe anemia.
[2]Pre-pregnancy lifestyle means lifestyle during up to 6 months before pregnancy.
[3]Paternal smoking was defined as smoking more than six cigarettes daily.

Cord blood 25(OH)D concentrations showed a seasonal distribution with a mean concentration of 39.52 nmol/L and SD of 20.23 nmol/L. The maximum fitted concentrations of cord blood 25(OH)D were observed in neonates born in autumn, reaching their nadir in winter (Figure 1A; $R^2 = 0.35$, $p < 0.001$). Of the neonates born in winter, 85.3% had cord blood 25(OH)D concentrations <30 nmol/L, and 98.9% had concentrations <50 nmol/L, compared to 5.8 and 40.3% of neonates born in autumn, respectively (Figure 1B; $p < 0.001$).

Table 2 presents the results of the trend analyses, which indicated that the best-fit relationship was observed in the regression model using a quadratic function between the ambient temperature of the eighth GM (29–32 gestational weeks) and cord blood 25(OH)D concentration. Thus, the eighth GM was considered the critical time for maternal exposure to temperature-influencing cord blood 25(OH) D concentrations in subsequent analyses. Figure 2 shows that cord blood 25(OH)D concentrations significantly increased with increasing ambient temperature in the eighth GM. Maternal exposure to ambient temperatures of 10 and 24.5°C was linked to the cutoff for vitamin D deficiency and vitamin D inadequacy in cord blood, respectively. Supplementary Figure S1 shows the relationship between ambient temperature in the different GM and cord blood 25(OH)D levels in pregnant women. We found similar thresholds, in that maternal exposure to different ambient temperatures was linked to the cutoff of vitamin D deficiency and vitamin D inadequacy.

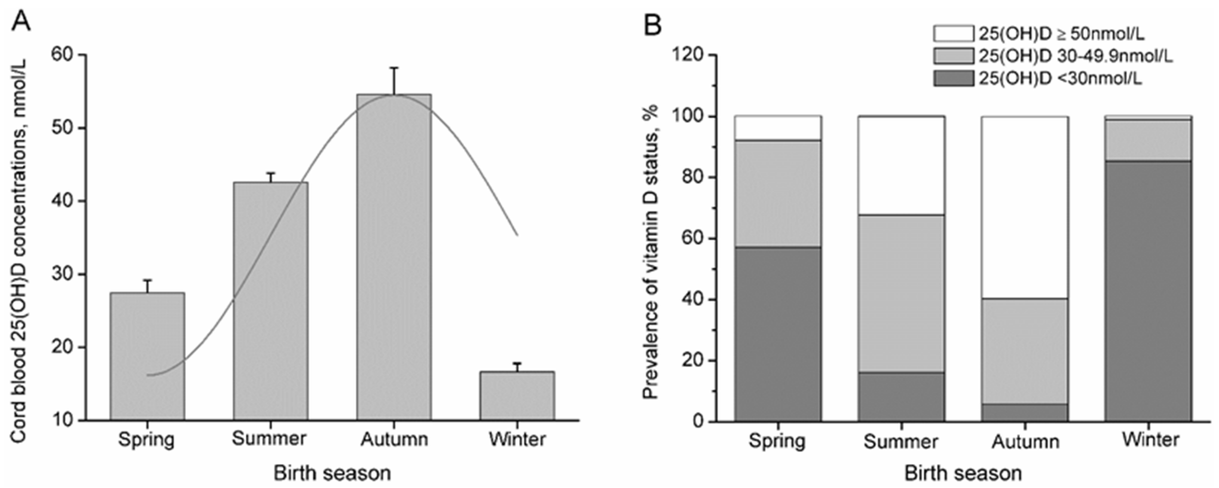

FIGURE 1
Cord blood vitamin D status across the birth season in pregnant women. The seasonality of cord blood 25(OH)D levels was estimated by fitting the data to the best-fitting linear model using a sinusoidal model **(A)**, and the bars represent the median and 95% CI **(A)** or percentage of subjects **(B)**.

TABLE 2 Linear, quadratic, and curve estimations for the associations between ambient temperature of gestation and cord blood 25(OH)D in pregnant women.

Ambient temperature	R^2	F	p
37–40 gestational weeks			
Linear	0.258	492.0	<0.001
Quadratic	0.270	261.9	<0.001
Cubic	0.271	243.3	<0.001
33–36 gestational weeks			
Linear	0.305	620.5	<0.001
Quadratic	0.329	346.5	<0.001
Cubic	0.328	344.3	<0.001
29–32 gestational weeks			
Linear	0.338	724.6	<0.001
Quadratic	0.358	394.0	<0.001
Cubic	0.358	392.4	<0.001
25–28 gestational weeks			
Linear	0.244	457.6	<0.001
Quadratic	0.271	262.5	<0.001
Cubic	0.273	260.4	<0.001
21–24 gestational weeks			
Linear	0.107	170.1	<0.001
Quadratic	0.152	126.8	<0.001
Cubic	0.154	114.6	<0.001

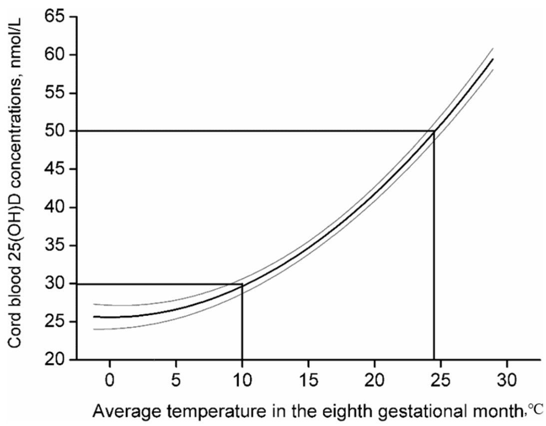

FIGURE 2
Relationship between ambient temperature in the eighth GM and cord blood 25(OH)D in pregnant women. The solid dark line represents the trend for changes in cord blood 25(OH)D mean values with increasing ambient temperature in the eighth GM, and the gray lines represent the 95% confidence interval.

Compared with maternal exposure to ≥24.5°C in the eighth GM, maternal exposure to 10–24.4°C or <10°C significantly elevated the risk of vitamin D deficiency and vitamin D inadequacy in cord blood. This increased risk remained significant even after adjusting for potential covariates and vitamin D supplementation during pregnancy. Additionally, maternal vitamin D supplementation for more than 2 months was significantly associated with a reduction in the risk of vitamin D deficiency and inadequacy in cord blood, even after controlling for the potential covariates and ambient temperature in the eighth GM (Table 3).

Stratified by ambient temperature in the eighth GM, the relative contributions of temperature in the eighth GM and vitamin D supplementation during pregnancy to cord blood 25(OH)D concentration were estimated. For maternal exposure to <10°C in the eighth GM, higher ambient temperature failed to significantly enhance cord blood 25(OH)D concentrations and only accounted for 0.3% of the variance. However, vitamin D supplementation was significantly associated with higher 25(OH)D concentrations in the cord blood and accounted for 0.5% of the variance. For maternal exposure to 10–24.4°C in the eighth GM, the temperature accounted for 11.7% of

TABLE 3 Risk for ambient temperature in the eighth GM and maternal vitamin D supplementation on vitamin D deficiency or inadequacy in cord blood in pregnant women.

Predictor variables	%	Vitamin D deficiency [25(OH) D < 30 nmol/L]		%	Vitamin D inadequacy [25(OH) D < 50 nmol/L]	
		Unadjusted OR (95% CI)	Adjusted OR[1] (95% CI)		Unadjusted OR (95% CI)	Adjusted OR[1] (95% CI)
Temperature						
<10°C	68.1	24.72 (16.35, 37.37)[#]	24.60 (15.83, 38.21)[#]	94.5	17.65 (11.41, 27.29)[#]	16.58 (10.23, 26.87)[#]
10–24.4°C	25.9	4.05 (2.68, 6.13)[#]	4.01 (2.64, 6.09)[#]	76.5	3.35 (2.53, 4.44)[#]	3.50 (2.61, 4.69)[#]
≥24.5°C	7.9	1.0	1.0	49.2	1.0	1.0
VD supplementation						
≥2 months	33.1	0.82 (0.66, 1.02)*	0.70 (0.54, 0.91)**	72.5	0.77 (0.60, 0.98)**	0.66 (0.50, 0.87)**
<2 months	37.8	1.0	1.0	77.6	1.0	1.0

Adjusted for gestational weight gain, pregnancy complications (diabetes mellitus, hypertension, abnormal heart function, glandula thyreoidea disease, intrahepatic cholestasis of pregnancy, moderate and severe anemia), paternal alcohol consumption, daily outdoor time, and infant sex.
*$p < 0.1$, **$p < 0.05$, #$p < 0.01$.

the variance in cord blood 25(OH)D concentrations, and vitamin D supplementation accounted for an additional 13.8% of the variance. For maternal exposure to ≥24.5°C in the eighth GM, the temperature accounted for 9.5% of the variance in cord blood 25(OH)D concentrations; however, vitamin D supplementation during pregnancy failed to significantly enhance cord blood 25(OH)D concentrations and only accounted for 0.4% of the variance.

Discussion

In this study, ambient temperature in the eighth GM was suggested as an effective predictor of vitamin D status in full-term neonates. The mean 25(OH)D concentration in cord blood significantly increased with increasing ambient temperature in the eighth GM. Maternal exposure to 10–24.4°C in the eighth GM had a significantly higher risk of vitamin D deficiency, and the risk was further substantially elevated when the mother experienced ambient temperature < 10°C in the eighth GM, even after controlling for potential covariates and vitamin D supplementation during pregnancy. Furthermore, an interesting finding was that the necessity of vitamin D supplementation during pregnancy appeared to be dependent on ambient temperature in the eighth GM. For maternal exposure to ≥24.5°C in the eighth GM, vitamin D supplementation during pregnancy failed to significantly enhance neonatal vitamin D concentrations. In contrast, for maternal exposure to <10°C in the eighth GM, maternal vitamin D supplementation may be a unique and effective way to increase the neonatal vitamin D concentration. To the best of our knowledge, this is the first study to focus on the relationship between maternal exposure to ambient temperature and fetal vitamin D concentrations.

Our study provides important evidence that ambient temperature can serve as a useful predictor of fetal vitamin D status and suggests that maternal vitamin D supplementation should be tailored to seasonal changes in UVB exposure. Our study provides actionable recommendations for public health policies. First, temperature-based predictors are integrated into clinical guidelines for vitamin D supplementation, especially in regions where the ambient temperature falls below the critical threshold. Second, we created geographically and seasonally tailored policies for vitamin D supplementation with an emphasis on high-risk groups. Third, supporting public health campaigns and maternal health surveillance focused on the risk of seasonal vitamin D deficiency. Fourth, routine vitamin D screening is based on ambient temperature data, especially for pregnant women during winter months. Vitamin D supplementation is essential for maintaining maternal and fetal health (20), particularly to prevent complications, such as gestational diabetes mellitus (GDM) and preeclampsia (21, 22). Temperature-based adjustments to supplementation may be a practical strategy to ensure optimal vitamin D levels, particularly in regions with low sunlight exposure. Previous studies have shown that temperature changes increase the risk of GDM and preeclampsia (23, 24). However, the direct effects of temperature-based vitamin D supplementation on these outcomes have not yet been fully explored. Further studies are required to confirm the efficacy of temperature-guided supplementation for reducing pregnancy-related complications.

Vitamin D is synthesized in the skin through exposure to UVB radiation, and solar UVB radiation is the primary source of vitamin D for most humans. Therefore, the assessment of vitamin D status in populations must consider sunlight exposure (15). However, sunlight is a complex exposure to measure because ambient UVB concentrations vary up to 30-fold by latitude, season, ground surface, time of day, clothing, sunscreen, and cloud or tree cover (25–29). Thus, simply asking people how much time they spend outside may not correctly classify UVB exposures. Studies assessing the relationship between sunlight measures and serum 25(OH)D levels also showed low correlations (30, 31); sunlight measures only accounted for approximately 10% of the variation in serum 25(OH)D concentrations. The ambient temperature is easy for an individual to access for an individual. Although there was no direct causality, the predictive value of ambient temperature in this study was substantial because the ambient temperature in the eighth GM at ≥10°C could account for approximately 12% of the variation in infant 25(OH)D concentrations, which appears to be more important than the season (32) and is similar to sunlight. In addition, ambient temperature can serve as a useful indirect measure, because temperature and UVB radiation levels are often positively correlated. For example, UVB radiation tends to be higher during warmer months and at higher latitudes closer to the equator, which corresponds to higher ambient

TABLE 4 Regression analyses for predictor variables and cord blood 25(OH)D, stratified by ambient temperature in the eighth GM in pregnant women.

Predictor variables	<10°C (*n* = 489)					10–24.4°C (*n* = 540)					≥24.5°C (*n* = 390)				
	Unstandardized *β*	SE	Standardized *β*	R^2	ΔR^2	Unstandardized *β*	SE	Standardized *β*	R^2	ΔR^2	Unstandardized *β*	SE	Standardized *β*	R^2	ΔR^2
Step 1				0.024					0.011					0.032	
Paternal alcohol consumption	1.37	1.45	0.04			1.97	1.75	0.05			4.13	2.67	0.08		
GWG	0.11	0.12	0.04			−0.13	0.15	−0.04			−0.31	0.21	−0.07		
Pregnancy complications	−1.00	1.57	−0.03			−2.98	1.84	−0.07			−3.40	3.20	−0.05		
Daily outdoor time	1.12	1.51	0.04			0.36	1.41	0.01			0.68	1.33	0.02		
Infant gender	−3.23	1.16	−0.13#			−0.42	1.40	−0.01			−1.09	2.07	−0.03		
Step 2				0.027	0.003				0.128	0.117	4.13	2.67	0.08	0.127	0.095
Paternal alcohol consumption	1.41	1.45	0.05			0.61	1.65	0.02			3.21	2.54	0.06		
GWG	0.1	0.12	0.04			−0.01	0.14	0.00			−0.28	0.2	−0.07		
Pregnancy complications	−0.97	1.57	−0.03			−2.16	1.73	−0.05			−4.73	3.05	−0.07		
Daily outdoor time	0.65	1.55	0.02			0.33	1.32	0.01			0.57	1.45	0.02		
Infant gender	−3.32	1.16	−0.13**			−0.53	1.31	−0.02			−0.67	1.97	−0.02		
Ambient temperature	0.24	0.2	0.06*			1.09	0.13	0.35#			4.36	0.65	0.31#		
Step 3				0.033	0.005				0.266	0.138				0.131	0.004
Paternal alcohol consumption	1.31	1.45	0.04			0.37	1.51	0.01			3.56	2.4	0.07		
GWG	0.11	0.12	0.04			−0.04	0.13	−0.01			−0.38	0.19	−0.09		
Pregnancy complications	−0.87	1.57	−0.03			−2.22	1.59	−0.05			−3.37	2.89	−0.05		
Daily outdoor time	0.67	1.76	−0.02			0.41	1.40	−0.01			0.27	1.25	0.01		
Infant gender	−3.42	1.16	−0.14#			−1.68	1.21	−0.05			0.31	1.87	0.01		
Ambient temperature	0.27	0.2	0.07			1.09	0.12	0.35#			3.65	0.62	0.26#		
Vitamin D supplementation	2.17	1.14	0.09**			4.65	1.30	0.14#			2.98	2.00	0.070		

GM, gestational month; GWG, gestational weight gain.
*$p < 0.1$, **$p < 0.05$, #$p < 0.01$.

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temperatures. Previous studies (33, 34) have demonstrated that the UVB radiation intensity is associated with seasonal temperature changes. We acknowledge that ambient temperature alone is an imperfect proxy but is often useful when combined with other contextual data (e.g., seasonality or geographic latitude).

It is important to note that there was a two-month lag effect of maternal exposure to ambient temperature on fetal vitamin D concentrations. The complex progression of the vitamin D endocrine system (35) and placental transmission of 25(OH)D (36) may explain this lag effect. The lag effect could be linked to the fact that maternal vitamin D synthesis is less effective during the winter months because of lower sunlight exposure, especially when ambient temperatures are low (e.g., <10°C). This reduced synthesis may take time to manifest as a deficiency or insufficiency in both the mother and the fetus. Another possible mechanism is placental transmission of 25(OH)D. Research suggests that the placenta is a key mediator of vitamin D transfer (37); however, the efficiency of this process can be affected by several factors, including maternal vitamin D status and ambient temperature. Placental transfer of vitamin D is not instantaneous and may involve a temporal delay, especially when maternal vitamin D levels are low. If the lag effect is further confirmed in the whole pregnancy through animal study, it will give an important "time window" to intervene ahead of time, which was supposed to start from 2 months before pregnancy. Furthermore, the findings of this study suggest that when pregnant women experience an ambient temperature of less than 10°C, vitamin D supplementation may be a unique and effective way to increase fetal vitamin D concentrations, as little detectable production of precholecalciferol occurs in the season of low ambient temperature when there are few ultraviolet photons with energies between 290 and 315 nm (38). This result was supported by a study from Australia showing that the contribution of sunlight to 25(OH)D concentrations is very important in the summer months but less important in the winter months (39). Given the adverse pregnancy outcomes associated with vitamin D deficiency, the potential public health implications of our findings are of immense importance.

In our study, we did not find a significant association between pre-pregnancy BMI or parity and fetal vitamin D levels (measured using cord blood 25(OH)D concentrations). This result contrasts with previous studies that have suggested that these maternal factors may influence vitamin D status (40, 41) during pregnancy. This may be because of several reasons. First, it was conducted in Hefei, China, a region that may have different seasonal patterns of UVB exposure and lifestyle factors. Second, in our cohort, maternal vitamin D supplementation was likely more widespread, especially in regions with lower UVB radiation, potentially reducing the impact of maternal BMI or parity on fetal vitamin D levels.

Our study has two major strengths. First, this is the first ecological study on the relationship between maternal exposure to gestational ambient temperature and fetal vitamin D status. Second, in contrast to previous ecological studies, adjustment for individual information (including GWG, pregnancy complications, paternal alcohol consumption, and infant sex) strengthened the conclusions of this study. Third, we considered the timing of gestational months when analyzing the effects of ambient temperature on fetal vitamin D status. This stratification allowed us to capture more nuanced relationships, which may have been overlooked in studies that did not account for such temporal factors.

However, this study has several limitations that should also be acknowledged. The missing data from October to December is an important limitation that may affect the ability of the study to fully capture the seasonal variations in ambient temperature and fetal vitamin D levels. The absence of this key period could lead to underestimation or overestimation of seasonal effects, especially because these months typically represent the transition from fall to winter, when temperature and sunlight levels fluctuate more dramatically. In addition, our study had a short duration, and the results were preliminary. Another limitation was that the duration of supplementation, but not the dose, was used to estimate maternal vitamin D supplementation in this study. Although the dose of commercial vitamin D3 that most pregnant women consumed ranged from 300 to 600 IU/d, the absence of an exact dose might have confounded the contribution of vitamin D supplementation in our study. Without knowing the exact dosage, it is challenging to determine the precise contribution of supplementation to vitamin D levels observed in cord blood. Additionally, we acknowledge that relying on self-reported data on vitamin D supplementation, including the duration of supplementation, introduces the possibility of recall bias. This bias occurs when participants may have forgotten, misremembered, or exaggerated the extent of their supplementation. Recall bias is a common challenge in retrospective studies, especially when assessing dietary or health behaviors over long periods. Although we did not capture the exact dosages, the range of supplementation (300–600 IU/day) was relatively narrow, and this range is consistent with the general guidelines for pregnant women. Overall exposure to vitamin D supplementation was within a reasonable range for most participants. In addition, a previous study (5) successfully used self-reported supplementation duration as a proxy for the exact dose of vitamin D supplementation in pregnant women, particularly when the exact doses are difficult to capture. Third, our study was based on a single cohort from Hefei, China, which may limit the generalizability of our findings to other regions with differing latitudes, UVB exposures, and socioeconomic conditions. Therefore, the results are geographically specific, and further multicenter or multi-region studies are needed to validate the relationship between ambient temperature and neonatal vitamin D levels. This would help identify whether ambient temperature during gestation is a universal predictor of fetal vitamin D status or whether it varies according to regional factors such as UVB exposure, diet, and cultural practices regarding sunlight exposure. Fourth, data collection from 2008 may not fully reflect current conditions such as climate change, advancements in supplementation practices, or shifts in maternal behaviors. Rising temperatures and shifting seasonal patterns may affect the amount of UVB exposure and, in turn, the vitamin D status of the pregnant women. Additionally, advancements in vitamin D supplementation practices (42), which have become more standardized over the past decade, could have influenced our results. Public health campaigns promoting prenatal vitamin D supplementation may increase compliance among pregnant women, potentially altering the relationship between ambient temperature and vitamin D levels. Despite the potential limitations of using historical data, these findings can provide valuable insights into the fundamental relationship between ambient temperature and vitamin D levels during pregnancy. Fifth, while the R^2 value is significant, it does not explain a large proportion of the variance in neonatal vitamin D levels. This is an important point, as it suggests that there may be additional factors contributing to the variability in the data that are not captured by the ambient temperature alone. We suggest that the inclusion of other uncollected covariates could improve the model's predictive power.

Conclusion

Maternal exposure to ambient temperature below 10°C during pregnancy is a critical predictor of vitamin D deficiency in newborns. These findings suggest that ambient temperature can be used as an indicator to guide vitamin D supplementation. Further studies are needed to confirm the predictive value of temperature and to optimize supplementation protocols based on environmental conditions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics Committee of Anhui Medical University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

WY: Methodology, Software, Visualization, Writing – original draft. LZ: Investigation, Writing – original draft. PZ: Data curation, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2025.1541427/full#supplementary-material

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Building blocks of life: improving nutrition and health outcomes through fortification and breastfeeding in the first 1000 days of a child's life

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Micronutrient deficiencies continue to be an important concern in India, particularly among mothers and young children. Food fortification and fortified rice as a scalable and cost-effective solution, has been accepted as a critical intervention to address these deficiencies. Our analysis examines how food fortification can improve the health of mothers and children in India. Focusing on the vital window of first 1,000 days since conception of a child, we examine the benefits of food fortification, the incidence of micronutrient deficiencies, and the incorporation of fortified foods into India's social safety net program. The analysis emphasizes the importance of successful public-private partnerships, local institutional commitment, and long-term political commitment to the success of fortification programs. We further emphasize that to ensure optimal nutrition during this critical stage, it essential to support breastfeeding, establish human milk banks, and encourage complementary feeding alternatives. Policymakers, program implementers, and stakeholders committed to improving maternal and child health outcomes in India will benefit from our findings.

KEYWORDS

food fortification, first 1000 days, rice fortification, breastfeeding, human milk banking, early childhood development, nutrition, global south

1 Introduction

The first 1,000 days, from conception to a child's second birthday, represent a crucial window for impactful interventions in health and nutrition. During this period, children are most vulnerable and in critical need of optimal nutrition to support healthy growth, brain development, and long-term health (1). This stage lays the groundwork for the foundations of a child's physical, cognitive, and emotional development, with nutrition playing a vital role in these outcomes (1). By the age of 2 years, 80% of a child's brain is developed. Optimal nutrition of mother during pregnancy, post-partum period and of a child during early years of life plays a critical role to develop, learn and thrive (1).

The SDG report 2024 (2) emphasizes that more countries are off-track than on-track for the seven global nutrition targets. Key indicators such as low birthweight, exclusive breastfeeding, stunting, overweight in children under 5 years, wasting, anemia in women aged 15–49, and obesity show significant challenges. The chart reveals the stark reality that a majority of countries fall into the "off-track" category, particularly for both anemia and obesity

(191 countries). A small number of countries have managed to achieve "on-track" status for targets like exclusive breastfeeding and low birthweight, but these remain exceptions rather than the norm. Hunger continues to pose a significant challenge globally, with Africa having the highest percentage of its population affected at 20.4%, which translates to 298.4 million people in 2023. Although the prevalence is lower in Asia at 8.1%, it accounts for 384.5 million people, making it the region with the largest absolute number of individuals facing hunger—more than half of the global total. Latin America and the Caribbean face hunger rates of 6.2%, affecting 41 million people, while Oceania, with a hunger rate of 7.3%, has 3.3 million people affected (3). The inability to assess progress in some areas further underscores the complexities in addressing global nutrition challenges (Figure 1) usually characterized by persistent undernutrition and micronutrient deficiencies that impact the population's overall health and development (4). Despite several strategies that have been proposed to provide target nutrients to infants and young children, optimal nutrition during the first 1,000 days since conception remains a significant public health challenge (Figure 2). The strategies include diversified diets, fortified complementary foods, fortified animal milk, micronutrient powders, and small quantities of lipid-based nutrient supplements (4).

During the first 1,000 days of life, eight key nutrients namely carotenoids (lutein and zeaxanthin), choline, folate, iodine, iron, omega-3 fatty acids, and vitamin D play essential roles. Other important nutrients for maternal, newborn, and toddler health include magnesium, vitamin A, B vitamins, and additional trace minerals. Iron fortification led to a significant increase in serum ferritin and hemoglobin levels in women of reproductive age and pregnant women. Folate fortification significantly reduced the incidence of congenital abnormalities like neural tube defects without increasing the incidence of twinning (5).

In 2020, approximately 149 million children under the age of five worldwide were impacted by stunting, and 49 million suffered from wasting (6, 7). The prevalence of maternal and child undernutrition in low-income and middle-income countries (LMICs) has remained unacceptably high (8). Stunting often begins in utero and increases, on average, for at least the first 2 years after birth (9). Evidence indicates that stunting becomes largely irreversible after the first 1,000 days of a child's life, perpetuating an intergenerational cycle of impaired growth and development (10). Folic acid and iodine are particularly critical for fetal neurodevelopment but are often lacking in the diets of pregnant women (11). India has made substantial strides in reducing child mortality and improving child survival (12). The Government of India has implemented various programs that target childhood illnesses, lower mortality rates, and promote early childhood development (13).

The latest National Family Health Survey (NFHS-5) (2019–21) (14) demonstrates some progress, with stunting reduced by 2.9%, wasting by 1.7%, and underweight prevalence by 3.7% compared to NFHS-4 (2015–16) (15). However, the prevalence of anemia remains high (Figure 3) (14), with over half of Indian women still affected, signaling an ongoing need for targeted nutritional interventions. Addressing this triple burden of malnutrition—including undernutrition, micronutrient deficiencies, and rising levels of obesity in children—requires a timely, comprehensive, and scalable approach to ensure adequate nutrition during the first 1,000 days. The quantity of food consumed by an infant is limited, and hence it is imperative to provide optimum nutrition in every meal. Home-based meals may not be adequate, and can leave gaps especially when the diet is predominantly vegetarian or if there is increased consumption of nutrients that adversely affect iron absorption (16, 17).

The initial 1,000 days cover the period from pregnancy through a child's second year, requiring an adequate supply of macro-and micronutrients for mothers and infants to promote proper fetal and early childhood development (9). Adequate caloric intake and nutrients such as iron, zinc, folate, iodine, and vitamin D are critical in preventing malnutrition-related complications such as low birth

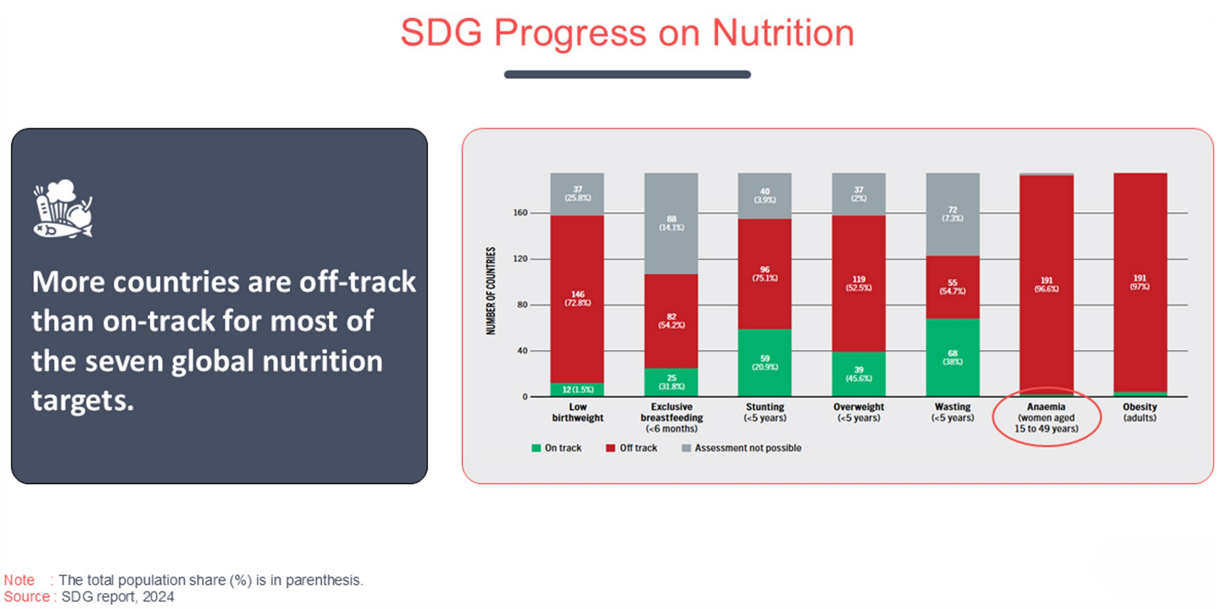

FIGURE 1
SDG progress on nutrition.

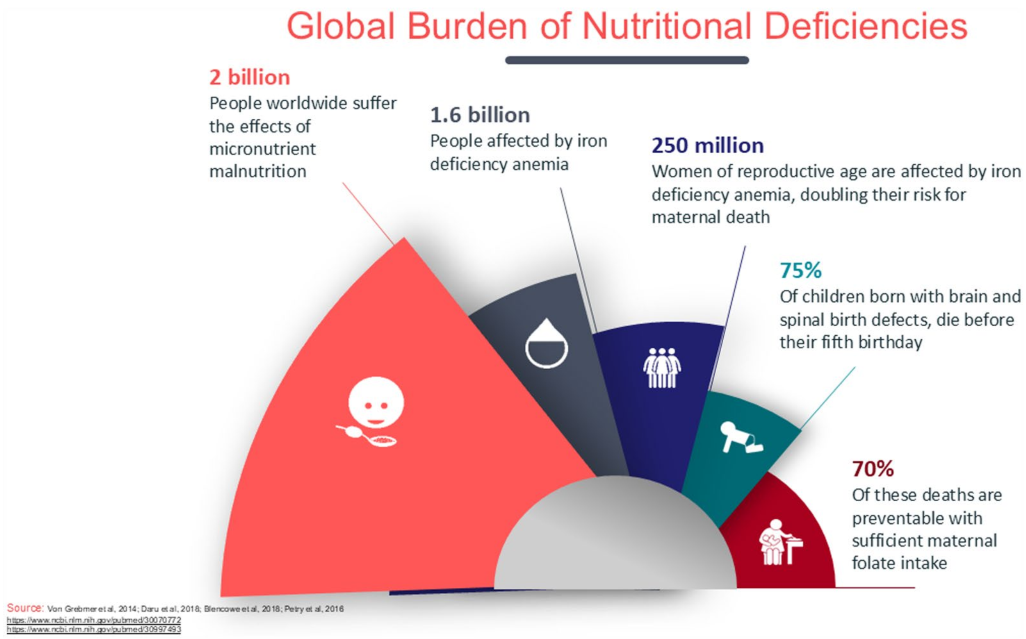

FIGURE 2
Global burden of nutritional deficiencies.

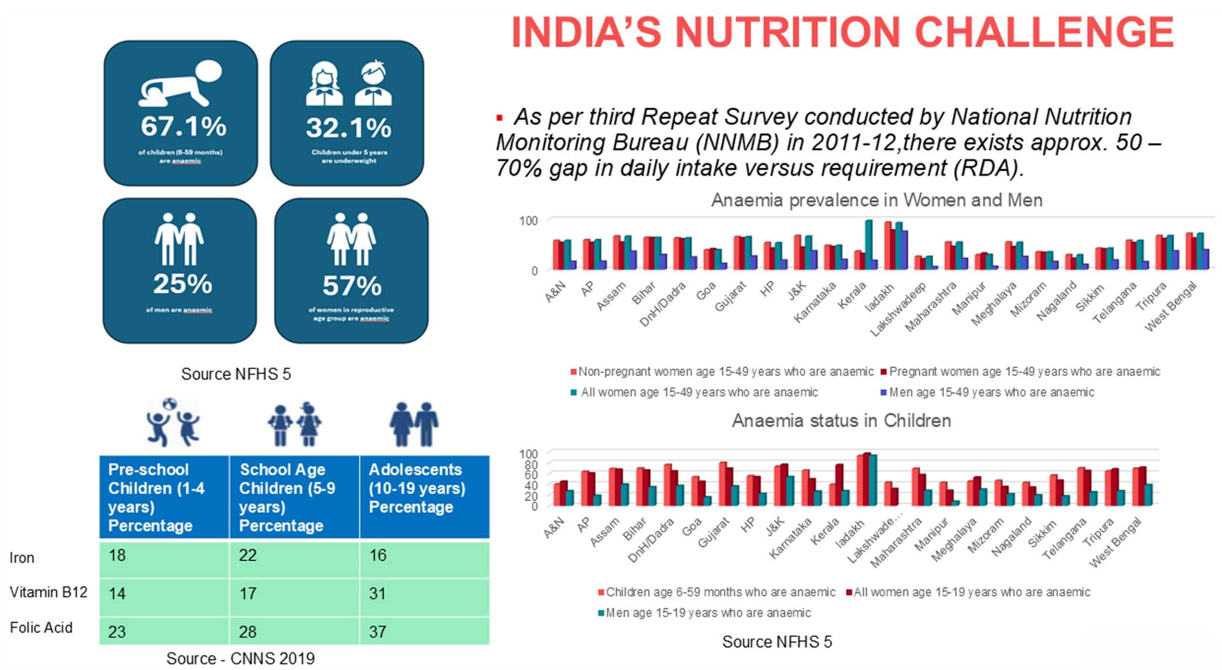

FIGURE 3
India's nutrition challenge.

weight, anemia, and impaired cognitive development (9). Nutritional supplementation during the first 1,000 days of life have shown improvements in birth and growth outcomes and newborn stunting (9). Compared to supplementation with iron alone or with iron and folic acid, multiple-micronutrient supplementation that includes iron and folic acid lowers the risk of small-for-gestational-age births, low birth weight, and stillbirth (18).

Multiple interventions contribute significantly to child development, including ensuring optimal maternal nutrition during pregnancy, iron and folic acid supplementation, early initiation of breastfeeding, and exclusive breastfeeding for the first 6 months of life (18). For small and sick newborns, access to donor human milk when needed and fortification of human milk as per clinical recommendations are crucial (19). When Mother's Own Milk (MOM) is unavailable or insufficient, donor human milk (DHM) is considered the optimal alternative, as recommended by the American Academy of Pediatrics, the European Society for Paediatric Gastroenterology, Hepatology and Nutrition, and the World Health Organization (20). Introducing nutritionally adequate and safe complementary (solid) foods at 6 months, alongside continued breastfeeding up to 2 years or beyond, further supports growth and development (18). Additionally, food fortification and addressing broader social determinants play essential roles in fostering child health (21, 22).

Fortifying staple foods with vital vitamins and minerals is an effective strategy for combating common nutritional deficiencies, ensuring that pregnant women and infants receive the essential nutrients needed for optimal development (18). This proactive approach significantly reduces the risk of malnutrition-related issues, supports healthy fetal growth, and promotes overall childhood development, ultimately leading to better health outcomes later in life.

In this review, we will explore interventions focused on achieving optimal nutrition during the crucial first 1,000 days of life, with a particular emphasis on food fortification.

2 Methodology

To explore the role of food fortification as a public health strategy to address nutritional challenges during the first 1,000 days of a child's life we used a structured methodology of focused literature search conducted across databases such as PubMed, Google Scholar, Scopus and organizational repositories, including WHO, UNICEF, and FAO. Keywords such as "food fortification," "maternal nutrition," "child nutrition," "nutritional challenges," "policy review," "breast feeding," "donor human milk" and "first 1,000 days" were used in various combinations to refine the search results. Studies related to both global and Indian fortification programs, policy notes, and opinion articles were included in addition to randomized controlled trials (RCTs), cohort studies, systematic reviews, case–control studies, and programmatic evaluations that addressed food fortification interventions and their impact on maternal and child health outcomes. Studies and guidelines related to human milk banks and programmatic experiences were also included to provide a comprehensive perspective. Studies that were not relevant to the target population group (mothers and children) or government programs were excluded along with studies focused on disease populations or conditions unrelated to the core topic of food fortification and maternal and child health.

The inclusion process also involved an initial screening of titles and abstracts to identify relevant sources, followed by a detailed review of full-text articles to extract information on strategies, implementation, outcomes, and challenges. Reference lists from key articles were cross-referenced to identify additional relevant materials. Expert consultations complemented the literature review, offering practical insights into the implementation, challenges, and policy implications of food fortification interventions. These consultations captured expert opinions of program implementers, public health professionals, and policymakers engaged in maternal and child health programs. The findings from the literature and expert insights were co-analyzed to identify gaps, highlight successful practices, and provide recommendations for strengthening food fortification policies and programs.

3 Results

3.1 Food fortification as a nutritional intervention

Food fortification involves the deliberate addition of essential vitamins and minerals to widely consumed foods to combat nutritional deficiencies (23). This intervention is both cost-effective and scalable (23), making it particularly relevant for public health improvement in low-resource settings where micronutrient deficiencies are prevalent (23). The practice of food fortification has a rich history, with early initiatives such as the iodization of salt in the 1920s aimed at reducing the incidence of goiter (23). The primary rationale behind fortification is to increase the intake of micronutrients in populations where dietary deficiencies are widespread (24–26), without necessitating significant alterations to individual food consumption patterns. Fortification is especially beneficial when applied to staple foods, as it guarantees that a large segment of the population receives the intended health benefits. A review of micronutrient fortification studies highlights notable improvements in nutrient levels and health indicators (5). Iron fortification, studied in 13 trials, increased hemoglobin concentration (Standardized Mean Difference SMD: 0.64, 95% Confidence Interval CI: 0.30–0.97), serum ferritin (SMD: 0.41, 95% CI: 0.23–0.60), and reduced anemia prevalence (Relative Risk RR: 0.68, 95% CI: 0.49–0.93), particularly benefiting iron-deficient populations (5). Zinc fortification (10 studies) improved serum zinc levels (SMD: 1.28, 95% CI: 1.06–1.51), while vitamin D fortification (13 RCTs) raised serum vitamin D (SMD: 1.23, 95% CI: 1.03–1.43) and decreased parathyroid hormone (SMD: −0.40, 95% CI: −0.78 to −0.02) (5). Vitamin A fortification improved serum retinol (SMD: 0.61, 95% CI: 0.34–0.89) and hemoglobin (SMD: 0.48, 95% CI: 0.17–0.80), while iodine fortification (16 studies) showed a significant rise in urinary iodine levels (SMD: 6.39, 95% CI: 4.85–7.93) and a reduction in hypothyroidism (RR: 1.42, 95% CI: 1.11–1.82). Dual iron and iodine fortification improved hemoglobin (SMD: 0.53, 95% CI: 0.16–0.89) and reduced anemia by 53% (RR: 0.47, 95% CI: 0.29–0.78). Multiple micronutrient (MMN) fortification increased hemoglobin (SMD: 0.75, 95% CI: 0.38–1.13) and reduced anemia (RR: 0.55, 95% CI: 0.42–0.72). Folate fortification, examined across 31 studies, notably reduced neural tube defects by 43% (RR: 0.57, 95% CI: 0.45–0.73) (5). Fortification is especially beneficial when applied to staple foods, as it guarantees that a large segment of the population receives the intended health benefits (27). The selection of natural fortificants in the fortification method depends upon various factors, like, (a) diverse micronutrients available in food, (b) quantity of micronutrients present in food, (c) types of micronutrient-rich foods, (d) influence of food vehicle on sensory characteristics and (e) consumer acceptability (27). Additionally, micronutrient fortification considers food preferences based on the dimensions of a culturally sustainable diet. Thus, we re-emphasize that investing in micronutrient fortification, which is also environmentally, culturally and economically sustainable, could play a significant role in preventing and controlling micronutrient deficiencies, improving diets (28).

A systematic review and meta-analysis encompassing 50 studies has addressed a crucial knowledge gap regarding the comprehensive impact of large-scale fortification programs in low-and middle-income countries (LMIC) (26). These programs, which focus on micronutrients such as iodine, folic acid, vitamin A, and iron, have resulted in significant health improvements in LMICs, as exemplified by:

- A 34% reduction in anemia attributable to improved iron stores, with findings indicating that all age groups benefited, particularly vulnerable populations like women of reproductive age and pregnant women (29).
- A 41% decrease in the odds of neural tube defects due to reduced folate deficiency among women of reproductive age (29).
- A notable reduction in vitamin A deficiency (VAD), positively impacting approximately 3 million children (aged 0–9 years) within a single year and significantly lowering their mortality risk (29).
- A World Health Organization (WHO) meta-analysis revealing that rice fortified with vitamins and minerals, including iron, enhances iron status by potentially reducing the risk of iron deficiency by 35% and increasing average hemoglobin concentration by nearly 2 g/L (30). Measurable improvements in the micronutrient and health status of women and children are possible with large scale food fortification (LSFF) (29).

Despite adequate food production, India's per capita nutrition intake ranks among the lowest globally. Although the per capita availability of various foods aligns with the Recommended Dietary Intake (RDI), the distribution of these foods is disproportionately unfavorable to vulnerable groups due to limited income and purchasing power. The ordinary Indian population predominantly relies on plant-based diets, which often lack essential nutrients. Micronutrient deficiency in the Indian diet poses a significant health challenge, impacting millions across the nation. The inadequate intake of essential vitamins and minerals, such as iron, zinc, vitamin A, and iodine, can lead to severe health issues, including anaemia, impaired cognitive development, and compromised immune function (31). Plant based diet might negatively impact iron absorption due to the presence of certain natural inhibitors (32). Plant foods contain compounds such as phytates (found in grains and legumes) and tannins (in tea and coffee), which can reduce the body's ability to absorb non-heme iron. Additionally, low bioavailability of iron from plant sources poses challenges, as the absorption rate for non-heme iron is significantly lower. Furthermore, uncalibrated vegetarian and vegan diets may also lack key nutrients like vitamin C, which helps enhance iron absorption, further compounding the issue (32, 33). Micronutrient fortification of staple foods adds essential vitamins and minerals without altering the taste, smell, or appearance of the food, ensuring no organoleptic changes. This makes it an effective and sustainable solution to prevent nutrient deficiencies across populations without requiring considerable behavioral changes. It is cost-effective and can significantly improve public health by proactively addressing micronutrient gaps. The fortification process typically entails the addition of minute quantities of nutrients—such as vitamin A, iron, and iodine—to staple foods like rice, wheat flour, oil, and milk (34). Therefore, increasing consumption of a variety of plant-based foods, in combination with food fortification and supplementation where needed, is recommended for children and adolescents to have sustainable and nutritionally adequate diets (35).

Globally, food fortification programs have been implemented with great success. For example, in the United States, the fortification of flour with folic acid has significantly reduced the incidence of neural tube defects (36). In South Africa, the fortification of maize and wheat with vitamins A and D has contributed to the reduction of micronutrient deficiencies (37, 38). These case studies highlight the effectiveness of fortification in improving public health outcomes (39). India has managed to scale the rice fortification program to feed nearly 800 million people (40). Since rice is a staple diet in many Indian states, fortifying rice is seen as one of the most affordable and sustainable ways to enhance health outcomes. Research has demonstrated that adding fortified rice to the diet is effective in improving hemoglobin levels, thereby reducing the prevalence of anemia and enhancing cognitive performance (41). However, despite its success, in places, large scale food fortification (LSFF) faces several challenges. Certain foods can be particularly challenging to fortify due to their unique characteristics, how they are processed, and the way people expect them to look, taste, and feel. For example, adding nutrients to beverages like soft drinks or juices can easily affect their taste or cause unwanted sediment, making them less appealing (42). Rice, which is a staple food in many parts of the world, is difficult to fortify consistently, especially in areas where small-scale milling is common. Dairy products, like milk, often face issues with sensory changes or nutrient stability, as added nutrients can interact with milk's natural components and reduce their effectiveness (42). Cereal-based foods, such as snacks or breakfast cereals, risk changes in texture or flavor when fortified, while condiments like soy sauce or fish sauce require careful attention to avoid altering their distinct and familiar tastes (42). Similarly, baked goods present a unique challenge because the high baking temperatures can break down heat-sensitive vitamins like thiamine (42).

3.2 Donor human Milk and fortification for vulnerable babies

Feeding premature, LBW, and small-for-gestational-age babies comes with additional challenges, such as prolonged separation of mothers and babies, delay in attachment to breast, low priority given to breastfeeding by physicians, and lack of skilled counselling and hands on support to mothers to breastfeed and express milk (54, 55). Moreover, a large number of babies do not receive mother's milk due to reasons, such as mother's illness, death, abandonment, delay in milk production, leaving them vulnerable, especially if they are born premature. Technological advances in human milk banking have revolutionized the way donor milk is collected, processed, stored, and distributed, ensuring higher safety and quality standards. Innovations such as automated pasteurization systems and real-time milk testing devices have significantly improved the efficiency and accuracy of pathogen elimination while preserving the essential nutrients and bioactive components of human milk (56).

As per a landscape study conducted by PATH and Lokmanya Tilak Municipal Medical College and General Hospital (LTMMC and GH), 30 to 50 percent of vulnerable babies admitted in the neonatal intensive care units (NICU) and 10 to 20 percent of term (healthy) babies in India do not have access to mother's own milk (MOM) to meet their short-or long-term needs (57). Alternatively, these babies are given formula milk or cow's milk. For such vulnerable infants, donor human milk is the next best option when a mother's own milk is unavailable, offering critical support in reducing the risk of infections, necrotizing enterocolitis, and other complications in these vulnerable infants. By ensuring access to safe, pasteurized human milk, milk banks play a crucial role in bridging nutritional gaps, promoting healthy development, and improving survival rates in this high-risk population, laying the foundation for a healthier start in life, especially newborns admitted in sick newborn care units (SNCU) or NICU.

Also to prevent extrauterine growth restriction (EUGR), which is linked to poor neurocognitive outcomes and specific nutrient deficiencies, nutrient fortification of human milk (HM) is recommended for very low birth weight (VLBW) infants (58). Current fortification methods include: 1. Standard fortification, and 2. Individualized fortification, which encompasses "Adjustable fortification" and "Targeted fortification" (59). Despite standard fortification, many very VLBW infants still experience suboptimal growth, highlighting the need for optimized human milk fortification. Adjustable fortification has been shown to enhance protein intake, support somatic and head growth, and appears to be a practical method for optimizing HM fortification. While targeted fortification has demonstrated feasibility and effectiveness in some trials, further improvements are needed. Additionally, enhancing the quality of human milk fortifiers (HMF) is crucial. Although HM-based fortifiers show promise, with some studies indicating benefits in morbidity and mortality for infants fed an exclusively human milk-based diet, concerns remain regarding their efficacy, safety, and ethical implications (19, 59).

As current evidence does not provide strong support for the use of multi-nutrient fortified breast milk in pre-term infants, more studies specially in LMICs are required for robust evidence generation (60) (Figure 6).

3.3 Navigating nutritional complexity in combined interventions

In low-resource settings, inadequate monitoring and evaluation mechanisms, along with limited awareness among consumers, can reduce the efficacy of fortification programs. The experience with fortification varies for different age groups and sub-groups in the population due to variations in baseline nutrient adequacy (or inadequacy), per capita consumption of different food vehicles and physiological needs (43). In India, the Food Safety and Standards Authority of India (FSSAI) followed a robust procedure to identify the optimum dosage of the fortificants that deliver only 30–50% of the Recommended Dietary Allowance (RDA). Considerations with respect to the RDA, and Tolerable Upper Limits as defined by Indian Council of Medical Research (ICMR) were also kept in mind. The analysis revealed that the current standards will only provide 30–50% of RDA given average per capita consumption levels, to fill the missing nutrient gap with no risk of overload (43).

As per global evidence interventions such as supplementation, consumption of fortified foods, and exclusive breastfeeding are safe and effective in improving nutrition outcomes among women and children (44, 45). The fortification of foods with essential vitamins and minerals is recognized as a critical priority within international development agendas (46). Correcting iron deficiency yields benefits in increased cognitive ability for children as well as greater endurance and work capacity for adults, with an estimated 8:1 cost–benefit ratio (47). These effective interventions not only combat malnutrition but also promote overall health, enhance cognitive development, and boost productivity, contributing to the nation's socioeconomic progress. Food fortification can significantly enhance the nutritional content of additional food provided to beneficiaries under India's Mission Poshan 2.0 (48), particularly benefiting children under 6 years old, pregnant women, and breastfeeding mothers.

4 Discussion

4.1 Importance of fortification for mother and child in the first 1,000 days

Fortification plays a pivotal role during the first 1,000 days, a critical period for ensuring the long-term health and development of both mother and child. Pregnant women have increased nutritional requirements, especially for iron and folic acid (49), and ensuring their access to fortified foods such as wheat flour and cooking oil can significantly reduce the risk of complications like anemia during pregnancy.

For infants, particularly those born prematurely or with low birth weight (LBW), breastmilk alone may not meet their nutritional needs. In such cases, breastmilk fortification with additional protein, fat, and minerals becomes necessary to support optimal growth (19). This highlights the importance of fortification efforts, which should be complemented by promoting dietary diversity. Ensuring access to a variety of nutrient-dense foods, including fruits, vegetables, legumes, and animal-source foods, is crucial to reducing malnutrition and supporting overall health.

4.2 Maternal nutrition and breast feeding

Maternal nutrition plays an essential role during pregnancy and lactation. Maternal malnutrition during pregnancy represents a pervasive global health concern (50). A well-nourished mother is more likely to give birth to a healthy child with fewer risks of complications such as pre-term birth or underweight infants.

In LMICs, more than 43% of children under the age of five are at risk of not reaching their full developmental potential due to the impacts of poverty and stunting (51). Proper prenatal nutrition not only supports immediate fetal health but also has long-term benefits, such as lowering the risk of chronic diseases and enhancing cognitive function and educational outcomes.

The early months of life are critical for establishing healthy growth patterns. Key practices include initiating breastfeeding within the first hour to provide colostrum, exclusively breastfeeding for the first 6 months to support immunity, and gradually introducing nutrient-dense complementary foods from six to 24 months (52). Responsive feeding, which involves recognizing and responding to hunger cues, fosters healthy eating habits. Interventions during this critical window can significantly improve developmental outcomes, especially in vulnerable populations, helping to mitigate stunting and other nutrition-related deficits (Figure 4).

As infants reach 6 months, their nutritional requirements outgrow what breastmilk alone can provide, necessitating the introduction of complementary foods. The four pillars of complementary feeding are timing, quality, quantity, and safety (Figure 5). However, poor-quality complementary feeding practices can lead to growth faltering, with children failing to meet developmental milestones. Ensuring nutrient-dense foods rich in iron, protein, and essential fats during this transition is critical to avoid stunting and other forms of undernutrition (53). The complementary feeding period is a sensitive time window that can influence growth, development, food preferences, and short-and long-term health outcomes.

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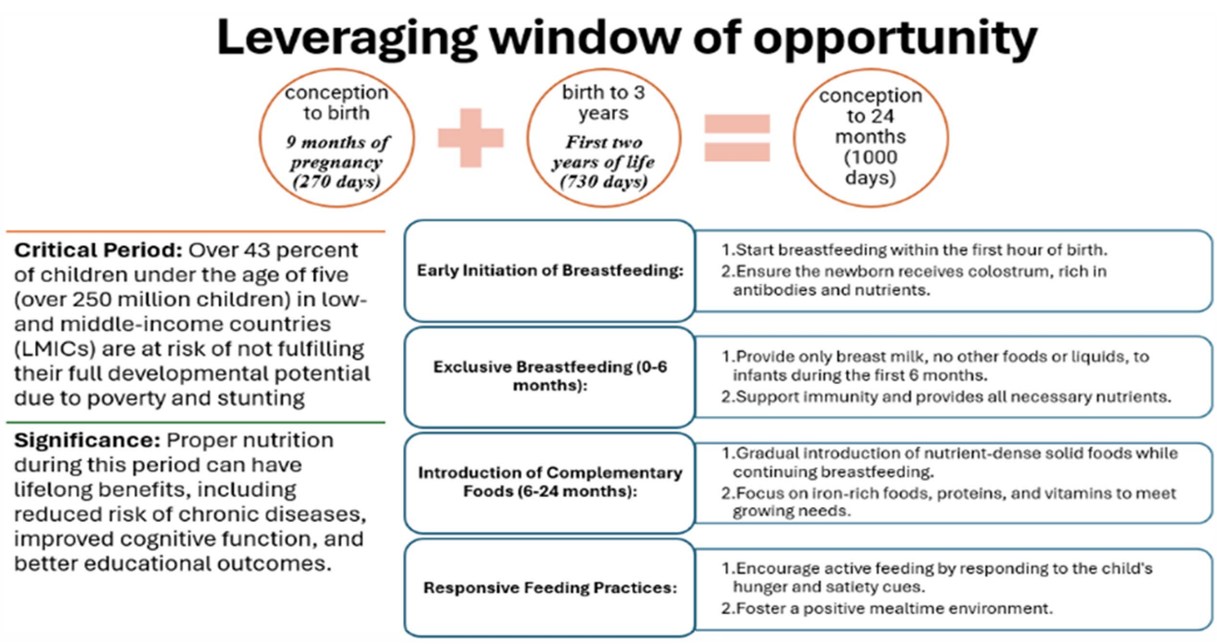

FIGURE 4
The first 1,000 days – a critical window of opportunity for child growth and development.

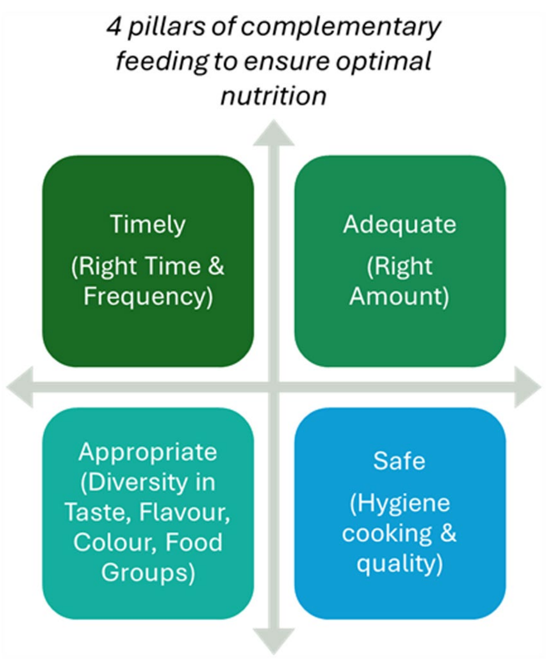

FIGURE 5
Four pillars of complementary feeding to ensure optimal nutrition.

4.4 Strengthening the ICDS framework and innovative approaches

The Anganwadi Services Scheme, Poshan 2.0 and Saksham Anganwadi formerly known as India's Integrated Child Development Services (ICDS), is a comprehensive program designed to combat malnutrition and promote child health through supplemental nutrition, health services, and early childhood education. Key nutritional interventions, such as staple food fortification and breastfeeding promotion, are critical for protecting the health of mothers and young children throughout this crucial developmental period.

ICDS provides essential support to millions of children and mothers, improving their access to nutrition and healthcare, thus contributing to child development outcomes in vulnerable populations. However, changes in ICDS utilization and underweight prevalence varied considerably across states, socioeconomic, and demographic characteristics (61).

A study found that ICDS coverage was higher among younger children and the poorest households in rural areas. Multilevel logistic regression results indicated a significant association between age and the outcome variable. Severely malnourished (SAM) children living in rural areas had significantly higher odds of being covered under ICDS services (Odds Ratio 1.57; Confidence Interval: 1.35, 1.82) than their urban counterparts (62).

Pregnant and lactating mothers who received ICDS services were significant determinants of SAM coverage under the program. However, there is no evidence that ICDS is more efficient in identifying and covering SAM children compared to non-SAM children.

The ICDS program plays a pivotal role in promoting food fortification, particularly by integrating fortified foods into the supplementary nutrition provided at anganwadi centers. With its vast reach across rural and urban areas, ICDS serves as a critical distribution platform for fortified foods, especially for pregnant women, lactating mothers, and young children, who are most vulnerable to nutrient deficiencies. Fortified rice, enriched with essential vitamins and minerals, provides a reliable source of nutrition for mothers and young children, supporting their dietary needs and reducing the risk of anaemia and other deficiencies. By incorporating

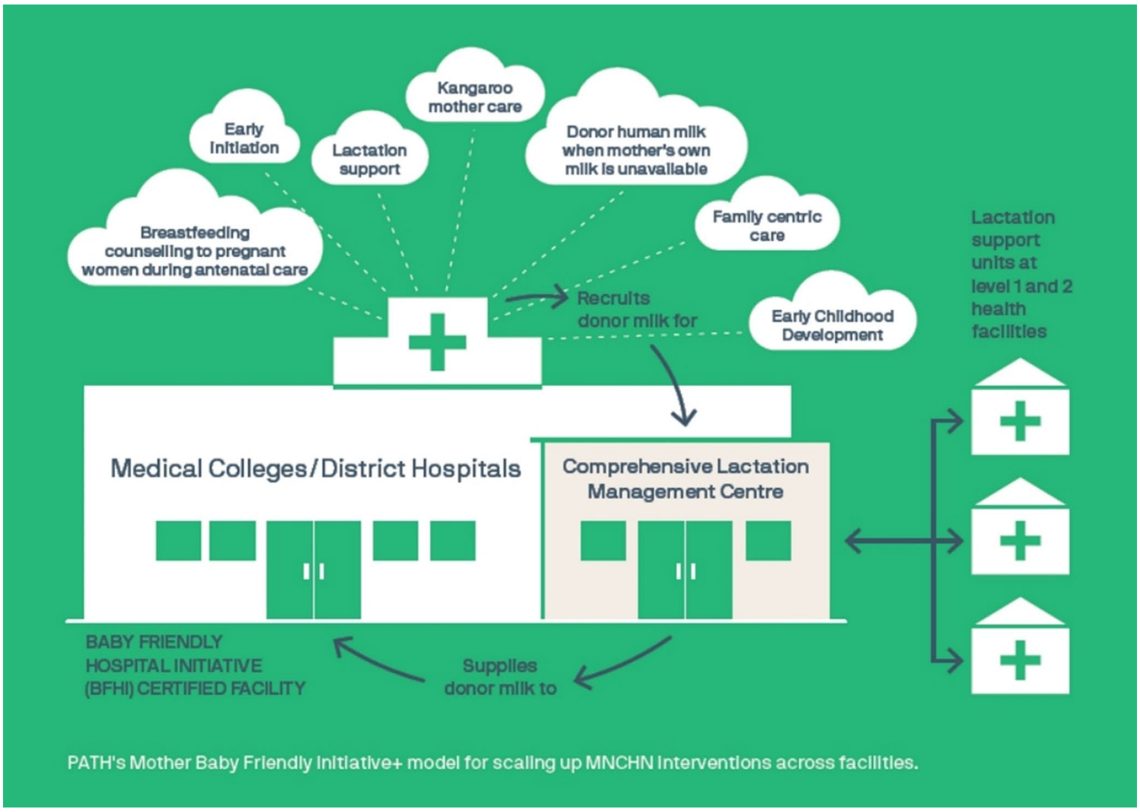

FIGURE 6
PATH's Mother Baby Friendly Initiative+ Model for scaling up Maternal, Newborn, Child Health and Nutrition (MNCHN) Interventions.

fortified rice into the ICDS framework, the program aims to address micronutrient deficiencies that can adversely affect health and development during this crucial window. This strategic intervention not only enhances the overall nutritional intake of beneficiaries but also aligns with the broader goals of the ICDS program to improve maternal and child health. By focusing on nutrition during the first 1,000 days, the ICDS initiative significantly contributes to long-term health outcomes and development, laying a strong foundation for the future of children in India.

4.5 Policy and implementation strategies

India has launched several nutrition initiatives (Figure 7) and launched fortification of staples such as rice, wheat flour, salt, milk and edible oil with key nutrients (40, 63). These initiatives are critical for addressing widespread micronutrient deficiencies across the population. Effective monitoring and evaluation are necessary to track the impact of fortification programs and ensure compliance with fortification standards. Digital tools and community-based monitoring can enhance the efficiency of these processes. Fortification efforts should be integrated with other public health programs, such as those addressing maternal and child health, water sanitation, and hygiene (WASH), to maximize impact. Coordinating these programs can lead to more comprehensive solutions for malnutrition.

Public-private partnerships (PPPs) can play a crucial role in scaling up fortification efforts. By leveraging private sector expertise and resources, the ICDS can improve the reach and sustainability of nutrition interventions. Childhood stunting incurs substantial economic losses for the private sector in LMICs, amounting to billions of dollars annually in foregone sales and reduced workforce earnings. The economic rationale for investing in childhood nutrition is supported by evidence from various nutrition interventions, which highlight the dual justification for such investments—both moral and financial—pertaining to the public and private sectors. Specifically, interventions aimed at reducing stunting demonstrate returns on investment that range from US$2 to US$81 for each dollar invested per year, representing an impressive return of 100 to 8,000% across different countries (64, 65). Collaboration with local academic and research institutions can provide the ICDS program with the expertise needed to design and implement innovative nutrition interventions. Such partnerships can also support capacity building at the local levels. Food fortification has become relevant in both developing and developed countries due to the changes in dietary patterns, particularly with increase in the consumption of processed foods (66). Figure 8 presents a detailed overview of the challenges and potential solutions associated with fortification.

4.6 Future directions and recommendations

Advances in fortification technologies, such as biofortified crops and improved techniques that do not alter the taste or

FIGURE 7
Nutrition initiatives launched by Government of India.

texture of food, offer great promise for addressing malnutrition. Scaling up fortification in low-resource settings, however, requires sustained political commitment, capacity building, and community engagement. The use of innovative financing mechanisms and support from international organizations will also be essential for the successful implementation of fortification programs.

Leveraging digital technology to monitor fortification efforts and track nutritional outcomes in real time can enhance the transparency and efficiency of programs like ICDS. Mobile apps and data analytics tools, for example, can play a critical role in improving program monitoring and evaluation.

Though food fortification is recognized as a highly effective approach for addressing dietary deficiencies in micronutrients like iodine, iron, and B vitamins, the success of fortification within ICDS and similar frameworks largely depends on strategic advocacy and behavior change interventions. These efforts should emphasize the importance of fortification to program beneficiaries, raising awareness around the specific nutritional needs of young children, pregnant women, and other vulnerable populations. Educational efforts should highlight the role of fortification in promoting health, covering its benefits, appropriate usage, and the practices required for different age groups.

To facilitate this awareness, comprehensive training and capacity building of Anganwadi Workers (AWWs) and other program functionaries is essential. These workers need resources, such as Information, Education, and Communication (IEC) materials and advocacy toolkits, tailored to fortification programs. Training modules should cover the nutritional importance of food fortification, detailed information on fortificants used, and specific guidelines on fortified supplementary nutrition. These resources should be accessible to both beneficiaries and program implementers, enhancing community knowledge and engagement.

Monitoring and regulatory mechanisms play a pivotal role in ensuring the quality and efficacy of fortified food distribution. Essential actions include mandatory spot checks of fortified supplementary foods, procedures for sample collection, and laboratory testing. Policymakers must also establish clear guidelines on the frequency and process for these checks. Providing spot-testing kits for qualitative assessment could be instrumental for field workers, enabling them to verify the presence of fortificants directly in communities and ensuring the integrity of the rice fortification program.

4.7 Recommendations for policy and practice

- Continued Nutritional Interventions – A sustained focus on foundational nutritional components, such as maternal nutrition, breastfeeding, and complementary feeding, remains crucial. Additionally, there is a growing recognition of the need for fortified food to address micronutrient deficiencies, alongside the continuous provision of supplementary nutrition. Such efforts are vital for ensuring both food and nutrition security. These interventions should prioritize vulnerable populations, particularly mothers and children, and be implemented consistently to address malnutrition and improve overall health outcomes. Ensuring an adequate balance in the number and mix of health workers is essential for the proper functioning of health system (67). Human resources must be carefully employed at all levels, from national to community, with a particular emphasis on guaranteeing the availability of competent health professionals, nutritionists, and program administrators. Furthermore, local community leaders and volunteers can help promote and implement these interventions. Budgets must be allocated to

FIGURE 8
Challenges and potential solutions associated with fortification.

cover not only the direct costs of nutrition services, but also administrative expenditures such as program administration, monitoring, and evaluation, to ensure the long-term viability of the projects. While allocating resources, policymakers should pay particular attention to influencing factors. The population covered in each region and the infrastructure available in each region were identified as key and important criteria in the resource allocation process. It is suggested that these factors be considered while allocating resources to different regions of the country (68). To monitor these interventions effectively, clear indicators should be established to measure progress and impact, such as the number of health workers trained, coverage rates of nutritional services, and improvements in nutritional outcomes among target populations. Regular evaluations should be conducted at national, regional, and community levels to assess the efficiency and effectiveness of resource utilization and service delivery.

- Enhanced Delivery Systems – The integration of public-private partnerships is essential for improving the delivery of nutritional services to beneficiaries, especially mothers and children. By leveraging the strengths of both sectors, these partnerships can enhance programmatic support and extend outreach to underserved communities. This model ensures that the delivery systems are not only efficient but also sustainable, providing long-term support to the populations most in need of nutritional interventions.
- Policy and Technological Innovations – There is an urgent need to align nutrition policies with comprehensive regulatory frameworks to address the multifaceted challenges of malnutrition. Technological innovations play a pivotal role in this process, with digital tools and monitoring systems offering opportunities for improved tracking and implementation. The establishment of human milk banks, for example, represents a significant advancement in maternal and child health, ensuring that newborns receive optimal nutrition. Digitalization further facilitates transparency and accountability, enabling policymakers and practitioners to track progress and respond to emerging needs more effectively. By creating tracking systems and real time data, sustainability and long term impact can be seen. Therefore, digital technologies and AI are promising tools for health promotion and disease prevention and management, but some issues still need to be addressed, mainly those connected with patient privacy. Thus, close collaboration between healthcare institutions and research is desirable in the future (69).
- Building Capacity of Local Institutes – Strengthening the local nutrition ecosystems requires a concerted effort to build the capacity and capability of local institutions. This entails a comprehensive approach, including the provision of tailored training and educational programs for health professionals, researchers, and policymakers. Collaborating with academic institutions can further enrich the local workforce by enhancing their knowledge and skills. In addition, technical assistance and mentorship from national and international experts can facilitate the development of context-specific solutions, which are crucial for effective program implementation. Infrastructure development is another key element, with the provision of research facilities, digital tools, and access to up-to-date resources enabling local institutions to improve data collection, foster

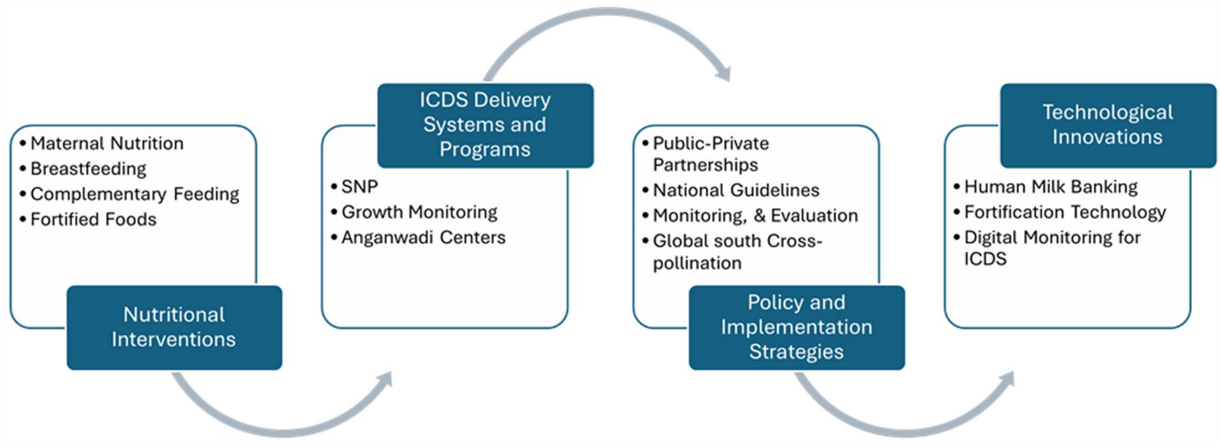

FIGURE 9
Overview of the article.

innovation, and contribute to evidence-based interventions. The sustainability of these efforts hinges on leadership training and policy advocacy, empowering local institutions to influence national nutrition policies. Moreover, building collaborative networks with non-governmental organizations (NGOs), international agencies, and the private sector will promote knowledge sharing and collective action, ultimately enhancing the capacity of local institutions to address malnutrition. A focus on sustainability is essential, ensuring that local institutions gradually assume leadership and management responsibilities, fostering long-term impact. With local support it is possible to create and sustain fieldwork for an extended period with meaningful outputs and impact. Central Sector Rice Fortification Scheme (40) demonstrates that it is possible to use healthcare professionals, students and volunteers with low-intensity training and a low-cost approach to produce action research with considerable impact and results in rapid, reliable and robust manner (70).

- Global South Cross-Pollination – Cross-pollination of ideas and best practices within the Global South is critical for advancing shared development goals, particularly in the areas of nutrition and food security. A key focus should be placed on the health of pregnant mothers and first 1,000 days of life, a crucial period for child's growth and development, during which nutritional interventions can have a profound and lasting impact. Regional collaboration is vital for facilitating the exchange of successful strategies to address maternal and child nutrition, with particular emphasis on combating anemia and micronutrient deficiencies through the scale-up of fortified rice and other nutrition programs. The creation of knowledge-sharing platforms, as well as exchange programs for health professionals, researchers, and policymakers, will enable countries in the Global South to learn from one another's experiences and adapt these strategies to local contexts. Establishing regional centers of excellence and organizing South–South learning events will further promote joint efforts to address shared nutritional challenges. Such initiatives will not only improve maternal and child health outcomes but also contribute to broader efforts to promote breastfeeding, human milk banking, and the expansion of fortified foods. By fostering partnerships and pooling resources, countries in the Global South can enhance their capacity to address malnutrition and food insecurity in a more effective and sustainable manner. The ongoing joint project between China and South Africa demonstrates the benefits of collaboration in developing robust remote sensing techniques for improved food security monitoring and decision making in the Global South (71).
- To address the critical health needs of LBW and preterm infants, establishing a national framework for human milk banking is essential. HMBs provide safe, pasteurized donor milk, offering life-saving benefits for infants who lack maternal milk due to medical complications. A policy for expanding HMBs should focus on integrating these banks into neonatal and public health facilities, particularly where LBW cases are high. Figure 9 provides a comprehensive summary of the article.

5 Conclusion

Addressing the nutritional needs of mothers and children during the first 1,000 days is key to improving long-term health outcomes and reducing malnutrition in India. Fortification programs, integrated with broader public health initiatives and supported by technological innovations, offer a promising solution for addressing micronutrient deficiencies. The success of these efforts, however, hinges on continued political commitment, effective public-private partnerships, and the engagement of local institutions. Strengthening the ICDS framework and promoting breastfeeding and human milk banking are critical steps toward ensuring that every child receives the nutrients they need for a healthy start in life.

Author contributions

RS: Writing – original draft, Writing – review and editing. JK: Writing – review and editing. MJ: Writing – review and editing. JS: Supervision, Writing – review and editing. SB: Writing – review and editing. AM: Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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Exploring factors that influence the knowledge and awareness of breastfeeding among Saudi mothers: a qualitative study

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Purpose: Breastfeeding provides short- and long-term benefits for mothers and babies. Despite these advantages, the prevalence of breastfeeding among Saudi mothers is low. We explored factors affecting the knowledge and awareness of breastfeeding among Saudi mothers in Riyadh.

Methods: This qualitative study included 17 mothers. The inclusion criteria were Saudi mothers aged 18–50 years, with at least one child, living in Riyadh. Semi-structured interviews of approximately 20–40 min were conducted online or in person between March and April 2024. Data were analyzed using the constant comparative method with NVivo 11. Ethical approval was obtained from an academic institutional review board prior to data collection.

Results: Two key themes emerged from the data. Theme 1 concerned factors facilitating knowledge and awareness of breastfeeding; subthemes included positive experience with breastfeeding, knowledge of breastfeeding, family support, and financial considerations. Theme 2 concerned factors limiting knowledge and awareness of breastfeeding; subthemes included negative experiences of breastfeeding, work situations, misconceptions, and mental health issues.

Conclusion: Despite the low prevalence of breastfeeding in Saudi Arabia, mothers were aware of its benefits. Physicians and midwives should provide ongoing education and support for mothers during ante- and post-natal periods to minimize misconceptions regarding breastfeeding and promote its use.

KEYWORDS

knowledge, awareness, breastfeeding, mothers, Saudi Arabia

Introduction

Breastfeeding confers considerable health benefits for infants and mothers (1). According to Bermejo-Haro et al. (2), breastfeeding provides essential nutrients, antibodies, and hormones necessary for infants' growth and the development of their immune systems. Other benefits for infants include minimizing the risk of infection and allergies and enhancing their cognitive development (3, 4). For mothers, breastfeeding is crucial for reducing the risk of breast and ovarian cancers, as well as enhancing postpartum recovery and helping to lose post-pregnancy weight (5). In addition, breastfeeding plays a vital role in fostering a maternal–child bond (Joseph, 2020). Although breastfeeding has these positive attributes, the prevalence of breastfeeding in Saudi Arabia remains low. According to Alyousefi (6), just 28% of mothers practiced exclusive breastfeeding for the first six months. This compares with the global prevalence of 48% in 2023 (7).

Within Saudi Arabia, breastfeeding practices are closely associated with cultural, economic, and social dimensions (6, 8). From a historical perspective, the culture of Saudi Arabia emphasizes the need for breastfeeding (9). Traditional practices and religious teachings also emphasize the importance of breastfeeding until the age of two years (10). However, Saudi Arabia has recently experienced a change in the dynamics associated with breastfeeding (11). Prelacteal feeding, which includes the introduction of formula milk and the delayed initiation of breastfeeding, has had a considerable impact on mothers and influenced their decision not to breastfeed their children (12, 13).

The World Health Organization (WHO) has emphasized the need for breastfeeding for at least the first six months of an infant's life; however, this trend has not been followed within Saudi Arabia in recent years (9). Several factors are crucial to understanding the low breastfeeding rate in Saudi Arabia. These include unhelpful hospital policies, such as not enforcing policies that encourage breastfeeding; healthcare staff who need additional training to effectively support women to breastfeed; the lack of ongoing social support; and the tensions associated with breastfeeding, for example when mothers have to juggle multiple roles, for example combining looking after their baby with a return to work or study (14, 15). A better understanding of these factors would assist in the development of interventions and policies to increase breastfeeding rates. Although some research has investigated breastfeeding in Saudi Arabia, many factors still need to be addressed (6). Against this backdrop, our current study aimed to address these gaps in our knowledge, in particular with regard to factors affecting breastfeeding knowledge and awareness in Saudi Arabia. This study examined facilitators of and barriers to breastfeeding in Riyadh, Saudi Arabia.

Materials and methods

We used a qualitative design to comprehensively explore which factors influenced the knowledge and awareness of breastfeeding among Saudi mothers. This approach provided rich and detailed data on the phenomena and allowed us to better understand current breastfeeding trends (16). We approached Saudi mothers in two ways: outreach in malls and in mosques. These avenues were chosen to ensure a broad representation of mothers living in Riyadh, who were accessible through these community-based networks. The outreach included providing detailed information about the study, such as its goals, eligibility criteria, and instructions on how to participate. Out of 83 mothers initially approached, 52 expressed a willingness to participate. The researchers then began conducting interviews until theoretical saturation was reached. Saturation occurred after 17 transcripts had been analyzed, as no new major themes or information emerged, suggesting that the data was sufficiently rich and diverse for the study's objectives. Thus, the final sample size was 17 Saudi mothers. Although the sample size was small, it allowed for a detailed exploration of the participants' views and opinions, as it reached theoretical saturation— the point at which gathering more data *"reveals no new properties nor yields any further theoretical insights*" (17, p. 345). The study inclusion criteria were any Saudi mothers aged between 18 and 50 years who had at least one child and lived in Riyadh. Any participant who did not meet these criteria was excluded. A purposive sampling technique was used. Two experts in research and midwifery reviewed the research instrument and formulated the following interview questions based on a pilot study:

- What is your source of knowledge and awareness about breastfeeding?
- How did this source contribute to your experience of breastfeeding?
- What factors affected your choice of how to feed your baby?
- What other factors affected your knowledge and experience regarding breastfeeding?

Data were collected through semi-structured, audio-recorded interviews that were conducted privately, online or in person, between April and May 2024. The interviews continued until the collected data were repeated and theoretical saturation was reached. Prior to the interviews, the participants signed informed consent forms. Each interview took between 20 and 40 min, and the participants were asked for their opinions about breastfeeding.

The recorded data were transcribed and analyzed using NVivo 11 software. We used the constant comparative method, applied iteratively as new data were collected. This approach allows researchers to compare transcripts for emerging themes and subthemes as they closely examine the data from each transcript and among transcripts to identify common themes, subthemes, ideas, and meanings that emerge repeatedly and form patterns (18).

Ethical approval for this study was obtained from an academic institution in March 2024. Participants were informed about the details of the study, of their right to withdraw from it at any time and for any reason, and of the recording and anonymous coding of the interviews, after which their written consent to participate in this study and for the recording of the interviews was obtained. Data confidentiality and privacy were maintained at all times.

Results

The factors we investigated were the facilitators of knowledge and awareness of breastfeeding and the barriers to knowledge and awareness of breastfeeding. Table 1 shows the themes and subthemes that emerged from the interviews.

TABLE 1 Themes and subthemes of breastfeeding that emerged from the interviews.

Theme	Subtheme
Facilitators of knowledge and awareness of breastfeeding	Positive experience with breastfeeding Knowledge of breastfeeding Family support Financial considerations
Barriers to knowledge and awareness of breastfeeding	Negative experience of breastfeeding Working situation Misconceptions Mental health issues

Theme 1: facilitators of knowledge and awareness of breastfeeding

This theme comprised four subthemes: positive experience with breastfeeding, knowledge of breastfeeding, family support, and financial considerations.

Subtheme 1: positive experience with breastfeeding

Fifteen participants emphasized this subtheme as the main factor in their decision to breastfeed and to continue breastfeeding. They considered breastfeeding enhanced their children's health, their health, and their mother–child bonding. Participant 9 (P9) spoke of the "positive result I observed for me and my baby".

P16 agreed that breastfeeding had benefited her first child's health: "My decision was due to the results of breastfeeding my child, which provided him with vitamins and immune strength, and the positive effects of increased bonding and emotion between me and my child." Moreover, P1 attributed her decision to continue breastfeeding to the "feeling of connection between me and the child. I loved that feeling".

P14 compared the difference between her previous baby, whom she had formula-fed, and her 10-month-old baby, whom she was breastfeeding exclusively. She "noticed a very big difference between them in terms of perceptions and attitudes to surroundings, overall well-being, and health." P3 and P17, who each had one child, agreed that breastfeeding had a positive effect on the mother in terms of rapid postpartum weight loss and an improved "psychological state" (P17). P7 suggested breastfeeding was "the best gift you can give to your child".

Subtheme 2: knowledge of breastfeeding

In this subtheme, P2, P3, P4, P5, P6, P7, P8, and P17, who were of different ages and levels of education and experience, highlighted the importance of acquiring knowledge about correct breastfeeding positions and latching on. For example, P3 noted, "This knowledge contributed to strengthening my confidence in breastfeeding" (P3). Family members, as well as members of the community and healthcare professionals, were critical sources of knowledge. P17 stated, "My doctor provided practical consultations on the correct position for me and my child during breastfeeding and explained to me […] the benefit of breastfeeding my child." P4 and P7 received knowledge about breastfeeding during their antenatal care and immediately after childbirth. According to P4, this "influenced my decision" (P4) to breastfeed her most recent child.

P2, P3, P4, P5, P6, P7, and P8 said that they received knowledge about the importance of breastfeeding and its benefits for mothers and their neonates directly from physicians and midwives. P5 and P8 gained their knowledge from various social media platforms. Midwives and physicians use these platforms to teach breastfeeding techniques and the benefits of breastfeeding, and P5 and P8 felt accessing these platforms was convenient. P5 emphasized the importance of easily accessible online resources in "educating and empowering me" and helping to promote and facilitate breastfeeding practices.

The participants' responses demonstrated that gaining knowledge in person or via social media from healthcare professionals' statements about breastfeeding played a crucial role in determining what mothers thought about matters such as "reducing my weight" and "improving child immunity" (P6). Participants found this knowledge useful and offered other reasons for supporting breastfeeding, including "minimizing the risk of breast cancer" (P3).

The knowledge they acquired led some Saudi mothers to adopt and continue with successful breastfeeding practices; as P3 stated, these were "positive reasons that encouraged me to breastfeed".

Subtheme 3: family support

In this subtheme, two participants highlighted the major influence and positive impact of family support on breastfeeding decisions. P6, who had five children, received considerable support, especially with her first child (the first grandchild in the family). P17, who had only one child, mentioned that her "sister was her backbone during the beginning of the breastfeeding journey."

Subtheme 4: financial considerations

Financial income can impact the decision to breastfeed because breastfeeding is the cheapest method of feeding. However, only one participant (P10), who had just finished her bachelor's degree and had one child, mentioned being able to save more money "to take care of myself and my child" as a factor in her decision to breastfeed.

Theme 2: barriers to knowledge and awareness of breastfeeding

Theme 2 comprised four subthemes: negative breastfeeding experiences, working situations, misconceptions, and mental health issues.

Subtheme 1: negative experience of breastfeeding

Eight participants (P1, P2, P4, P5, P7, P8, P12, and P17) mentioned insufficient education and awareness of breastfeeding, especially during their early pregnancies (i.e., with their older children). P8 spoke of "a lack of awareness of the health benefits and how to breastfeed my first two babies." P1 insisted that education should be ongoing, starting before pregnancy and continuing until after birth. She stated that for exposure to breastfeeding education, "one time is not enough."

P12 emphasized her negative experience with breastfeeding, raising the issue of starting breastfeeding late due to insufficient awareness and knowledge: "Unfortunately, my baby rejected breastfeeding because, at birth, I started bottle feeding. Nobody encouraged me to breastfeed, so the infant became accustomed to it and relied on it, and it was difficult to breastfeed later."

Subtheme 2: working situation

P2, P3, P15, and P17 mentioned that work was one of the factors influencing their failure to continue breastfeeding exclusively. P17 said that "returning to work two months after giving birth made me consider formula feeding along with breastfeeding, especially as there is no time or place to pump my breast milk," whereas P3 stated that "living in crowded Riyadh makes it difficult to breastfeed. It took me 2 h [of] transportation to leave home and get back to my baby, and I came home very exhausted from the traffic and workload."

Subtheme 3: misconceptions

Three participants, P1, P5, and P15, stated that various misconceptions they had heard from their mothers or other family members affected their decisions to breastfeed exclusively or also to use formula. P1 shared her personal experience of her first pregnancy, highlighting the impact of misconceptions acquired from her mother, namely, "do not conceal the child's face while breastfeeding" and "do not hold your breast while breastfeeding." In addition, P15 shared that she thought her "breast shape would change and look very ugly."

Subtheme 4: mental health issues

Mental health was one of the factors that affected a mother's decision to introduce formula feeding. Two participants mentioned how postpartum depression influenced their decision not to breastfeed and introduce formula milk. P1 highlighted the psychological changes that mothers undergo, which can contribute to feelings of "depression, fear, and mixed emotions related to motherhood and the responsibilities it entails." Another participant (P15) said, "I just got married and became pregnant. I could not accept all the changes in my body, and I felt I could not care for my child or breastfeed, it was too much."

Discussion

This study investigated various factors that acted as facilitators and barriers to breastfeeding in Saudi Arabia. Here, we also compare our findings with relevant reports from the literature, although we did not conduct a full literature review. In defining the facilitators of breastfeeding, researchers refer to factors that encourage breastfeeding among mothers (19). In contrast, barriers to breastfeeding are factors that hinder and discourage mothers from breastfeeding their infants (20). Personal breastfeeding experiences can impact a mother's decision to continue or discontinue breastfeeding (21). If these experiences were positive, then the result is a strong commitment to breastfeeding, but if they were negative, this could have a corresponding negative impact on their attitude toward breastfeeding (22). In our study, the participants outlined a sense of positivity when it came to shaping their attitudes toward breastfeeding through their acquisition of positive firsthand experiences. As shown by our findings, mothers who experienced considerable health benefits and strengthened mother–child bonds through breastfeeding were likely to continue breastfeeding their children. These findings align with those of Alyousefi (6), who discussed the benefits of breastfeeding and how it can promote maternal and infant health. Personal experiences are, therefore, crucial in validating a mother's practices and serve as powerful motivators for them to continue breastfeeding their children.

The participants in our study highlighted that breastfeeding was crucial for enhancing immunity and reducing the risk of infections in their infants. Our results also indicated that mothers felt breastfeeding was important to them in terms of a more rapid return to their pre-pregnancy weight and a reduced risk of certain cancers. Respondents further stated that breastfeeding was essential for strengthening the bond between mothers and children, particularly by creating a deeper emotional connection. These findings are supported by the results of Bailey (23), who emphasized the importance of skin-to-skin contact during breastfeeding in creating appropriate emotional and psychological development. Overall, the participants in our study reported positive firsthand experiences regarding breastfeeding, including feeling a sense of accomplishment and satisfaction.

Some mothers may require additional knowledge regarding breastfeeding and its associated benefits (24). Knowledge of breastfeeding is generally promoted through education provided by healthcare professionals who can assist in shaping the confidence of mothers and their abilities to breastfeed successfully (25). Our findings highlighted the role of mothers' knowledge of breastfeeding and how it influenced their breastfeeding decisions. As indicated by the respondents, education about correct breastfeeding techniques, including current advice regarding positions and effective latching, was vital for boosting their confidence in breastfeeding and increasing the likelihood of successful breastfeeding. Obtaining accurate information involves acquiring knowledge from healthcare providers about correct breastfeeding techniques, which subsequently promotes breastfeeding ability. In addition, education about correct breastfeeding latch techniques is important when it comes to effective milk transfer, as well as other issues, such as nipple pain and an inadequate supply of milk. Proper latching is vital to ensure the baby receives adequate nutrition; it also reduces the risk of complications, thus reinforcing the mother's commitment to breastfeeding. Our study highlighted the importance of education targeted at effectively enhancing breastfeeding. Such education programs should involve hands-on demonstrations, as well as the use of visual aids and useful tips. Our findings also showed the importance of education during the antenatal period, with continuous follow-up and support after delivery and beyond, to enhance successful breastfeeding among mothers.

Another important factor is the support that breastfeeding mothers acquire from their families (25). If the support is appropriate, there will be positive reinforcement toward breastfeeding, encouraging its continuation. Our study's findings highlighted the vital role of the family in supporting breastfeeding among mothers in Saudi Arabia. Encouragement, support, and assistance from family members are important elements in creating a positive, fostering environment for breastfeeding. These findings align with those reported by Aledreesi and Omar (26), who indicated that family support could have a significant positive influence on breastfeeding.

Family support exists in various forms, including emotional reassurance, practical assistance, and positive reinforcement. Practical assistance the family provides to the mother is also crucial, including assisting mothers with household tasks, offering to care for children, and providing helpful physical support during breastfeeding. This form of assistance plays a key role in enhancing a mother's focus on breastfeeding and simultaneously reducing the stress of managing multiple responsibilities. Our findings indicated that family members, specifically sisters and mothers, actively supported breastfeeding, sharing responsibilities with and encouraging mothers to breastfeed. These findings agree with those of Theodorah and Mc'Deline (27), who found that family members provided invaluable support for mothers, helping them to continue breastfeeding exclusively. This type of support is essential for creating a nurturing atmosphere that reinforces a mother's decisions regarding breastfeeding.

Another factor to consider is finance because breastfeeding is considered a cost-effective method compared with formula feeding. This is especially the case for lower-income households for whom cost savings are crucial (28–30). Our results indicated that financial factors are critical in shaping Saudi mothers' views on breastfeeding. A participant in our study indicated the economic benefits of breastfeeding, with respondents arguing that breastfeeding was more cost-effective than formula feeding. This is because of the cost of purchasing formula, bottles, and other feeding supplies. As indicated by Murad (31), these financial benefits are particularly important for families on a tight budget, for whom the reduced cost associated with breastfeeding can result in greater financial stability. Economic pressures can, therefore, influence breastfeeding, especially for families with limited financial resources who must manage their household expenses effectively.

However, certain factors act as barriers to mothers' breastfeeding, including negative experiences of breastfeeding, which can result in mothers discontinuing breastfeeding (32, 33). Our findings showed that negative experiences related to breastfeeding included a lack of timely education and support, which can influence the duration of breastfeeding. The perceptions of individuals with adverse breastfeeding outcomes could be attributed to a lack of timely education. This included insufficient knowledge regarding the initiation of early breastfeeding following delivery, as well as a lack of knowledge about appropriate breastfeeding techniques, latching on, and positioning, all of which can result in difficulties when encouraging new mothers to breastfeed.

These results align with those reported by Aledreesi and Omar (26), who indicated that inadequate education can lead to a variety of issues, such as nipple pain and poor milk production, which can result in the early cessation of breastfeeding. In addition, physical discomfort, inadequate support, and perceived feeding problems result in many individuals discontinuing breastfeeding. Thus, there is a need for timely education and support to help mothers deal with the negative experiences that may be associated with breastfeeding. Education during the prenatal phase, such as providing basic practical guidance and overcoming common challenges, is crucial in preparing mothers for the realities of breastfeeding (34–36). The healthcare system should implement appropriate practices, specifically by employing well-trained midwives who can enhance prenatal education, as well as provide immediate postnatal support, accessible lactation consultations, and education for family members who may be involved in breastfeeding (37).

A mother's work situation is another factor that can pose a challenge to exclusive breastfeeding. Our study revealed the importance of balancing work responsibilities and breastfeeding. In addition, the work environment can impact most working mothers' abilities to continue breastfeeding exclusively. These challenges show the importance of managing work and breastfeeding and the need to provide supportive workplace policies and flexible work arrangements. These findings align with the existing literature, showing that workplace constraints are the main factors that result in a reduced duration of breastfeeding. For example, a study involving hospital employees in Thailand found that 76% of mothers continued breastfeeding before returning to work, but 24% had to stop breastfeeding within three months of returning to work (38). It is important for breastfeeding mothers that workplaces have supportive policies and flexibility regarding hours, with appropriate facilities for breastfeeding and expressing milk (39, 40).

The participants in our study reported various obstacles to continuing breastfeeding exclusively when they returned to work. The main challenges highlighted included limited time for breastfeeding, a lack of appropriate facilities for expressing milk and breastfeeding, and pressures from the workplace that discouraged mothers from breastfeeding. These findings are consistent with other reports in the literature, including studies of working mothers' experiences of exclusive breastfeeding in Ghana and Kenya (41, 42). The difficulty of balancing work with breastfeeding is exacerbated by various demands placed on mothers due mainly to the work environment, where long hours and inflexible schedules can hinder the ability of a mother to maintain exclusive breastfeeding (43). To solve some of these issues, it is important to create flexible working hours or remote working arrangements that allow work and breastfeeding to be managed effectively (44). Additionally, there is a need for lactation breaks; ensuring that mothers have sufficient time and privacy to express milk during work hours can support continued breastfeeding (45, 46). This can be achieved by providing comfortable and private breastfeeding and pumping rooms within the workplace. Regarding the workplace, employers and policymakers can play key roles in developing an environment that is supportive when it comes to breastfeeding. This includes creating policies to address the challenges of balancing the time spent working with the time needed for breastfeeding (47).

An additional barrier to breastfeeding is the existence of misconceptions and misinformation regarding breastfeeding, which can negatively impact a mother's decision to breastfeed (8, 15, 48). In our study, the participants articulated that these misconceptions created anxiety and reluctance to breastfeed, leading to the introduction of formula or the early cessation of breastfeeding. Furthermore, participants stated that misinformation regarding breastfeeding undermined their confidence and willingness to continue breastfeeding, resulting in them needing more motivation to overcome common obstacles to breastfeeding. This misinformation originated from opinionated family members, mainly the older generation, who had outdated information, consistent with findings reported elsewhere. For example, a study in Ghana noted that the older generation had misconceptions about breastfeeding and that information about breastfeeding should be provided to grandmothers in addition to mothers (49). Furthermore, the marketing materials for formula sometimes reinforce misconceptions that common infant behavior, such as crying, is a sign of feeding problems that can be ameliorated using formula (40). To address these misconceptions, comprehensive education programs and public health campaigns aimed at breastfeeding mothers and their family members will be necessary. Our findings highlight the need for support programs that involve the entire family in breastfeeding and encouraging mothers. In addition, it is necessary to integrate family support into healthcare practices, which includes recognizing the role of the family unit in breastfeeding (34).

Another factor that can affect the decision to breastfeed is a mother's mental health issues. This includes a variety of conditions, including postpartum depression, which can impact a mother's ability to initiate or maintain breastfeeding (50). The participants in our study highlighted the negative effects that poor mental health had on breastfeeding and breastfeeding practices, including anxiety, depression, and stress. Furthermore, they considered that these mental health issues could result in decreased motivation, a sense of inadequacy, and difficulties when it came to managing the demands of breastfeeding. High levels of anxiety and depression can result in mothers finding it challenging to maintain the emotional and physical stamina needed during breastfeeding. As reported by Al-Nassir (11), various symptoms, including low energy, the feeling of being overwhelmed, and impaired concentration, can hinder the abilities of mothers to establish and sustain breastfeeding. It is important to note that breastfeeding can help prevent depressive symptoms in mothers (50). To address mental health issues, mothers should be screened and assessed, and easy access must be provided to mental health services, supportive counseling and therapy, peer support groups, and breastfeeding support networks. Integrating mental health support into maternal care will improve breastfeeding and maternal health. Therefore, there is a need to create a comprehensive support system for dealing with the psychological and physical aspects of maternal care. This should include developing maternal and infant care services that support better breastfeeding practices and overall well-being.

Overall, our findings suggest that, despite Saudi Arabia's relatively low breastfeeding rates, Saudi mothers generally have a positive attitude toward breastfeeding. However, considerable efforts are needed to encourage and promote family, healthcare, and workplace support if Saudi mothers and their infants are to fully take advantage of the benefits breastfeeding offers.

Limitations

Our study had some limitations. First, our participants resided in a limited geographical area, namely Riyadh, the capital of Saudi Arabia. Future research should include participants from other areas of Saudi Arabia, including rural areas, whose inhabitants may have different perspectives. Second, as this was an exploratory study to investigate factors affecting breastfeeding knowledge and awareness among Saudi mothers in Riyadh, we did not collect detailed data regarding rates of exclusive breastfeeding versus mixed feeding, or information about the initiation of breastfeeding and the introduction of formula. However, such information would be valuable and could form the basis of future research. Third, we did not specifically assess the socioeconomic status of the participants or whether they employed a nanny. While this information would undoubtedly be useful, our focus was on Saudi women of reproductive age, who may or may not have social support. This is particularly relevant for women who have relocated to Riyadh to seek better opportunities for themselves or their husbands. Again, future studies could investigate these dimensions to obtain a more comprehensive understanding. Finally, there are the researchers' position as an "insider" in Saudi Arabian society. This could have led participants to feel mistrust toward the researchers and their motivations for conducting the study (51). Furthermore, because of the researchers' and the participants' shared backgrounds, potential assumptions regarding the similarity of some of their shared experiences could have led to researcher bias (52). Overall, however, we viewed having insider status to be an advantage, enabling access to the community, a good response rate, and the development of trust-based relationships between the researchers and the participants.

Conclusion

To improve breastfeeding practices and thus improve maternal and infant health outcomes in Saudi Arabia, it is necessary to address breastfeeding facilitators and barriers. Future research should explore interventions tailored to address these factors, including investigating the effectiveness of various strategies for sustainable breastfeeding practices. We propose several recommendations to promote breastfeeding among Saudi mothers and address the barriers. Mothers' support systems should be enhanced by promoting emotional and physical support from family members, healthcare providers, and the wider community. Improving knowledge and education through comprehensive breastfeeding education programs and information and awareness campaigns for expectant mothers and the wider community would help to dispel misconceptions and promote breastfeeding. Addressing cultural and social influences by challenging barriers to breastfeeding and promoting positive cultural beliefs that support breastfeeding is also important. Workplace and university support for breastfeeding mothers is also essential. Breastfeeding-friendly policies and facilities in the workplace and in universities can enable successful breastfeeding practices. Access to professional support, such as skilled lactation consultants and breastfeeding support services, should be available to all mothers. Furthermore, hospital policies should adhere to UNICEF and WHO's Baby-Friendly Hospital Initiative to provide a supportive environment for breastfeeding (53), while increasing the number of certified lactation consultants through appropriate training can enhance support for breastfeeding in the community and healthcare institutions.

By implementing these recommendations, Saudi Arabia can create a supportive and enabling environment for breastfeeding mothers that will contribute to increasing breastfeeding rates and improving mothers' and infants' overall health and well-being.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the studies involving humans were approved by the protocol for this study was approved by the Princess Nourah Bint Abdulrahman University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AAA: Conceptualization, Formal analysis, Funding acquisition, Methodology, Software, Supervision, Validation, Writing – original draft. NA: Conceptualization, Methodology, Supervision, Writing – review & editing. LA: Validation, Writing – review & editing. RS: Validation, Writing – review & editing. MTA: Investigation, Resources, Writing – review & editing. LA-M: Investigation, Resources, Writing – review & editing. MAnA: Data curation, Writing – review & editing. RA: Writing – review & editing. ATA: Writing – review & editing. FHA: Visualization, Writing – review & editing. MAwA: Visualization, Writing – review & editing. FMA: Project administration, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Effects of folic acid supplementation before conception on innate immunity and anti-HBs levels of offspring born to HBsAg-positive mothers

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Introduction: Folic acid has been associated with fetal development, especially in fetal immunity. Therefore, limited evidence regarding the effects of different folic acid supplementation of hepatitis B surface antigen (HBsAg) positive mothers in innate immunity in offspring. Herein, this study aimed to explore the association between folic acid supplementation and the innate immunity of neonates and the immunological efficacy of hepatitis B vaccine (HepB), which may provide insights that could inform pre-pregnancy health management in HBsAg-positive mothers.

Materials and methods: It is an ambispective cohort study with 293 pairs of HBsAg-positive mothers-offspring in Taiyuan, Shanxi Province, China. Mothers were classified into three groups according to the time of starting folic acid supplementation, non-supplementation group, pre-pregnancy group and post-pregnancy supplementation group. Immunological indexes such as immune cells proportion and innate immune mediators in cord blood and anti-HBs in infants were measured. Differences in immunological indexes were analyzed by One-Way ANOVA test. Univariate and multivariate analyses were performed for factors associated with abnormal immunological indexes and potential confounders were adjusted.

Results: The preconception folic acid group showed a significantly higher expression levels of STING ($P = 0.005$) and pNF-κB ($P = 0.010$) in cord blood along with higher anti-HBs titres ($P = 0.006$), when compared to both non-supplementation group and post-pregnancy supplementation group. Higher anti-HBs levels indicate a stronger immune response to HepB and may enhance protection against HBV infection during early life. Infants in the high pNF-κB expression group exhibited a significantly elevated seropositive rate of HepB compared to those in the low pNF-κB expression group ($P = 0.037$). There were no mediation effects and no moderation effects in this study, potentially due to the direct influence of folic acid supplementation on immune responses or the limited sample size.

Discussion: In conclusion, our findings demonstrate that preconception folic acid supplementation may enhance HepB vaccine responsiveness in infants of HBsAg-positive mothers. Meanwhile, high pNF-κB expression in cord blood can increase seropositive rates in infants. This discovery has significant public health implications, as it may provide a simple and accessible intervention to improve vaccination outcomes and reduce HBV transmission in endemic regions.

KEYWORDS

anti-HBs, cohort study, folic acid, HBsAg-positive mothers, innate immunity

1 Introduction

Pregnancy, even before the onset of pregnancy, as a primary stage of life development for 10 months, has a crucial impact on infants development. Folic acid is an essential water-soluble vitamin that plays an essential role in cell growth and division and the maintenance of new cells. It is reported that folic acid contribute to immune function, immune response and immune-mediated diseases (1). In experimental animals, folic acid deficiency resulted in poor dendritic cell and spleen cell responses (cytokine production) and altered T cell phenotypes, and impairs antibody production (2), Folic acid supplements have been reported to increase some immune biomarkers, including those associated with anti-viral defense, and to decrease infections and immune-related proteins (3).

Hepatitis B virus (HBV) infection affects 300 million people globally (4), with mother-to-child transmission (MTCT) accounts for over one-third of chronic cases (5). High maternal HBsAg level may increase the risk of immunoprophylaxis failure in infants (6), underscoring the unique immune challenges in this population. While maternal folic acid supplementation can improve the persistence of protective antibodies (7), whether and how maternal folic acid supplementation affect HBsAg-positive mothers infants immune system remains unclear.

The umbilical cord serves as a critical connection between the fetus and mother. Umbilical cord blood, which is representative of neonatal blood, contains a rich source of immune cells and have many biological functions, such as anti-inflammation, and immune regulation (8). The proportion of immune cells in umbilical cord blood can reflect the immune status of infants to a certain extent.

Innate immunity is first line of host of defense, which can prevent infection and attack the invading pathogens (9). Innate immunity can distinguish structural components from microbial pathogens by a variety of proteins present in the host cells such as the pattern recognition receptors (PRRs). PRRs include TLRs, NOD-like receptors (NLRs), C-type lectin receptors (CLRs), and RIG-I-like receptors (RLRs) (10). Several molecules include the myeloid differentiation primary-response protein 88 (MyD88), TIR domain-containing adaptor-including interferon-β(TRIF) have been described participate in the process of TLRs binds to its ligand. Moreover, these adaptors mediate the activation of transcription factors such as the nuclear factor-κB (NF-κB) and the interferon regulatory factor (IRF) and induce the expression of inflammatory and anti-inflammatory cytokine and chemokine genes in turn (9, 11). Stimulator of interferon genes (STING) signaling pathway can produce protective immune responses against pathogens with a variety of DNA structures. When abnormal DNA including exogenous DNA produced by viruses and bacteria, such as HBV, is present in the cytoplasm, cGAS can recognize exogenous DNA and combine to synthesize cyclic GMP-AMP (cGAMP) and activate downstream STING. When it is activated, STING can recruit interferon regulatory factor 3 (IRF3) to phosphorylate to synthesize interferon. Moreover, NF-κB dimer can be activated by STING to produce inflammatory cytokines (12). Mitochondrial antiviral signaling protein (MAVS) functions as a platform for antiviral innate immune signal transduction (13). Upon viral infection, MAVS bind to cytosolic RNA sensor RIG-I and subsequently activates downstream NF-κB and IRF3/7-related signal pathways (14, 15). Innate immune mediators play a critical role in neonatal immunity. However, the influence of maternal folic acid supplementation on infants innate immune mediators has been neglected.

Hepatitis B (HepB) vaccination is the most effective way to prevent HBV infection and good responses to the HepB is a sign of good immune status. The production of hepatitis B surface antibody (anti-HBs) is the result of a combination of innate and adaptive immunity. HepB vaccine response is a continuation of neonatal immunization. It is reported that the recipients' response to the HepB may be influenced by their T-cell immunity (16). Moreover, low expression of neonatal innate immune mediators STING and pIRF3 and low percentage of plasma cells were risk factors of non/hypo-response to HepB in infants (17).

While folic acid supplementation is known to influence immune development, its specific effects in HBsAg-positive mothers and on infants innate immunity remains poorly understood. This study addresses a gap by investigating how preconception folic acid supplementation modulates both innate immunity and anti-HBs levels in offspring of HBsAg-positive mothers—a population at high risk of chronic HBV infection. Our findings may also provide actionable insights for optimizing prenatal guidelines in HBsAg-positive mothers.

2 Materials and methods

2.1 Study subjects

This ambidirection cohort study integrated prospective and retrospective data from November 2019 to January 2023. This study was approved by the Ethics Committee of Shanxi Medical

University (No. 2018LL323, 9 March 2018). All participants provided signed informed consent before enrollment. From November 2019 to June 2022. A total of 293 HBsAg-positive mothers and their neonates were enrolled at the Department of Obstetrics and Gynecology of the Taiyuan Third People's Hospital, China. Baseline demographic and biological specimens were collected at delivery. Infants were followed up at 7–9 months age and their peripheral blood samples were collected to assess indicators of HBV infection status and evaluate the immune response to HepB.

The specific inclusion criteria are as follows: (1) The mother was HBsAg-positive; (2) The newborns was a single live birth without birth defects. The exclusion criteria are as follows: (1) mother infected with hepatitis C virus, HIV or other virus; (2) twins or multiple births; (3) neonates or infants were HBsAg-positive. The study was approved by the Ethics Committee of Shanxi Medical University. All participants provided written informed consent.

2.2 Demographic and obstetric data collection and sample collection

The demographic and obstetric data of mothers (including age, education level, gestational week and HBV infection status) and neonates (including sex, birth weight, birth length, and Apgar score) were collected by questionnaires survey and medical record review. The stage, frequency and dose of folic acid supplementation during 1 year prior to conception were also collected. Follow-up was conducted for infants for 1–3 months after the full vaccination of HepB. The follow-up data including HepB vaccination and feeding pattern were collected by in-person questionnaires and certificates of vaccination.

Before delivery, 5 ml of venous blood of each woman was collected and centrifuged at 1,000 rpm/min for 5 min, then the serum was obtained and stored in the refrigerator at −80°C for later use. Venous blood was collected from each neonate within 12 h before immunoprophylaxis and from every infant aged 7–9 months. 3 ml neonatal and infant blood was collected and placed in an anticoagulant tube. The plasma was obtained after centrifuge and stored in −80°C.

2.3 Anti-HBs measurement

Serum anti-HBs was detected by chemiluminescence microparticle immunoassay (CMIA). All samples were processed and determined strictly according to the manufacturer's instructions.

2.4 Flow cytometry

The key proteins of innate immune signaling pathway molecules in neonatal cord blood were detected by flow cytometry. For endoprotein staining, the cells need to be fixed by fixation buffer. After 20 min remove fixation buffer, cells were permeabilized by perm buffer. After 5 min remove perm buffer, the cell suspensions were incubated for 15 min at 4°C with Recombinant anti-MyD88 antibody (Abcam, ab133739) and after wash three times the cells were incubated for 15 min at 4°C with Goat Anti-Rabbit IgG H&L (Alexa Fluor® 488) (Abcam, ab150077), Alexa Fluor 647 Mouse Anti-Human STING antibody (BD bioscience, 564836), MAVS (D5A9E) Rabbit mAb (PE Conjugate) (Cell Signaling Technology, 18930), PE Mouse Anti-Human TRIF (BD bioscience, 566354), Human/Mouse RelA/NF-kB p65 APC-conjugated Antibody (R&D, IC5078A), PE Mouse anti-NF-κB p65(BD bioscience, 558423), Alexa Fluor® 647 Mouse Anti-Human IRF-3 (BD bioscience, 566347), Phospho-IRF-3 (Ser396) (D6O1M) Rabbit mAb (PE Conjugate) (Cell Signaling Technology, 83611). Samples were washed and analyzed by FACS (Beckman Cytoflex).

For dendritic cell staining, the cell suspensions were incubated for 15min at 4°C with Human Hematopoietic Lineage Antibody Cocktail, FITC (eBioscience, 22-7778-72), HLA-DR-PerCP-Cy5.5 (BD bioscience, 339205), CD11c-PE (555392) and CD123-APC (eBioscience, 17-1239-42). For T cell staining, the cell suspensions were incubated for 15 min at 4°C with CD3-FITC (BD bioscience, 557832), CD4-PE (BD bioscience, 555346) and CD8-APC (BD bioscience, 566852). For B cell staining, the cell suspensions were incubated for 15 min at 4°C with CD3-APC-CyTM7 (BD bioscience, 557832), CD19-PerCP-Cy5.5 (BD bioscience, 561295), CD38-APC (BD bioscience, 555462), CD45-FITC (BD bioscience, 555482), and CD138-PE (BD bioscience, 550805).

2.5 Statistical analysis

The database was built by using Epidata 3.1 software and data were double entered by two trained data entry staff. Statistical analysis were implemented with SAS 9.4 and SPSS 18.0 software. Continuous variables were expressed as mean ± standard deviation (SD), proportions or geometric mean concentrations (GMCs) with 95% CI as appropriate. Categorical variables were expressed in frequency (%). Statistical methods included Chi-square test, Fisher's exact test, One-Way ANOVA test, with $P < 0.05$ considered statistically significant. Linear regression model, analysis of variance, mediation effect and moderation effect analysis were used to evaluate the effect of folic acid supplementation on non/hypo-response to HepB and innate immune mediators in infants and the relationship between various factors.

3 Results

3.1 Baseline data of pregnant HBsAg-positive mothers and neonates

A total of 332 mother-neonate pairs and 253 mother-infant pairs were recruited in this cohort study. One HBsAg-positive infant was excluded. All infants received standardized HepB immunoprophylaxis, including three-dose recombinant HepB (administered within 12 h after birth and at 1 and 6 months) combined with hepatitis B immunoglobulin (HBIG) within 12 h after birth. The rate of loss to follow-up was 23.80% (79/332). The key demographic, clinical characteristics did not differ between the infants retained in the study and the loss to follow-ups. According to the time of starting folic acid supplementation, the pregnant woman was divided into non-supplementation group, pre-pregnancy supplementation group and post-pregnancy supplementation group (Supplementary Table 1). Folic acid supplementation included folic acid supplementation alone, iron folic acid supplementation and multivitamin supplementation with folic acid. The follow-up rate did not differ among three groups. Critical demographic parameters remained balanced among the three groups, thereby strengthening the comparability framework.

The demographics and obstetrics characteristics were compared in Table 1. None of the 253 neonates born with any malformations. Notably, the post-pregnancy supplementation group demonstrated superior socioeconomic status, with significantly higher monthly household income compared to both non-supplementation and pre-pregnancy supplementation group ($P = 0.025$). The pre-pregnancy supplementation group showed a prolonged gestational duration relative to other groups ($P = 0.009$).

3.2 The association between maternal folic acid supplementation and innate immunity of neonates

Folic acid supplementation timing did not influence neonatal immune cell proportions. As shown in Table 2, the proportion of immune cells remained stable in neonates among the pre-pregnancy supplementation group, the post-pregnancy supplementation group, and the non-supplementation group.

Folic acid supplementation timing significantly affected STING and pNF-κB expression levels in cord blood. Table 3 shows the expression level of STING ($P = 0.005$) and pNF-κB ($P = 0.010$) in cord blood were significantly different among three folic acid supplementation groups. *Post hoc* analyses confirmed that the pre-pregnancy supplementation group had significantly higher levels of STING and pNF-κB level compared to non-supplementation group and post-pregnancy supplementation group.

3.3 The effects of STING and pNF-κB expression level in cord blood on the anti-HBs level of infants

Neonatal innate immune mediators STING and pNF-κB expression levels varied significantly among folic acid supplementation groups. As shown in Table 3, significantly differences in STING ($P = 0.005$) and pNF-κB ($P = 0.010$) expression levels were found across the three folic acid supplementation groups. This finding promoted further investigation into whether these differences play a role in infant antibody production.

High pNF-κB expression in cord blood was associated with improved seropositive rates for anti-HBs in infants. In this study, all infants received three doses of HepB vaccination. Anti-HBs levels were measured 1–3 months after full vaccination of HepB by CMIA. The effect of different STING and pNF-κB expression level in neonates cord blood on the anti-HBs level of 7–9 months old infants were compared in Table 4. Infants were stratified into high and low expression groups based on the median expression level of STING and pNF-κB in cord blood. The seropositive rate (anti-HBs >10 mIU/ml) in the high pNF-κB expression group was significantly higher than in the low pNF-κB expression group ($P = 0.036$). However, no significant differences in anti-HBs levels was observed between high and low STING expression groups (Table 4). Strong seropositive rates (anti-HBs >100 mIU/ml) were also analyzed, but no significant differences were found between groups.

3.4 The impact of maternal preconception folic acid supplementation on anti-HBs in infants born to HBsAg-positive mothers

Preconception folic acid supplementation was associated with significantly higher anti-HBs levels in infants. The GMCs of anti-HBs differed significantly among the non-supplementation group, the preconception supplementation group and the post-pregnancy supplementation group ($P = 0.006$). Specifically, infants in the preconception supplementation group had significantly higher anti-HBs levels compared to the other two groups, while no significant diferences were observed between the non-supplementation group and post-pregnancy supplementation group (Table 5).

Preconception folic acid supplementation independently predicted higher anti-HBs levels in infants. A linear regression model was used to assess the effects of preconception folic acid supplementation on infants anti-HBs levels. The definition of the variables was displayed in Supplementary Table 2. After adjustment of potential confounders, preconception folic acid supplementation was significantly associated with higher anti-HBs levels in infants, as evidenced by an adjusted β-value of 2063.55 ($P = 0.001$, 95%*CI*: 774.358–3,174.135). No significant associations were found in other variables ($P > 0.05$) (Table 6).

3.5 Effects of folic acid supplementation before pregnancy on anti-HBs level of infants by pNF-κB expression in cord blood

Cord blood pNF-κB expression did not mediate the association between maternal preconception folic acid supplementation and infant anti-HBs levels. A mediation model was performed to explore the potential role of cord blood pNF-κB expression in the observed association between maternal preconception folic acid supplementation and higher anti-HBs levels in infants. After adjusting for the same adjusted factors as above linear regression model, no significant association was found between neonates pNF-κB expression and infant anti-HBs levels ($P > 0.05$) (Supplementary Table 3, Supplementary Figure 1). This indicated that neonatal pNF-κB expression did not act as mediators in this relationship.

No moderation effects were observed between maternal folic acid supplementation, neonatal pNF-κB expression,

TABLE 1 The demographics and obstetrics characteristics of HBsAg-positive mothers and their offspring.

Characteristic	Non-supplementation group ($n = 20$)	Pre-pregnancy supplementation group ($n = 70$)	Post-pregnancy supplementation group ($n = 163$)	*P*
HBsAg positive mothers				
Age (year)	28.83 ± 3.80	30.77 ± 3.66	30.46 ± 4.37	0.353
Education status *n*(%)				
High school and below	9 (45.00%)	25 (35.71%)	70 (42.94%)	0.626
Technical school/secondary school	5 (25.00%)	29 (41.43%)	54 (33.13%)	
College and above	6 (30.00%)	16 (22.86%)	39 (23.93%)	
Monthly household income *n*(%)				
Less than 5,000 RMB	2 (10.00%)	13 (18.57%)	41 (25.15%)	0.025*
5000–10,000 RMB	2 (10.00%)	35 (50.00%)	77 (47.24%)	
More than 10,000 RMB	1 (5.00%)	17 (24.29%)	19 (11.66%)	
Refuse to answer	15 (75.00%)	5 (7.14%)	26 (15.95%)	
Type of medical insurance *n*(%)				
New rural cooperative	0 (0.00%)	6 (9.23%)	20 (12.27%)	0.923
Medical insurance for urban workers or residents	8 (61.54%)	36 (55.38%)	87 (53.37%)	
Self-pay	4 (30.77%)	15 (23.08%)	36 (22.09%)	
Other types	1 (5.39%)	8 (12.31%)	20 (12.27%)	
HBV DNA (IU/ml) *n*(%)				
$<2 \times 10^5$	16 (80.00%)	61 (87.14%)	139 (85.28%)	0.726
$\geq 2 \times 10^5$	4 (20.00%)	9 (12.86%)	24 (14.72%)	
HBeAg *n*(%)				
–	7 (35.00%)	28 (40.00%)	68 (41.72%)	0.838
+	13 (65.00%)	42 (60.00%)	95 (58.28%)	
Antiviral drug use *n*(%)				
Yes	15 (75.00%)	48 (68.57%)	103 (63.19%)	0.478
No	5 (25.00%)	22 (31.43%)	60 (36.81%)	
Gestational weeks				
Mean ± SD	39.05 ± 0.94	39.24 ± 1.04	38.80 ± 1.03	0.009*
Delivery mode *n*(%)				
Vaginal delivery	32 (69.57%)	41 (61.19%)	80 (57.14%)	0.324
Cesarean delivery	14 (30.43%)	26 (38.81%)	60 (42.86%)	
Neonates				
Sex n(%)				
Female	10 (50.00)	41 (58.57)	89 (54.60)	0.755
Male	10 (50.00)	29 (41.43)	74 (45.40)	
Apgar score	10.00 ± 0.00	9.99 ± 0.08	9.99 ± 0.03	0.515
Body weight (g)	3339.75 ± 483.20	3407.21 ± 442.26	3284.20 ± 386.50	0.111
Body length (cm)	50.05 ± 3.38	49.73 ± 2.25	49.73 ± 1.59	0.785

One-way analysis of variance and Chi-square and Fisher's exact test were used to compare the differences among three groups. *In the table indicate statistical significance ($p < 0.05$).

and infant anti-HBs levels. A moderation effects model was also performed to assess potential interactions. There were no moderation effect between "maternal folic acid supplementation" and "neonatal pNF-κB expression" or "infants anti-HBs level" and "neonatal pNF-κB expression" ($P > 0.05$) (Supplementary Table 4).

TABLE 2 The effects of different folic acid supplementation on immune cells proportion of cord blood (%).

Immune cells proportion	Non-supplementation group (n = 20)	Pre-pregnancy supplementation group (n = 70)	Post-pregnancy supplementation group (n = 163)	P
DCs	1.13 ± 0.88	1.75 ± 2.43	2.40 ± 4.34	0.705
mDCs	0.75 ± 0.86	0.64 ± 0.93	1.52 ± 3.53	0.856
pDCs	0.47 ± 0.35	0.62 ± 1.05	0.51 ± 0.55	0.398
T cells	31.93 ± 19.25	22.13 ± 15.56	28.20 ± 18.03	0.627
$CD8^+$ T cells	5.46 ± 4.50	4.94 ± 3.96	6.05 ± 4.41	0.297
$CD4^+$ T cells	15.21 ± 11.20	12.29 ± 9.47	16.95 ± 11.05	0.092
B cells	8.55 ± 5.89	5.37 ± 3.59	7.95 ± 4.85	0.713
Plasma cells	0.83 ± 2.74	0.18 ± 0.25	0.59 ± 2.35	0.490

One-way analysis of variance were used to compare the differences of immune cells proportion among three groups.

TABLE 3 The effects of different folic acid supplementation on the expression levels of innate immune mediators in cord blood (%).

Innate immune mediators	Non-supplementation group (n = 20)	Pre-pregnancy supplementation group (n = 70)	Post-pregnancy supplementation group (n = 163)	P
MAVS	78.73 ± 24.20	85.23 ± 18.91	85.31 ± 20.34	0.387
TRIF	90.81 ± 13.38	95.96 ± 7.03	95.63 ± 10.66	0.113
MyD88	75.93 ± 23.33	83.20 ± 22.32	81.42 ± 22.65	0.448
STING	36.53 ± 37.95	66.70 ± 34.31	62.45 ± 36.86	0.005*
NF-κB	78.70 ± 16.15	78.59 ± 24.10	78.51 ± 26.65	0.999
pNF-κB	31.00 ± 22.70	50.87 ± 28.08	49.45 ± 26.46	0.010*
IRF3	98.83 ± 3.03	97.24 ± 12.48	97.21 ± 13.88	0.868
pIRF3	21.99 ± 23.58	30.36 ± 27.60	23.14 ± 23.18	0.121

One-way analysis of variance were used to compare the differences of innate immune molecular expression levels among three groups. *In the table indicate statistical significance ($p < 0.05$).

TABLE 4 The effects of STING and pNF-κB expression in cord blood on anti-HBs level of infants born to HBsAg-positive mothers.

Different level of innate immune mediators	Anti-HBs level in 7–9 months old infants (%)					Seropositive rate (%)	P	Strong seropositive rate (%)	P	GMC (mIU/ml) (95% CI)	P
	Total	<10	10–	100–	1,000–						
STING											
High	127 (50.20)	5 (45.45)	7 (46.67)	49 (52.69)	66 (49.25)	122 (96.06)	0.748	115 (90.55)	0.663	2,892.92 (2,153.98–3,632.09)	0.836
Low	126 (49.80)	6 (54.55)	8 (53.33)	44 (47.31)	68 (50.75)	120 (95.24)		112 (88.89)		2,780.77 (2,006.42–3,555.12)	
pNF-κB											
High	127 (50.20)	3 (27.27)	5 (33.33)	44 (47.31)	75 (55.97)	124 (97.64)	0.120	119 (93.70)	0.036*	3,153.40 (2,394.98–3,911.82)	0.240
Low	126 (49.80)	8 (72.73)	10 (66.67)	49 (52.69)	59 (44.03)	118 (93.65)		108 (85.71)		2,518.28 (1,767.26–3,269.20)	

1. Chi-square test and Fisher's exact test were used to compare the differences of seropositive rate and strong seropositive rate between high and low expression groups.
2. One-way analysis of variance was used to compare the GMCs of anti-HBs between high and low expression groups.
3. *In the table indicate statistical significance ($p < 0.05$).

4 Discussion

As an important water-soluble vitamin, folic acid is closely related to cell proliferation and differentiation and plays important role in fetus development. WHO recommendations indicate that women should take a folic acid supplement during 8 weeks before and 8 weeks after conception (18). Therefore, it is still unknown whether and how maternal folic acid supplementation before

TABLE 5 The effects of folic acid supplementation on anti-HBs level of infants born to HBsAg-positive mothers.

Folic acid supplementation subgroup	Anti-HBs level in 7–9 months old infants (%)					Seropositive rate (%)	*P*	Strong seropositive rate (%)	*P*	GMC (mIU/ml) (95% *CI*)	*P*
	Total	<10	10–	100–	1,000–						
Non-supplementation group	20	0 (0.00)	1 (5.00)	11 (55.00)	8 (40.00)	20 (100.00)	0.529	19 (95.00)	0.472	1,554.30 (888.42–2,220.13)	0.006*
Pre-pregnancy supplementation group	70	2 (2.86)	3 (4.29)	19 (27.14)	46 (65.71)	68 (97.14)		65 (92.86)		4,178.30 (2,851.52–5,505.23)	
Post-pregnancy supplementation group	163	9 (5.52)	11 (6.75)	63 (38.65)	80 (49.08)	154 (94.48)		143 (87.73)		2,418.43 (1,838.00–2,998.91)	

1. Chi-square test and Fisher's exact test were used to compare the differences of seropositive rate and strong seropositive rate between high and low expression groups.
2. One-way analysis of variance was used to compare the GMCs of anti-HBs between high and low expression groups.
3. *In the table indicate statistical significance ($p < 0.05$).

TABLE 6 The impact of preconception folic acid supplementation on anti-HBs level of infants born to HBsAg-positive mothers.

variable	β-value	SE	95% *CI*		Adjusted β-value	*t*	*P*
			Lower	Upper			
Preconception folic acid supplementation	2,063.550	609.112	774.358	3,174.135	0.203	3.241	0.001*
Maternal HBV DNA	0.000	0.000	0.000	0.000	−0.100	−0.817	0.415
Maternal HBeAg	0.054	0.041	−0.027	0.134	0.161	1.318	0.189
Maternal antiviral drug use	470.928	572.735	−657.301	1,599.158	0.050	0.822	0.412
Maternal education status	332.547	345.865	−348.772	1,013.866	0.061	0.961	0.337
Monthly household income	−154.194	282.357	−710.408	402.020	−0.036	−0.546	0.586
Delivery mode	−856.150	555.128	−1949.696	237.397	−0.098	−1.542	0.124
Neonatal prematurity	−1,647.618	2,152.162	−5,887.158	2,591.922	−0.048	−0.766	0.445
Neonatal birth weight	−494.821	1,003.049	−2,470.724	1,481.082	−0.031	−0.493	0.622
STING expression in cord blood	808.701	755.632	−679.817	2,297.218	0.069	1.070	0.286
pNF-κB expression in cord blood	938.892	1,015.221	−1,060.989	2,938.773	0.059	0.925	0.356

*In the table indicate statistical significance ($p < 0.05$).

pregnancy and infants innate immunity are related, especially in infants born to HBsAg-positive mothers. In our study, the innate immune mediators and anti-HBs level of offspring in pre-pregnancy group were observed, with significant differences compared to non-supplementation group and post-pregnancy supplementation group. As expected, the expression level of STING and pNF-κB and anti-HBs level were increased in pre-pregnancy group and high pNF-κB expression in cord blood can increase seropositive rates of HepB in infants.

The Chinese government has launched the National Free Preconception Health Examination Project (NFPHEP) since 2010, in which, women planning a pregnancy within 6 months are freely provided daily 0.4 mg folic acid and recommended to take folic acid starting from 3 months before conception until the end of the first trimester in order to prevent NTDs (19). Moreover, the US Preventive Service Task Force recommended women should take a daily dosage of 0.4–0.8mg folic acid when planning to get pregnancy (20). Most guidelines recommend folic acid supplementation starting at least 3 months before conception, but the end time is inconsistent (19, 21). In Japan, 45.1% of women initiated folic acid supplementation before pregnancy (22). It has been reported that the percentage of folic acid supplementation in pregnant women of general population were 74.7–94.5% (23–25) in the mainland of China, among them 52.3%−54.37% take folic acid before conception (23, 26). For HBsAg-positive mothers, previous study showed the percentage of folic acid supplementation during the first trimester was 63.59% (27). However, when considered the pre-conceptional periods, an equally important period for fetus development, the percentage of folic acid supplementation was 15.38% (27). In our study, only 27.67% pregnant women took folic acid before conception. Previous studies have shown that the percentage of folic acid supplementation in pregnant women was associated with educational level, the women with lower educational level are less likely to take folic acid supplementation than those with higher educational level (28). In this study, approximately half of HBsAg-positive mother has a high school education or below, which lead to low percentage of folic acid supplementation before and during pregnancy. In this study, we observed that the folic acid supplementation groups (including both pre-pregnancy and post-pregnancy supplementation groups) had a higher average monthly household income compared to the non-supplementation group. This finding is consistent with previous studies, which have reported that mothers with lower educational attainment and lower household income are less likely to take folic acid supplements before pregnancy. This disparity may be attributed to insufficient access to preventive healthcare during early pregnancy and a lack of awareness regarding the importance of folic acid supplementation among these populations (29).

The immune system in the newborn is immature and may be affected by several external factors. However, the evidence of maternal folic acid supplementation of HBsAg-positive mothers in the innate immunity of offspring is scarce. In our study, we observed innate immunity mediators and HepB vaccine responses in offspring across different folic acid supplementation groups. Notably, the pre-pregnancy supplementation group exhibited significantly higher expression of STING and pNF-κB in cord blood compared to the non-supplementation and post-pregnancy supplementation groups. It is reported that maternal folic acid supplement during pregnancy was associated with changes in DNA methylation located in genes implicated in embryonic development, immune response and cellular proliferation in the offspring (30). STING is an endoplasmic reticulum dimeric adaptor protein and expressed in various immune cells and acts as a major regulator of type I interferon release and innate immune response (31). Moreover, a major transporter of folate nutrients can recognize and transport cyclic dinucleotides (CDNs), thereby can act as second messengers to activate STING and elicit broad downstream responses (32). This suggests a potential mechanistic link between folate metabolism and STING pathway activation. Folic acid has been shown to ameliorate the inflammatory response in LPS-activated THP-1 macrophages, and this effect is dependent on the NF-κB signaling pathway (33). In this study, maternal folic acid supplementation affect the expression of STING pathway and the downstream molecule NF-κB, which was highly expressed in T cells. T cells constitute approximately half of cord blood mononuclear cells, and while no significant differences in T cell proportions were observed among the three groups, the functional impact of maternal folic acid supplementation on T cells cannot be ruled out. Specifically, folic acid-mediated changes in DNA methylation and STING pathway activation may enhance T cell responsiveness or alter their functional profile without affecting their overall proportion. These findings suggest that maternal folic acid supplementation may influence innate immunity in offspring by modulating the STING/pNF-κB signaling axis, potentially through epigenetic regulation and folate-dependent metabolic pathways. Further research is needed to elucidate the precise mechanisms by which folic acid impacts immune cell function and vaccine response in neonates.

HBV infection remains a global public health burden. The Asia-Pacific region having half of the 20 most heavily burdened countries and experiences a greater challenge of HBV infection (34). HepB vaccination is the most effective way to prevent HBV infection. The immunogenicity of HepB depends on synergistic interactions between innate and adaptive immune systems, ultimately manifested through anti-HBs production. Previous study focus on the relationship between maternal folic acid supplementation during pregnancy and infant vaccine responsiveness at 11–12 months (27) and 5 years (35), critical knowledge gaps persist regarding early immune maturation. Notably, the 1–2 month post-vaccination window, a pivotal phase for assessing primary humoral response, has been underexplored in this high-risk populations. Our study analyzed 253 HBsAg-positive mother-infant pairs, among them, 25 infants were non/hypo-responders (anti-HBs titres <100 mIU/ml) and the rate of non/hypo-response was 9.88%. Comparatively, it is reported that the non/hypo-response rates in this population was 12.2%−24.4% at 7 months and 28.4%−30.2% at 12 months (36, 37). It can be seen that the non/hypo-response rate of infants born to HBsAg-positive mothers has a downward trend, as China has a large population base, which remains an important public health issue. For poor responders of HepB, additional interventions are urgently needed to protect them from HBV.

The association between the expression of STING and pNF-κB in neonates and anti-HBs level in infants was also explored in this study. The seropositive rate of infants in the high pNF-κB expression group was significantly higher than low expression group and there are high anti-HBs titer trends in high pNF-κB expression group. It is reported that the STING/NF-κB pathway was one of the important pathways to activate innate immunity (38), which means that pNF-κB may promote HepB vaccine response in infants.

Whether folic acid supplementation affects infants antibody level were further explored. Compared with non-supplementation group, the anti-HBs level of infants in the supplementation group including pre-pregnancy group and post-pregnancy group were significantly higher. The linear regression model also showed that take folic acid before conception was associated with high anti-HBs levels. At present, many researchers are studying on improving the nutritional status before conception and during pregnancy in order to promote the development of immune response to vaccine. Previous study had shown that giving nutritional supplements to nutritionally vulnerable pregnant mothers in African improves antibody response to vaccination in early infancy (39). In addition, maternal folic acid supplementation during pregnancy could improve the persistence of protective antibodies in infants, this improvement may due to folic acid deficiency can reduce iron absorption and lead to anemia, and iron deficiency anemia may influence non-specific immunity. Moreover, folic acid may also affect the persistence of anti-HBs through methyl mechanisms (35).

Furthermore, mediation model and moderate model were constructed to explore the relationship among maternal folic acid supplementation, neonate pNF-κB expression and infants anti-HBs level. However, there were no mediation effect and no moderation effect in these models. The “black box” between the maternal folic acid supplementation and infants anti-HBs were not clarified yet in this study. There are complex mechanisms in epidemiological studies. pNF-κB may not be the only mediator in this study, and there were no statistical difference may due to the sample size. We hypothesized that the effect of folic acid supplementation on immune-related genes in infants may be one of the underlying mechanism for the difference in protective antibody levels three folic acid groups. Further studies were needed to increase the sample size or add indicators to explore and evaluate biological or social mechanisms between maternal folic acid supplementation and infants anti-HBs level.

The study assessed that HBsAg-positive mothers who in-took folic acid before conception, the expression of innate immune mediators tend to increase in cord blood and their infants tend to have higher protective antibody titers after HepB vaccination. Moreover, higher expression of pNF-κB in cord blood might substantially increase the seropositive rate of infants. Therefore, our findings suggested that folic acid supplementation should be taken before conception period for HBsAg-positive mothers who are planning to become pregnant.

Our findings may have some clinical implications for the relevant policies and practices of folic acid supplementation in HBsAg-positive mothers in China to some extent. Our results highlighted that the critical window for increasing offspring anti-HBs level is the prenatal period. These findings might be useful for maternal health care of HBsAg-positive mothers considering implementation of folic acid supplementation to reduce the risk of infants non/hypo-response to HepB and reach the goal of eliminating viral hepatitis as a major public health threat by 2030 set by WHO. Further studies are required to elucidate whether folic acid supplements be used consistently over the periods demarcated and whether HBsAg-positive mothers should be asked to take the supplements from preparation to the end of pregnancy or only up to a certain point.

In our ambispective cohort study, the information if innate immunity of neonates were collected at the time of delivery, while the information of maternal folic acid supplementation were collected retrospectively and the anti-HBs level of infants were collected prospectively. At the same time, this study also assessed whether there is a causal relationship among maternal folic acid supplementation, innate immune mediators protein expression level and anti-HBs levels, which has not been studied yet.

Regarding the limitations, we collected folic acid supplement information by questionnaire survey and did not measure the maternal folic acid levels. The use of questionnaires might introduce potential recall bias, but it remains one of the most effective investigation methods in epidemiological studies and can achieve the purpose of this study to a certain extent. To minimize recall bias, questionnaire data were cross-referenced with maternal pregnancy records and prenatal examination reports during data collection. Follow-up studies were needed to collect the dosage of the folic acid supplementation and collect peripheral blood in early, middle and late pregnancy to measure the serum folic acid levels to investigate the dose–response associations before and during prenatal periods. Besides, the relationship among maternal folic acid supplementation, neonate pNF-κB expression and infants anti-HBs level were not elucidated in this study. In China, the National Pre-pregnancy Health Check Project provides free folic acid supplementation to women planning to conceive within 6 months, recommending initiation 3 months before conception and continuation through early pregnancy. As a result, the number of participants in the non-supplementation group was relatively small, leading to an imbalance in group sizes. Additionally, the overall sample size of this study was limited, resulting in suboptimal statistical power. Nevertheless, our findings provide preliminary insights and offer valuable clues for informing folic acid supplementation policies targeting HBsAg-positive mothers. A larger sample size studies were needed to confirm the stability of our results in the future.

5 Conclusion

In summary, preconception folic acid supplementation may facilitate the expression of STING and pNF-κB in neonates and anti-HBs level in infants. Meanwhile, high pNF-κB expression at birth can lead to higher seropositive rate of HepB in infants aged 7–9 months.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving humans were approved by Ethics Committee of Shanxi Medical University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

JLian: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. ZM: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. XX: Writing – review & editing, Data curation, Investigation. YanL: Writing – review & editing. JLi: Writing – review & editing. WW: Writing – review & editing. TY: Writing – review & editing. YuL: Writing – review & editing, Investigation, Methodology. YQ: Investigation, Methodology, Writing – review & editing. YF: Writing – review & editing, Conceptualization, Funding acquisition, Project administration, Supervision. SW: Funding acquisition, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Food consumption score and the Nexus of maternal nutritional status among pregnant women in Gamo Zone, South Ethiopia

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Background: Food consumption score is an indicator used to evaluate food security, ensuring that individuals have reliable access to sufficient, safe, and nutritious food that meets their dietary needs and preferences for an active and healthy life. Poor nutrition during the first 1,000 days of life can result in developmental delays, stunted growth, cognitive impairments, and a higher risk of chronic diseases later in life. This study, therefore, aims to evaluate the level of food consumption scores and its associated factor among pregnant women.

Methods: A community-based cross-sectional study was conducted among 638 randomly selected pregnant women from October to March 2023 at the Arba Minch Health and Demographic Surveillance site in Southern Ethiopia. Data were collected using a pre-tested, interviewer-administered structured questionnaire. Modified Poisson regression was employed to measure prevalence ratios, while both bivariate and multivariable analyses were performed to identify potential variables for further analysis and to determine factors associated with an acceptable food consumption score, respectively.

Result: Among the 638 pregnant women, 8.15% (95% CI: 6.26, 10.55) had poor, 14.89% (95% CI: 12.33, 17.87) had borderline, and 76.96% (95% CI: 73.52, 80.07) had acceptable food consumption scores While 31.97% of the pregnant women were suffering from under nutrition. Acceptable food consumption score was higher among women who were urban dwellers (APR = 1.09; 95% CI: 1.02, 1.20), in higher economic status (APR = 1.05; 95% CI: 1.01, 1.16), had planned pregnancy (APR = 1.13; 95% CI: 1.02, 1.25), were exposed to mass media (APR = 1.19; 95% CI: 1.07, 1.31), had a vegetable garden (APR = 1.14; 95% CI: 1.04, 1.25), attend health facility for antenatal care (APR = 1.13; 95% CI: 1.02, 1.26), and those who consumed food four or more times per day (APR = 1.23; 95% CI: 1.11, 1.36). Also the level of acceptable food consumption score increased by 2, 3, and 4% for every one-unit increase in BMI (APR = 1.02; 95% CI: 1.01, 1.04), MUAC in cm (APR = 1.03; 95% CI: 1.01, 1.05), and gestational age in weeks (APR = 1.04; 95% CI: 1.01, 1.07), respectively.

Conclusion: Nearly one-third and three-fourths of the pregnant women were undernourished and had acceptable food consumption scores, respectively. Factors associated with acceptable food consumption scores included place of residence, wealth status, planned pregnancy, exposure to mass media, having a vegetable garden, attending antenatal care at health facilities, consuming four or more meals daily, and gestational age. Thus addressing these factors is crucial for improving FCS among pregnant women. Furthermore, efforts should be directed toward increasing media exposure, boosting household income, promoting vegetable gardening, and improving planned pregnancies and antenatal care visits.

KEYWORDS

associated factors, food consumption score, nutritional status, pregnant women, South Ethiopia

Introduction

Maternal nutrition represents a significant public health challenge as it influences the health of the mother, the fetus, and subsequent generations (1). Meeting the nutritional demands for fetal growth and maternal tissue expansion requires additional nutrients (2). However, pregnant women in low and middle-income countries like Ethiopia typically consume diets based on a limited number of staple foods (primarily cereals), resulting in gaps between their dietary intake and the nutritional requirements for various nutrients (2, 3).

The first 1,000 days of human life are a crucial period not only for growth and development but also for long-term health impacts (4). Evidence indicates that inadequate nutrition during this period can cause developmental delays, stunted growth, cognitive impairments, and increased susceptibility to chronic diseases in adulthood (5).

Adequate and quality dietary intake is crucial for pregnant women to meet nutritional requirements for anatomical, physiological, and biochemical changes during pregnancy (6). Also it plays a pivotal role in enhancing pregnancy outcomes, preserving maternal health, and promoting fetal growth and development (7, 8). However, suboptimal intake increases the risk of maternal morbidity, intrauterine growth retardation (IUGR), prematurity, stillbirth, low birth weight (LBW), maternal and prenatal death and reduces gestational weight gain (8–11).

In developing countries like Ethiopia, dietary practices during pregnancy are shaped by restrictions on essential foods and/or drinks considered unacceptable in society, rooted in religious, cultural, historical, and social norms (12, 13). A recent systematic review in Ethiopia found that around 34.22% of pregnant women are restricted from consuming essential foods due to cultural taboos, with the prevalence varying significantly by region. The variation in food taboos across regions, with 67.4% in the Somali region compared to 11.5% in Tigray region, highlights significant socio-cultural differences that influence maternal nutrition (14). The most commonly prohibited foods include cereals (such as wheat, maize, and millet), nuts (groundnuts), vegetables (like green pepper, spinach, kale, broccoli, and cabbage), fruits (banana and tomato), and animal source foods (such as meat, dairy, and eggs) (14, 15). This restriction significantly impacts the FCS, even among households considered food-secure, consequently increasing the risk of malnutrition.

The prevalence of under nutrition among pregnant women in Ethiopia varies significantly, ranging from 21.8 to 43.1% (16–18); with certain regions showing even higher rates. Similarly, the level of adequate dietary practices during pregnancy is generally low and varies across the country, with Addis Ababa having the highest at 63.9% and eastern Ethiopia the lowest at 15.2% (19, 20). Furthermore, maternal dietary knowledge during pregnancy is also insufficient, with the highest proportion of good dietary knowledge in Addis Ababa at 73.9% and the lowest in southwest Ethiopia at 21% (19, 21).

The FCS is a food frequency indicator developed by the World Food Programme (WFP) aiming to capture both the quantity and quality of dietary intake (22). It serves as an indicator for the diversity index, balanced food consumption, and composite score of dietary diversity, food frequency, and the relative nutritional significance of various food groups (23, 24). It is among the indicators used to assess food security, which ensures that every person has consistent access to sufficient safe and nutritious food meeting their dietary needs and preferences, enabling them to lead an active and healthy life (25).

In southern Ethiopia, the level of household food insecurity was 50, and 54% of pregnant women lived in food-insecure households (26, 27), which is significantly associated with under nutrition during pregnancy (28). Additionally, the FCS ranged from 57.6 to 68.3% for acceptable, 17.4 to 35.2% for borderline, and 7.1 to 14.3% for poor, indicating that household-level FCS was low (25, 29). Furthermore, 36.4% of households experienced both poor dietary diversity and a lack of stable access to, as well as availability of, sufficient food (25), suggesting that both diversified food consumption and access to food were low. All of these factors contribute to under nutrition, which is particularly severe during pregnancy when nutritional requirements are high.

The FCS among pregnant women in Ethiopian ranges from 51.20 to 81.50% acceptable, 16.60 to 42.60% borderline, and 1.90 to 10.49% poor (30–32). Factors influencing acceptable FCS included socioeconomic status (30, 32), residence (31), religion (31), maternal educational status (32), ANC follow-up (30), consumption of animal source foods (30), possession of agricultural land (30), skipping meal (32), and attitudes toward dietary diversity during pregnancy (30, 32). However, it did not address the association between nutritional status and FCS (30, 31). In addition, dietary practices were significantly influenced by geographical and sociocultural variations, underscoring the necessity for tailored interventions. Hence, this study aims to evaluate the factors influencing FCS and its association with nutritional status among pregnant women in Gamo Zone, South Ethiopia.

Materials and methods

Study setting, design, and period

A study involving 638 randomly selected pregnant women was conducted in Arba Minch Zurea and Gacho Baba districts of southern Ethiopia from October to March 2023. This study aimed to establish a baseline for a prospective cohort investigating the relationship between dietary practices and newborn nutritional status.

The provincial capitals, Arba Minch Zurea and Gacho Baba, are located 437 km and 439 km south of Addis Ababa, the capital of Ethiopia, respectively. The two districts have a total population of 164,629 (82,499 male and 82,630 female) as of the year 2023/24, projected from the 2007 CSA census data. Among them, 74,257 reside in the Arba Minch Health and Demographic Surveillance site (AM-HDSS), which covers 9 representative kebeles (the smallest administrative unit in Ethiopia) from these districts. In the surveillance site, it was anticipated that 2,598 women would be pregnant for the year 2023/24 and would access healthcare from 7 nearby health centers, 37 health posts, and private healthcare facilities.

Source population and study population

All pregnant women identified in AM-HDSS constituted the source population, while the study population comprised selected pregnant women from AM-HDSS who met the inclusion criteria.

Inclusion and exclusion criteria

All pregnant women who were permanent residents of AM-HDSS were included in the study, except for those who were critically ill, declined to participate, or had known chronic conditions like HIV and diabetes mellitus.

Sample size determination

Single population proportion formula was used to calculate the sample size, assuming a 95% confidence interval, 5% precision level, and an expected prevalence of acceptable food consumption score of 54.46%, as reported in a study from Eastern Ethiopia (30), with a 10% possible non-response.

$$\mathbf{n} = \frac{\left(\mathbf{Z_{1-\alpha/2}}\right)^2 * \mathbf{P}\left(\mathbf{1-P}\right)}{\left(\mathbf{d}\right)^2} \quad \mathbf{n} = \frac{\left(\mathbf{1.96}\right)^2 * \mathbf{0.5446}\left(\mathbf{1-0.5446}\right)}{\mathbf{0.05^2}} = \mathbf{381}$$

Where

n = Desired number of samples.

P = expected Proportion of acceptable food consumption score = 54.46%.

$Z_{1\text{-}a/2}$ = Standard value for 95% CI = 1.96.

d = 5%.

The calculated sample size was 419; however, the baseline survey of the prospective cohort study assessed 638 pregnant women. Therefore, all 638 participants were included in this analysis.

Sampling techniques

The sample was allocated proportionally to each kebele based on the anticipated number of pregnant women, and participants were selected using a computer-generated simple random sampling method.

Data collection tools, procedures, and measurements

A structured questionnaire, pre-tested and administered by face-to-face interviewers, was used to collect data on maternal socio-demographic, health and dietary factors. Dietary data was collected using a validated food frequency questionnaire (FFQ) (33) customized for local conditions. This FFQ included recalling food intake over 24 h and dietary habits over one week, covering a total of 46 food items categorized into ten groups to assess both actual and habitual dietary intake, respectively.

The data were digitally collected with the help of an open-source toolkit (Kobo Collect). This mobile app is user-friendly and functions offline. A questionnaire template was developed in a computer database, uploaded to a server, and then downloaded to the data collectors' mobile phones via an internet connection. Specific training was provided on how to download the template and upload data (34).

Maternal nutritional status was assessed using mid-upper arm circumference (MUAC) and body mass index (BMI). MUAC was measured using a flexible, non-stretchable standard tape, placed at the midpoint between the acromion process and olecranon, with an accuracy of 0.1 cm (17). Weight was assessed in kilograms (kg) using a WHO standard scale accurate to 0.1 kg, with participants wearing light clothing. Height was measured standing upright without shoes, using a stadiometer accurate to 0.1 cm. then, BMI was computed by dividing body weight in kilograms by the square of height in meters (35).

Maternal dietary knowledge was evaluated using questions adapted from previous research. Responses were categorized as either "0" for incorrect answers indicating lack of awareness, or "1" for correct answers indicating awareness. Scores ranged from 0 to 100%. Mothers scoring below 60% were categorized as having "poor knowledge," those scoring between 60 and 79% were categorized as having "moderate knowledge," and those scoring 80% or higher were categorized as having "good knowledge" (36–38).

Household wealth status was assessed using items adapted from the 2016 EDHS. These items included the number of livestock owned, availability of agricultural land, materials used in house construction, source of drinking water, presence of electricity, type of cooking fuel used, and ownership of modern household goods (e.g., bicycle, television, radio, motorcycle, sewing machine, telephone, car, refrigerator, mattress, bed, and mobile phone). The assumption was that owning these assets, services, and amenities reflects the economic standing of the household (39).

The meal frequency of pregnant women was assessed based on the number of meals (main and snacks) consumed per day. Those consuming more than three meals were categorized as having adequate meal frequency, while those consuming three or fewer meals were categorized as having inadequate meal frequency (18).

Minimum Dietary Diversity for Women (MDDW) was assessed, with pregnant women classified as having adequate minimum diet diversity if they consumed at least 5 of the 10 food groups in the past 24 h (40).

Animal source food consumption (ASFC) among pregnant women was estimated by adding up all animal source foods consumed over the previous 7 days and converting the total into terciles. Pregnant mothers in the highest tercile were categorized as having "high" ASFC, while those in the lower terciles were categorized as having "low" consumption (30).

The Food Variety Score (FVS) is determined by summing all the foods pregnant women have eaten in the last 7 days and the mean was computed. Pregnant women with FVS higher than mean score classified as having a "high," otherwise classified as having a "low" food variety score (30).

The FCS is a sensitive measure of food frequency and dietary diversity, evaluated using WFP guidelines based on the previous 7 days of survey data. Each food item receives a score from 0 to 7, depending on how many days it was consumed. These items are categorized into groups, and the frequencies of all items within each group are added together. The FCS is computed by multiplying the frequency of each food group by its respective weight, and then summing these values to create a composite score. This score is classified as follows: Poor food consumption score ranges from 0 to 28, Borderline food consumption score ranges from 28.5 to 42, and Acceptable food consumption score is greater than 42 (41).

Data quality control

Proper data collection tools were developed and utilized to ensure data quality. Trained data collectors were regularly supervised to guarantee accurate data collection. All collected data were submitted daily, checked for completeness and consistency, and approved by supervisors. Following a pre-test among 35 pregnant women in the non-AM-HDSS kebele, the questionnaire was revised, reducing the number of food items from 50 to 46.

Data processing and analysis

All collected and submitted data were downloaded, cleaned in Excel, exported to, and analyzed with STATA 16.0 version statistical software. Two-way tables with Pearson's chi-square test or Fisher's exact test were used to present and compare food consumption scores for categorical predictors, while means with standard deviations were used for continuous variables. Exploratory factor analysis using the principal component analysis (PCA) method was employed to determine household wealth status and maternal dietary knowledge. Sample adequacy, Bartlett's test for sphericity, commonality tests, and assessments for lack of correlation assumptions in complex structures were conducted. PCA identified four factors explaining 67 and 75% of the total variance, respectively. The factor value of the first component, explaining the maximum variance, was used and ranked into terciles to classify household wealth status and maternal dietary knowledge.

Modified Poisson regression model was used to improve accuracy and robustness while directly measuring prevalence ratios (PRs). Variables with p-values $\leq$0.25 from bivariate analysis, were entered into a multivariable regression model to identify the determinants of acceptable food consumption scores. Adjusted prevalence ratios (APRs) with 95% confidence intervals were used to determine the direction and strength of associations. Statistical significance was defined as a p-value less than 0.05. The deviance, Akaike's information criterion (AIC) and Bayesian information criterion (BIC) test were used to assess the model fitness, and multicollinearity test was used to determine correlations between independent variables using variance inflation coefficients (VIF).

Results

Baseline characteristics of the study participant

A total of 638 pregnant women participated in the study, with a mean age of 26.29 years (± 5.77), ranging from 17 to 42 years, at 16 to 20 weeks of gestation. The majorities of the respondents attended formal education (62.85%), were rural dwellers (90.28%), were aged between 20 to 35 years (80.56%), were housewives (67.08%) visited health facilities for ANC services (67.87%), and had planned pregnancies (67.87%). Almost one-third of the respondents reported no exposure to media and did not have a vegetable garden (Table 1).

Food consumption score and nutritional status

The food consumption score among pregnant women showed that 76.96% had an acceptable, 14.89% had a borderline, and 8.14% had a poor. Regarding nutritional status, 68.03% had MUAC > = 23 cm, 27.43% had MUAC between 21 and 23 cm, and 4.55% had MUAC less than 21 cm (Figure 1).

Among the participants, 59.72 and 53.61% achieved high dietary diversity and food variety scores, respectively. About two-thirds 63.32% of the pregnant women had a meal frequency of four or more times per day. The majority 88.24 and 83.39% of the respondents consumed coffee leaf tea beverages and did not receive information about dietary intake during pregnancy (Table 2).

Determinants of food consumption score

The level of acceptable food consumption score increased by 2, 3, and 4% for every one-unit increase in BMI (APR = 1.02; 95% CI: 1.01, 1.04), MUAC in cm (APR = 1.03; 95% CI: 1.01, 1.05), and gestational age in weeks (APR = 1.04; 95% CI: 1.01, 1.07), respectively. Food consumption score was higher among women who were urban dwellers (APR = 1.09; 95% CI: 1.02, 1.20), in higher economic status (APR = 1.05; 95% CI: 1.01, 1.16), had planned pregnancy (APR = 1.13; 95% CI: 1.02, 1.25), were exposed to media (APR = 1.19; 95% CI: 1.07, 1.31), had a vegetable garden (APR = 1.14; 95% CI: 1.04, 1.25), had ANC visit (APR = 1.13; 95% CI: 1.02, 1.26), and those who consumed food four or more times per day (APR = 1.23; 95% CI: 1.11, 1.36) (Table 3).

Discussion

Nutrition is crucial for the proper functioning of the body systems. However, chronic energy deficiency is common among pregnant women due to consuming unbalanced diets lacking adequate nutrients (42). This deficiency is exacerbated by food taboos, infectious diseases, food insecurity, and poor dietary knowledge, leading to a higher risk of adverse birth outcomes, morbidity, and mortality (43). This study aims to determine the level of food consumption score and associated factors among pregnant women in Gamo Zone, South Ethiopia.

TABLE 1 Baseline characteristics of the study participants in AM-HDSS, Gamo Zone of South Ethiopia.

Variable	Category	Number	Percent
Maternal age	Less than 20 years	81	12.70
	20 to 35 years	514	80.56
	36 years and more	43	6.74
	Mean (± SD)	26.29 (± 5.77)	
Place of residence	Rural	576	90.28
	Urban	62	9.72
Religion	Orthodox	123	19.28
	Protestant	515	80.72
Educational status	No formal education	237	37.15
	Attend formal education	401	62.85
Partner educational status	Unable to Read and write	273	42.79
	Read and write only	365	57.21
Occupation	House wife	428	67.08
	Farmer	82	12.85
	Merchant	74	11.60
	Government employ	34	5.33
	Student	20	3.13
House hold asset decision making	By both partner	118	18.50
	Mainly by husband	520	81.50
Number of family member	Less than five	309	48.43
	Five and more	329	51.57
	Mean (± SD)	4.30 (1.78)	
Wealth status	Low	218	34.17
	Middle	208	32.60
	High	212	33.23
Birth interval	less than 2 years	59	17.61
	2 years and more	276	82.39
Pregnancy status	Planned	433	67.87
	Unplanned	205	32.13
ANC visit	Yes	433	67.87
	No	205	32.13
Had nausea vomiting	Yes	339	53.13
	No	299	46.87
Had obstetric complication	Yes	11	1.72
	No	627	98.28
Media exposure	Yes	432	67.71
	No	206	32.29
Had vegetable garden	Yes	409	64.11
	No	229	35.89
Number of pregnancy	Mean (± SD)	3.02 (± 1.70)	
Number of delivery	Mean (± SD)	2.50 (± 1.46)	
Gestational age	Mean (± SD)	18.17 (± 1.72)	

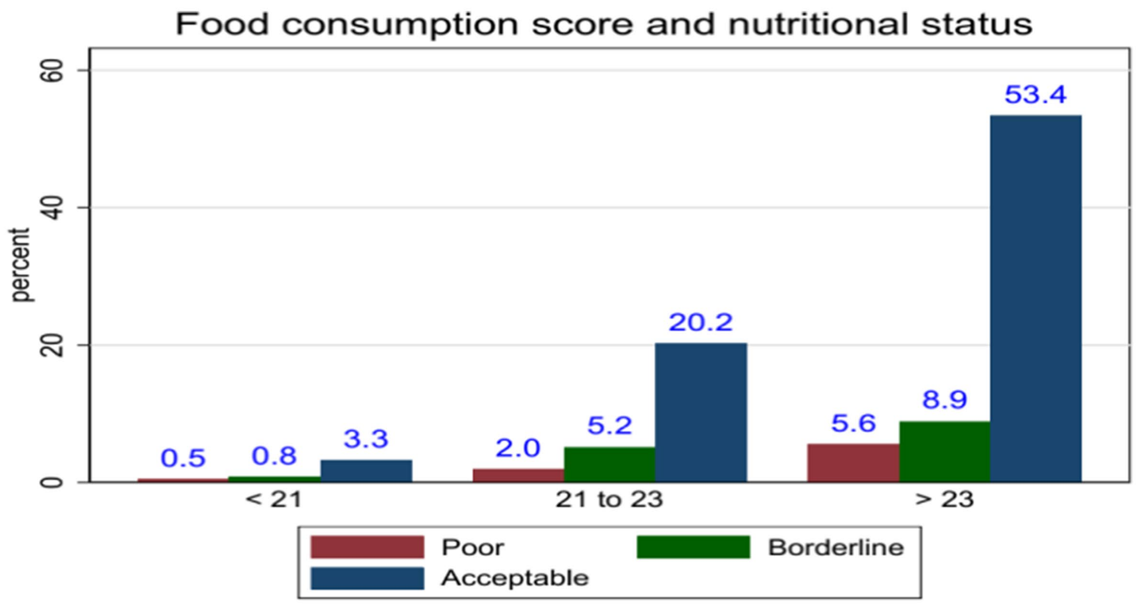

FIGURE 1
Magnitude of food consumption score and nutritional status among pregnant women in AM-HDSS, Gamo Zone of South Ethiopia.

The current study report revealed that about three-fourths (76.96, 95% CI: 73.52–80.07%) of the study participants had acceptable FCS. In contrast, less than two out of ten participants had borderline (14.89%) or poor (8.15%) FCS. This finding is consistent with the results from studies conducted in Nigeria (80.30%), and Northwest Ethiopia (80.30 and 81.50%) (31, 44, 45), though it falls short of the WFP recommended threshold of 90% (24). However, it surpasses the findings from studies in Addis Ababa, Ethiopia (51.2%), Eastern Ethiopia (54.46%), and Bangladesh (58%) (30, 32, 46). This is due to the fact that dietary intake in Ethiopia is highly influenced by seasonal variation. During the autumn and winter seasons, food access, including fresh produce and staple foods, increases due to harvest time. Consequently, the FCS also increases (31, 32). In contrast, the FCS decreases during fasting months when consumption of animal source foods is restricted due to religious rules (32, 47). Also the difference is probably due to cultural geographical and religious difference among the studies areas.

A total of 204 pregnant women (31.97, 95% CI: 28.46–35.70%) of the respondents were undernourished, with a MUAC measurement of less than 23 cm. This finding was nearly comparable to the pooled prevalence of under nutrition among pregnant women in Ethiopia (32%) (48), and the Afar regional state of Ethiopia (30.9%) (49). However, it was lower than studies from Jordan (49.2%) (50), western Ethiopia (39.2%) (51), southern Ethiopia (38 to 44.90%) (52, 53), eastern Ethiopia (43.8 to 47.90%) (54, 55), and southwest Ethiopia (42.4%) (56). It was also higher than recent studies conducted in various parts of Ethiopia (17.7, 21, and 27.6%) (57–59). The discrepancies in the findings may arise from variations in the timing of enrollment. In this study, participants were enrolled during early pregnancy, a period commonly associated with nausea and vomiting, which can result in reduced body fluid and subsequently lower MUAC measurements. Also the discrepancies could be attributed to differences in study settings, sociocultural and socioeconomic factors, sample sizes, and variations in the MUAC cutoff points.

In this study, the nutritional status of pregnant women showed a direct correlation with their food consumption score. Specifically, each 1 kg/m^2 increase in BMI was associated with a 1.02 times higher in level of acceptable food consumption score, and each 1 cm increase in MUAC was linked to a 1.03 times higher level of acceptable food consumption score. This is in line with findings from earlier studies conducted across different regions of Ethiopia, indicating that food insecurity increases the risk of under nutrition among pregnant women (48, 51, 52, 56). Therefore, the nutrition program should focus on promoting healthy weight gain, regular monitoring of BMI and MUAC, and providing supplementation for pregnant women with low BMI or MUAC, ultimately enhancing their nutritional status and improving pregnancy outcomes.

In low-and middle-income countries like Ethiopia, limited accessibility to healthcare and underutilization of maternal health services among rural women prevents them from receiving adequate awareness about healthy dietary practices during pregnancy (60), resulting in lower food consumption scores. Furthermore, prevalent food taboos among rural pregnant women limit their intake of specific foods, contributing to reduced food consumption scores (14). The present study corroborates this, where the level of acceptable food consumption score was 1.09 times higher among urban dwellers compared to their counterpart. This finding was supported by a previous study conducted in eastern Ethiopia, indicating that urban pregnant women had a higher consumption of five or more food groups (61). In contrast, research from northwest Ethiopia showed that rural women had a higher FCS (31). This discrepancy is likely due to differences in the study setting and participants. The current study was community-based, with a majority of participants from rural areas, whereas the former study was hospital-based, with most participants from urban areas.

In this study, pregnant women from higher wealth status had a higher level of acceptable food consumption score than those from lower wealth status. It is a known fact that wealth plays a crucial role

TABLE 2 Dietary related characteristics of the study participants in AM-HDSS, Gamo Zone of South Ethiopia.

Variable	Category	Number	Percent
Maternal minimum dietary diversity	Low	257	40.28
	High	381	59.72
	Mean (± SD)	4.74 (± 1.76)	
Food Varity score	Low	296	46.39
	High	342	53.61
	Mean (± SD)	55.34 (± 19.83)	
Meal frequency	≤ 3	234	36.68
	> 3	404	63.32
	Mean (± SD)	3.66 (± 0.61)	
Alcohol consumption	Yes	21	3.29
	No	617	96.71
Drink coffee	Yes	302	47.34
	No	336	52.66
Drink coffee leaf tea	Yes	563	88.24
	No	75	11.76
None nutritional crave	Yes	40	6.27
	No	598	93.73
Food aversion	Yes	91	14.26
	No	547	85.74
Receive dietary counseling	Yes	106	16.61
	No	532	83.39
Iron folic acid started	Yes	391	61.29
	No	247	38.71
Maternal nutritional knowledge	Poor	298	46.71
	Moderate	270	42.32
	Good	70	10.97
MUAC	Mean (± SD)	23.68 (± 2.23)	
BMI	Mean (± SD)	23.36 (± 2.55)	

in meeting basic human needs, accessing healthcare services, and ensuring adequate dietary intake in terms of both frequency and quality (62). Consequently, individuals with lower socio-economic status often face lower food consumption scores due to financial constraints limiting their ability to purchase sufficient food. Similarly a previous study conducted in Ethiopia has shown that financial limitations and household income are frequently quoted as barriers to dietary intake during pregnancy (63). The finding of this study is consistent with studies conducted in Ethiopia (30, 32). However, wealth status is not associated with acceptable food consumption scores among pregnant women in Northwest Ethiopia (31). Therefore, addressing access to affordable and nutritious food through food assistance, subsidized food packages, or the special Productive Safety Net Programme for poorer pregnant women would be helpful.

The level of acceptable food consumption score was 1.13 times higher among participants who had planned pregnancies compared to those with unplanned pregnancies. This may be attributed to a higher incidence of maternal mental disorders like depression, anxiety, and stress among women with unplanned pregnancies (64), as well as lower utilization of maternal health services (65), which reduces the level of food consumption score. A study conducted in Iran supports this finding by reporting an association between unplanned pregnancies and food insecurity (66). Additionally, it is consistent with evidence from low-and middle-income countries, which suggests that unwanted pregnancies can affect maternal nutrition (65). Similarly pregnant women who were exposed to audiovisual mass media had a higher acceptable food consumption score compared to those who were not exposed. This finding was supported by studies done in Bangladesh, Indonesia and Ethiopia, where it was observed that mothers exposed to print and audiovisual media tended to offer a wider variety of foods to their infants (67–69). This is probably due to audiovisual information improvements awareness, attitudes, and practices regarding healthy behavior. Moreover, women who are exposed to media are more likely to obtain dietary information, which can lead to a higher food consumption score.

This study found that the acceptable food consumption score was 1.13 times higher among participants who visited a healthcare

TABLE 3 Factors associated with food consumption score among pregnant women in AM-HDSS, Gamo Zone of South Ethiopia.

Variable	Category	Food consumption score		CPR (95% CI)	APR (95% CI)
		Acceptable	Unacceptable		
Place of residence	Rural	435 (88.59)	141 (95.92)	Ref	Ref
	Urban	56 (11.41)	6 (4.08)	1.20 (1.09, 1.31)	1.09 (1.02, 1.20)
Educational status	No formal education	166 (33.81)	71 (48.30)	Ref	
	Formal education	325 (66.19)	76 (51.70)	1.16 (1.05, 1.27)	
Partner educational status	No formal education	197 (40.12)	76 (51.70)	Ref	
	Formal education	294 (59.88)	71 (48.30)	1.12 (1.02, 1.22)	
Households asset decision-making	By both partner	101 (20.57)	17 (11.56)	1.14 (1.04, 1.25)	
	Mainly by husband	390 (79.43)	130 (88.44)	Ref	
Wealth status	Low	164 (33.40)	54 (36.73)	Ref	Ref
	Middle	151 (30.75)	57 (38.78)	0.96 (0.86, 1.08)	0.98 (0.87, 1.10)
	High	176 (35.85)	36 (24.49)	1.11 (1.01, 1.22)	1.05 (1.01, 1.16)
Maternal nutritional knowledge	Poor	235 (47.86)	63 (42.86)	Ref	
	Moderate	204 (41.55)	66 (44.90)	0.96 (0 0.88,1.05)	
	Good	52 (10.59)	18 (12.24)	0.94 (0.81, 1.09)	
Current pregnancy	Planned	352 (71.69)	81 (55.10)	1.20 (1.08, 1.33)	1.13 (1.02, 1.25)
	Unplanned	139 (28.31)	66 (44.90)	Ref	Ref
Mass media exposure	Yes	356 (72.51)	76 (51.70)	1.26 (1.13, 1.40)	1.19 (1.07, 1.31)
	No	135 (27.49)	71 (48.30)	Ref	Ref
Had vegetable garden	Yes	333 (67.82)	76 (51.70)	1.18 (1.07, 1.30)	1.14 (1.04, 1.25)
	No	158 (32.18)	71 (48.30)	Ref	Ref
ANC visit	Yes	356 (72.51)	77 (52.38)	1.23 (1.12, 1.39)	1.13 (1.02, 1.26)
	No	135 (27.49)	70 (47.62)	Ref	Ref
Meal frequency	≤ 3	154 (31.36)	80 (54.42)	Ref	Ref
	>3	337 (68.64)	67 (45.58)	1.27 (1.14, 1.40)	1.23 (1.11, 1.36)
Receive dietary counseling	Yes	91 (18.53)	15 (10.20)	1.14 (1.04, 1.25)	
	No	400 (81.47)	132 (89.80)	Ref	
Gestational age (weeks)	Mean (± SD)	18.27(+ 1.69)	17.81(+ 1.77)	1.04 (1.01, 1.06)	1.04 (1.01, 1.07)
Body mass index	Mean (± SD)	23.61 (± 2.64)	22.51 (± 2.01)	1.04 (1.02, 1.05)	1.02 (1.01, 1.04)
MUAC	Mean (± SD)	23.88 (+ 2.20)	23.07 (+ 2.21)	1.04 (1.02, 1.06)	1.03 (1.01, 1.05)

facility for antenatal care compared to those who did not visit. This is consistent with a study conducted in Western and Eastern Ethiopia (30, 70). This may be due to the increased likelihood of receiving information about the importance of dietary diversity and increasing meal frequency during pregnancy (71). However, ANC visits are not associated with the FCS among pregnant women in Addis Ababa, Ethiopia (32). This discrepancy is likely due to differences in study settings: the current study was community-based and primarily involved rural residents, while the previous study was facility-based and on urban residents. Similarly, the level of FCS was 1.04 times higher for every one-week increase in gestational age. This is similar with the study conducted in Western Ethiopia (70). This is the fact that, as gestational age increases, morning sickness tends to lessen, leading to an increase in dietary intake (72).

This study found that the likelihood of having an acceptable food consumption score was 1.23 times higher among pregnant women who consumed four or more meals per day compared to those who ate at least three meals per day. This might be due to the fact that increased meal frequency enhances dietary diversity, which in turn raises the food consumption score. This finding was supported by evidence from Western and Eastern Ethiopia, where meal frequency had a significant effect on food consumption (61, 70, 73, 74). Similarly, the level of FCS was higher among participants from households with home gardening compared to those without home gardening. This might be due to the prolonged increase in availability of different food groups in households with home gardening (75). This finding is in line with studies conducted in Eastern and Northwest Ethiopia, which found that the consumption of minimum dietary diversity is higher among pregnant women from households with home gardening (69, 73). Therefore, enhancing meal frequency counseling, providing training, and offering resources to support home gardening, which enables households to grow nutritious food, can help improve dietary practices during pregnancy.

Strength and limitation of the study

In this study, using both the 24-h recall method and a one-week dietary history, along with conducting the assessment at the community level enhances the quality and accuracy of the data. Despite employing rigorous measurement, there is a chance that respondents over-reported or under-reported their dietary intake due to social desirability and recall bias. Additionally, as this is a cross-sectional study, it cannot establish causality.

Conclusion

The level of acceptable food consumption scores was low in the study area, and under nutrition was high among pregnant women. This study identified several factors independently associated with the level of food consumption scores among pregnant women, including urban residence, higher wealth status, planned pregnancy, exposure to audiovisual mass media, having a vegetable garden, visiting health facilities for antenatal care, and consuming four or more meals per day. Additionally, food consumption scores were higher with increasing gestational age, body mass index, and mid-upper arm circumference. Thus addressing these factors is crucial for improving FCS among pregnant women. Furthermore, efforts should be directed toward increasing media exposure, boosting household income, promoting vegetable gardening, and improving planned pregnancies and antenatal care visits.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Institutional Research Ethics Review Board (IRB) of Jimma University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

TF: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. DT: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. BA: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Glossary

AIC - Akaike's Information Criterion

AM-HDSS - Arba Minch Health and Demographic Surveillance site

ANC - Anti Natal Care

APR - Adjusted Prevalence Ratio

ASFC - Animal Source Food Consumption

BIC - Bayesian Information Criterion

BMI - Body Mass Index

EDHS - Ethiopian Demographic and Health Survey

FCS - Food Consumption Score

FFQ - Food Frequency Questionnaire

FVS - Food Variety Score

HIV - Human Immunodeficiency Virus

IRB - Research Ethics Review Board

IUGR - Intrauterine Growth Restriction

LBW - Low Birth Weight

MDDW - Minimum Dietary Diversity for Women

MUAC - Mid Upper Arm Circumference

PCA - Principal Component Analysis

VIF - Variance Inflation Coefficients

WFP - World Food Programme

WHO - World Health Organization

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Evaluation of feeding practices in the first 12 months of life and nutritional status in an urban setting of a low-resource country: Beira, Mozambique

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Background: Stunting is a major public health problem, especially in developing countries. In 2020, 37.5% of children under 5 years in Mozambique were stunted.

Objectives: This study aims to describe the nutritional practices in a cohort of Mozambican children and to compare them with international recommendations. The secondary objective is to find differences between chronic malnourished (M) versus non-malnourished (NM) children and to detect factors related to malnutrition.

Methods: A retrospective study was conducted, including children admitted to Beira Central Hospital in Mozambique, using a questionnaire focusing on early nutritional and complementary feeding (CF) practices. We compared the clinical and feeding characteristics of M and NM children and conducted logistic regression to identify factors associated with chronic malnutrition. Data management was performed using Microsoft Excel Office 365 and statistical analysis with Jamovi (version 2.3).

Results: A total of 103 children were studied (median age: 19 months). Seventy percent were exclusively breastfed, 56% continued breastfeeding during CF, but only 8% breastfed until 2 years of age. The introduction of CF occurred at a median age of 6 months, with the main reason being the baby's crying. Sugar, salt, and sugary drinks were introduced before 1 year of age. At the time of the survey, 42% of the children's diets were adequately varied. Statistical analysis showed that M children had statistically significant differences in birth weight percentile, were less likely to be breastfed, and consumed fewer dairy products than NM children. Multivariate logistic regression showed that risk factors for chronic malnutrition included HIV infection in both mother and child (OR: 7.5, 95% CI: 1.6–35.09), unaware initiation of CF (OR: 4.35, 95% CI: 1.45–13.05), and birth weight below the 10th percentile (OR: 3.26, 95% CI: 1.02–10.47). In contrast, early and frequent dairy consumption, as well as ongoing maternal breastfeeding during CF, were identified as protective factors.

Conclusion: In our population, the percentage of children with a minimally acceptable diet was low. The use of human milk could be increased, and mistakes in CF practices could be corrected. Our findings highlight the need to raise awareness about the importance of breastfeeding and the timely introduction of appropriately composed CF. Increased attention should be given to children suffering from HIV, with lower birth weights, less breastfeeding, and lower dairy product consumption, in order to prevent malnutrition.

KEYWORDS

malnutrition, children, Mozambique, stunting, nutritional practices

Background

Globally, malnutrition is considered one of the main public health issues, and its end by 2030 is part of the Sustainable Development Goals (SDGs) of the United Nations (UN) (1). According to the World Health Organization (WHO), malnutrition is defined as a deficiency, excess or imbalance in the intake of energy or nutrients compared to the body's needs (2). Considering energy or nutrient deficiency, malnutrition can be classified in acute malnutrition (wasting), chronic malnutrition (stunting) and underweight. Wasting refers to a recent and severe weight loss due to an insufficient nutritional intake in a short period or an acute illness that has resulted in rapid weight loss (3). Stunting is the result of chronic or recurrent malnutrition, usually associated with poor socioeconomic conditions, poor maternal health and nutrition, recurrent or chronic illness or inadequate feeding and care of infants and children in early childhood (3, 4). Stunting prevents children from reaching their physical and cognitive genetic potential (5, 6). Chronic malnutrition is caused by inadequate nutritional intake between conception and the first 2 years of life. It is associated both with an altered nutritional status of the mother during pregnancy and breastfeeding and with an altered diet in the first 2 years of life (7).

According to UNICEF, on a global level, in 2022, children under 5 years of age affected by chronic malnutrition were 148.1 million while those with acute malnutrition were 45 million (4); of these, 95 and 97%, respectively, live in Asian and African regions. Despite this, the prevalence of chronic malnutrition on a global level has gradually, albeit slowly, declined over the years, except in Central Africa and Oceania (4).

Mozambique is an African country with a very high prevalence of chronic malnutrition. Even if Mozambique has seen a significant reduction in the prevalence of stunting in children under 5 years, the prevalence remains very high (from 42.6% in 2012 to 36.4% in 2022) (4). In particular, according to the Demographic Health Survey for Mozambique 2022–2023 (8), the prevalence of chronic malnutrition in 2022 was 37%, with regional differences; in particular, the prevalence of chronic malnutrition was higher in the northern regions and lower in the Maputo region. In Sofala province, the prevalence of chronic malnutrition was 30% (8).

In addition, in 2020, the number of children under 5 years who presented acute malnutrition was 3.9% (4). The Mozambican government has made reducing malnutrition a top priority, utilizing both national and international plans to promote food security and nutrition actions in order to support child health and fight malnutrition. For example, some of the focuses of the Multisectoral Action Plan for the Reduction of Chronic Undernutrition in Mozambique 2011–2015 (2020) are the reduction of low birth weight and chronic malnutrition, the promotion of exclusive breastfeeding in the first 6 months of age and to guarantee of at least three meals a day (9). These objectives are also addressed in the National Strategy for Infant and Young Child Feeding (10).

Nonetheless, chronic malnutrition remains at 35%, and it is necessary to conduct regular evaluations and provide additional nutrition education to health professionals in order to enhance the supply chain for nutrition.

Several studies on malnutrition in Mozambique are available, but as far as we know, very few focus on nutritional practices in the first year of life. The study of Marroda et al., conducted in the district of Namuno in Cabo Delgado (Mozambique), evaluated the nutritional practices in the first 2 years of life and found that the WHO indicators were not fulfilled (11).

Furthermore, the DHS data showed that the percentage of children receiving exclusive breastfeeding decreased with the increasing age of the baby, with only one-third of children receiving exclusive breastfeeding in the age group of 4–5 months. Moreover, among children aged 12–23 months, only 68% still had some breastfeeding (8). Regarding complementary feeding (CF), 79% of infants were introduced to solid, semisolid, or soft foods by 6–8 months of age, 15% of breastfed infants aged 6–23 months received a minimal dietary diversity, while 29% received minimal meal frequency and 5% had a minimally acceptable diet (8).

To the best of our knowledge, no studies on this topic have been done specifically in the district of Beira, Sofala Province.

Therefore, the main objective of this study was to analyze the nutritional practices in the first year of life in Beira, Mozambique, particularly focusing on complementary nutrition in a group of children in a low-resource setting, and to compare them to the international guidelines to know which are the critical and the possible improvement points to fight malnutrition.

A secondary objective was to study the nutritional practices in a group of malnourished (M) versus non-malnourished (NM) children.

Materials and methods

Study design

This is an observational study that retrospectively described nutritional practices in children during their first year of life.

Population

Children aged between 6 and 23 months, admitted to the non-intensive care units of the Pediatrics Department of the Central Hospital of Beira (Mozambique), were included in the study. Exclusion criteria were as follows: children suffering from genetic disorders, chronic diseases (apart from HIV infection), or major malformations.

Setting

The study was conducted at the Pediatrics Department of the Central Hospital of Beira, Mozambique. It is a 1,040-bed referral hospital in the Sofala province, a geographical area that covers approximately 1.7 million people.

Data collection

Data were collected through a questionnaire administered two times a week between September 2018 and February 2019 to mothers or caregivers of children who met the inclusion criteria. Chronic malnutrition was defined as height-for-age z-score <-2, and normal nutritional status was defined as weight-for-length/height z-score >-1 and height-for-age z-score >-2.

Further data were obtained and/or verified by accessing the patient's medical record.

The questionnaire was developed based on the 2001 WHO document on CF (12), the 2017 ESPGHAN guidelines on CF (13), and the 2007 WHO document on indicators for assessing infant and young child feeding practices (14).

The questionnaire was not pilot-tested to determine its validity and reliability.

The questionnaire was composed into seven sections (see Supplementary data Sheet).

In the first two sections, demographic data and health information were collected relating to the child (sex, date of birth, gestational age at birth, chronological age, and serological status for HIV infection) and the mother (age, number of pregnancies, number of children, abortions and dead children, and HIV serological status). Children's HIV status was confirmed by blood polymerase chain reaction (PCR) for HIV.

In the third section, child anthropometric parameters at birth and at the time of the evaluation were recorded. The anthropometric parameters considered were weight, length, and head circumference at birth and at the time of the visit. The weight, expressed in kilograms (kg), was measured using scales Laica®; the length, expressed in centimeters (cm), was measured using an infantometer Gima®; the head circumference, expressed in centimeters (cm), was measured with a flexible tape measure; the mid-upper arm circumference, measured at the time of the visit, expressed in centimeters (cm), was measured using a special metric bracelet. These measures were then transformed into percentiles using the reference growth charts: Fenton 2003 growth charts (15) for the anthropometric parameters at birth in case of gestational weeks (GWs) < 37; the WHO 2006 growth charts (16) for the anthropometric parameters at birth in case of GWs ≥ 37 and for the anthropometric parameters measured at the time of evaluation. The percentile calculation was performed using "The WHO anthro software for PC, version 3.2.2."

The fourth part of the questionnaire concerned breastfeeding practices. Data were collected relating to the kind and frequency of milk administered in the first 12 months of life (maternal, formula, or others) and, at the time of investigation, if there was the sterilization of the teats and if the water used for the reconstitution of powdered milk was boiled; finally, the age of discontinuation of breastfeeding was assessed.

The fifth section of the questionnaire concerned CF practices. In the first part, data were collected on how to start weaning (age of introduction of the first food, motivation, and the sequence of introduction of the first foods). Furthermore, the type and frequency of milk consumed daily in conjunction with the CF, and the frequency of non-milk meals during the day, were evaluated. In the second part of the section, information was requested about the time of introduction of numerous types of food (cereals, roots, tubers, legumes and nuts, dairy products, meat, fish, eggs, fruit, vegetables, oil, butter, salt, sugar, spices, water, and sugary drinks).

Through the data collected, adherence to the WHO indicators for the evaluation of feeding practices in early childhood was verified for indicators 2 (exclusive breastfeeding under 6 months), 3 (continued breastfeeding at 1 year), 4 (introduction of solid, semisolid, or soft foods), 5 (minimum dietary diversity), 6 (minimum meal frequency), 7 (minimum acceptable diet), 9 (children ever breastfed), 10 (continued breastfeeding at 2 years), 11 (age-appropriate breastfeeding), 13 (duration of breastfeeding), 14 (bottle feeding), and 15 (milk feeding frequency for non-breastfed children) (14).

Ethical consideration

The study was approved by the Direction of the Beira Central Hospital (N°729/024.1/GDCP-HCBeira/2017), and we collected data in an anonymous form. We explained the study objectives to the caregivers, and they were free to accept or not to answer the study questionnaire.

Data analysis

Population characteristics were described using the mean ± standard deviation or the median and interquartile range (IQR; Quartiles I–III).

Statistically significant differences between groups were assessed using the chi-squared test (or Fisher's exact test for small sample sizes) for categorical variables, and the Mann–Whitney U-test for continuous variables. Finally, we performed a multivariable logistic regression with a stepwise method to detect variables associated with chronic malnutrition. We used a stepwise selection approach, combining forward selection and backward elimination. Specifically, we added relevant variables based on a significance threshold of $p < 0.05$. After each addition, we checked whether any included variables should be removed due to $p > 0.10$. The final model was selected when no further changes improved its fit and when it had the lowest Akaike Information Criterion (AIC) value.

Variables considered for inclusion were chosen based on theoretical relevance from the available literature and on variables that were significant in stratified analyses.

Data management was performed using Microsoft Excel Office 365 ®(Microsoft Corporation) and statistical analysis with Jamovi (The Jamovi project 2023), Jamovi (version 2.3), and Software R (R Core Team 2022).

Significance was set at $p < 0.05$.

Results

Descriptive analysis: subjects of the study

A total of 103 children were included in the study (they satisfied the inclusion criteria, and the caregiver accepted to fulfill the

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questionnaire); the median age at the time of administration of the questionnaire was 19 months (IQR: 15–23.5). Among these, 49 (48%) were male and 54 (52%) were female. The median gestational age at birth was 39 (IQR: 37–40) GWs. The median birth weight was 2,900 g (IQR: 2,600–3,200) with a median percentile of 23 (IQR: 11–58) (Table 1). The mothers of these children had a median age of 25 years (IQR: 21–29), two children (IQR: 1–3), and two pregnancies (IQR: 1–3). Additionally, 17 women (18%) reported having at least one dead child. Overall, 42 (44%) mothers and 24 (24%) children were HIV positive. Anthropometric measures at the time of the study are reported in Table 2.

Descriptive analysis: nutritional practices

Concerning nutritional practices, 72 children (70%) had exclusive breast milk, 29 (28%) had breast milk and formula milk, and two (2%) had only formula milk until the beginning of CF. Concerning the WHO indicator 2 (12), 55% of subjects practiced exclusive breastfeeding until 6 months of age, 76% continued to have breast milk until 12 months and 8% up to 24 months.

During the CF phase, breast milk was continued by 57 (55%), while 26 (25%) had breast milk and formula, 15 (15%) only formula milk and 5 (5%) did not receive any milk. The median age at which breastfeeding was discontinued was 12.5 months (IQR: 7.20–16).

Only 12 (29%) used boiled water and sterilized the bottle when using formula milk.

The introduction of the first complementary food, made in 43% of cases with millet flour, occurred on average at 6 months (IQR: 5–6). The main reason for starting CF was baby's excessive crying with breastfeeding alone (61%); the second most frequent reason was the mother's knowledge of the timing of starting CF (18%). Nonetheless, in some cases, the age of initiation of CF deviated greatly from the WHO recommendations: out of a total of 103 subjects, for two (1.9%) children, the introduction of the first food was at 2 months, for seven (6.8%) at 3 months, and for four (3.9%) at 8 or 9 months.

At the time of the interview, children ate a median of 3 (3–4) meals per day, and 68% used a dedicated plate.

The first food was 'gruel,' made using 43% millet flour, 26% with an industrial multicereal product (Cerelac Nestlè), 10% corn flour, 9% rice flour, and 12% other unspecified types of flour.

Figure 1 shows the percentage of children who had already been introduced to each type of food at the time of the survey, and Figure 2 shows the ages of introduction in months of the various types of food.

Cereals, fruits, and vegetables had already been introduced to all children by the time of the interview, but there were greater discrepancies regarding other protein sources. In particular, 4% of children had not yet been introduced to legumes and nuts at the time of the interview, and the same can be said of meat and fish (5%). Eggs were introduced by 70% of children, and dairy products were introduced by 61%. Regarding meat and fish, fish was introduced by a greater number of children than meat, respectively, by 97 (94%) and 80 (77.7%).

Sugar and salt were introduced on average at 6 months, and sugary drinks at 9 months. In particular, sugar was consumed by 94% of children, while sugary drinks by 58%.

The condiment most already introduced was oil (85%), while for butter and olive oil; the percentage of children who had not yet consumed them was higher, 61 and 73%, respectively.

Finally, spices had already been introduced by 43% of children at the time of the interview.

Cereals were introduced at a median age of 6 months, followed by fruit, vegetables, legumes, and dairy products at a median age of 7 months (IQR: 7–9, IQR: 6–9, and IQR: 6–9, respectively). Meat, fish, and eggs were introduced at a median of 9 months (IQR: 7–12 and IQR: 7–12, respectively).

Regarding drinks, water was introduced on average at six (IQR: 5.50–6) months, while soft drinks at 9.50 months (IQR: 8–12) with a median weekly consumption of 2.5 times. Finally, for cow's milk, data are available for only seven children, but it was introduced on average at 12 (IQR: 9–18) months.

From the analysis of the WHO indicators for the evaluation of feeding practices in infancy, it emerges that 55% of children were exclusively breastfed up to 6 months of age, 76% continued to have breast milk until 12 months, and 8% up to 24 months. The average duration of breast milk intake was 12 months. The minimum

TABLE 1 Anthropometric data at birth.

	Median value (I–III quartile) at birth	Percentile (I–III quartile) at birth
Weight (g)	2,900 (2,600–3,200)	23.00 (11.00–58.00)
Height (cm)	48.00 (44.00–49.00)	21.45 (5.05–52.40)
Head circumference (cm)	34.00 (32.00–35.00)	35.80 (2.80–66.40)

TABLE 2 Anthropometric data at the time of the study.

	Median value (1^–3^ quartile) at the time of the study	Percentile (1^–3^ quartile) at the time of the study
Weight (g)	8.50 (7.00–10.00)	2.35 (0.00–35.30)
Height (cm)	74.00 (70.00–82.00)	1.30 (0.00–22.27)
Head circumference (cm)	45.50 (44.00–47.00)	24.70 (2.30–64.00)
Arm circumference (cm)	13.00 (12.00–15.00)	6.70 (0.08–53.75)

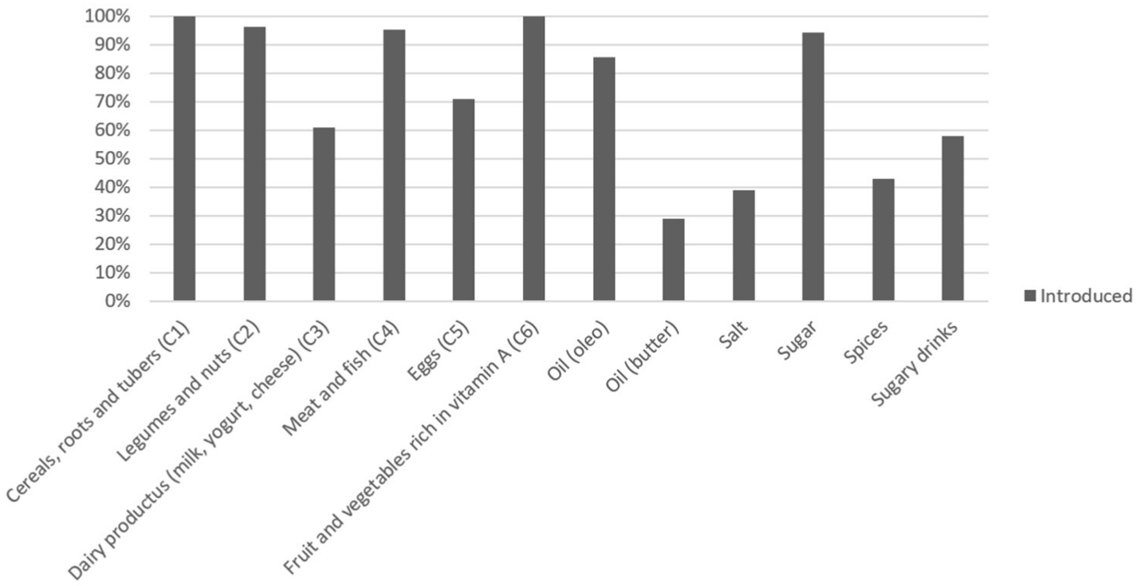

FIGURE 1
Percentage of children who had already introduced each type of food at the time of the survey.

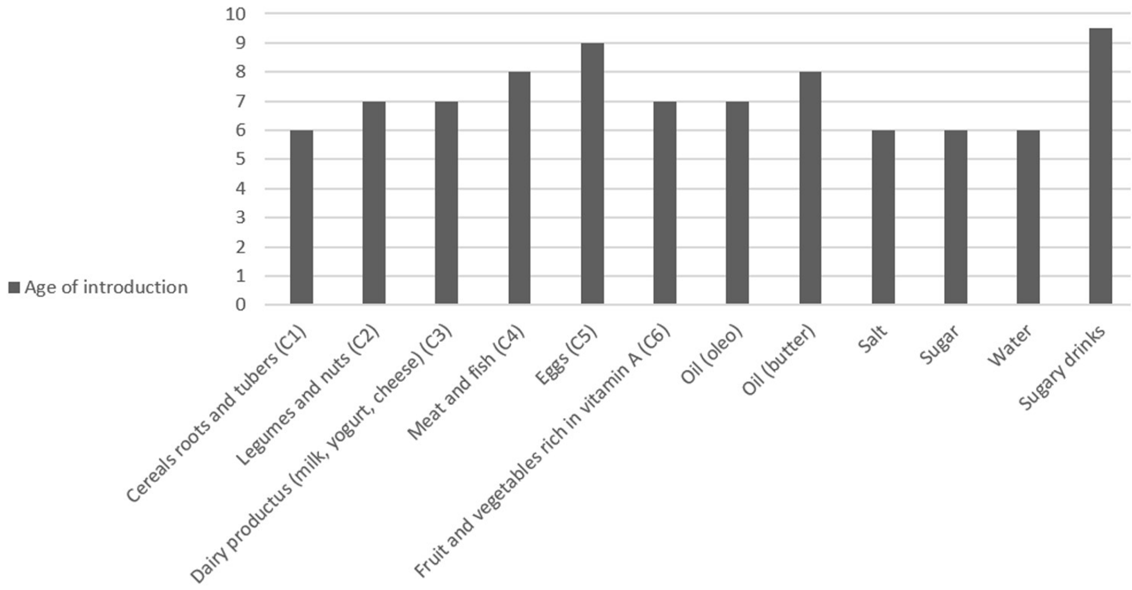

FIGURE 2
Ages of introduction in months of various type of food.

frequency of meals was found to be adequate at 80%, dietary diversity at 42%, and a minimum acceptable diet at 36% (Table 3).

Comparative analysis: subjects of the study

We then analyzed M versus NM children. NM and M Children were comparable in terms of gestational age at birth and age at the time of the interview (Table 4). Furthermore, no significant differences were found in sex distribution in the two groups (p-value 0.35). In both groups, mothers were 25 years old and had two (1–3) children each.

HIV infection was more present in the group of cases than in the controls: 54% mothers and 35% children versus 30% mothers and 11% children ($p = 0.01$ and $p = 0.02$, respectively).

Birthweight and the relative percentile were statistically significantly lower in cases than in controls: the median weight at birth of children with chronic malnutrition was 2,800 g with a median percentile of 23, while in healthy children, the median values were 3,095 g and 42 (see Table 5).

TABLE 3 Outcome of the WHO indicators for the evaluation of dietary practices in the 103 subjects of study (2007).

Indicators	% size of the sample*	Results
2-exclusive breastfeeding under 6 months	100%	55%
3-continued breastfeeding at 1 year	93%	76%
4-introduction of solid, semisolid, or soft foods	100%	71%
5-minimum dietary diversity	81.60%	42%
6-minimum meal frequency	98%	80%
7-minimum acceptable diet	83.50%	36%
9-children ever breastfed	84.50%	28%
10-continued breastfeeding at 2 years	36.90%	8%
11-age-appropriate breastfeeding	82.50%	34%
13-duration of breastfeeding	82.50%	12 months
14-bottle feeding	78.60%	30%
15-milk feeding frequency for non-breastfed children	64.10%	33%

*% size of the sample in which the indicator was calculated.

TABLE 4 Gestational age at birth and age at the time of the interview in the two groups.

	M		NM		*p*-value
	Median value (I–III quartile)	Percentile (I–III quartile)	Median value (I–III quartile)	Percentile (I–III quartile)	
Gestational age at birth	39.00	37.00–40.00	39.00	37.00–40.00	1.00
Age at the time of the study (months)	19.00	15.00–23.00	20.00	13.50–25.00	0.47

TABLE 5 Anthropometric data at birth in the two groups.

	M		NM		*p*-value	
	Median value (I–III quartile)	Percentile (I–III quartile)	Median value(I–III quartile)	Percentile (I–III quartile)	Median value	Percentile
Weight (g)	2.80 (2.60–3.00)	23.00 (7.00–34.00)	3.10 (2.80–3.46)	42.00 (23.00–72.00)	0.00	0.01
Height (cm)	47.00 (43.00–49.00)	14.20 (0.82–52.10)	48.50 (48.00–49.00)	31.65 (15.99–77.75)	0.07	0.25
Head circumference (cm)	34.00 (31.20–35.00)	36.00 (5.60–96.30)	34.00 (32.00–34.00)	35.80 (2.60–54.10)	0.91	0.28

Comparative analysis: nutritional practices

Considering 73% of cases and 66% of controls received exclusive breastfeeding (*p*-value 0.42). Once the introduction of complementary foods began, 55% of cases and 57% of controls continued to have breast milk (*p*-value 0.77). In particular, during weaning, 5% of children with chronic malnutrition did not have any type of milk.

Considering the WHO indicator number 3 (continued breastfeeding at 1 year), 74% of cases and 79% of controls still had breast milk at 12 months (*p*-value 0.53).

The stop of breast milk's administration occurred at a median (IQ) of 12 (7.50–15.00) months in cases and 13.5 in (7.80–17.20) in controls (*p*-value 0.34). At 2 years, however (the WHO indicator number 10, continued breastfeeding at 2 years), 6% of cases and 10% of controls were still receiving breast milk (*p*-value 0.68).

Crying was the main reason for introducing complementary foods for 71% of cases and 48% of controls (*p*-value 0.61). For both groups, the second most frequent motivation was the mother's knowledge of the child's feeding practices, which concerned 13% of cases and 25% of controls (*p*-value 0.18).

In both groups, the majority of children ate a corn flour-based meal as their first food, and no significant differences were found between the two groups in the distribution of the other flours used (Figure 3).

The study did not highlight statistically significant differences in the percentage and age of introduction of the various classes of foods.

The controls introduced dairy products at a median age of 7 (IQR: 6.0–9.0) months, while cases at a median age of 8.5 (IQR: 6.0–12.0) months. M children ate dairy products 3.0 (IQR: 1.0–7.0) times a week, while NM children 5.0 (IQR: 1.0–7.0) times a week. At the time of the survey, 48% of M and 28% of NM children had not introduced dairy products into their diet yet (*p-value 0.033*).

Water was introduced at a median of 6 months in both M and NM children.

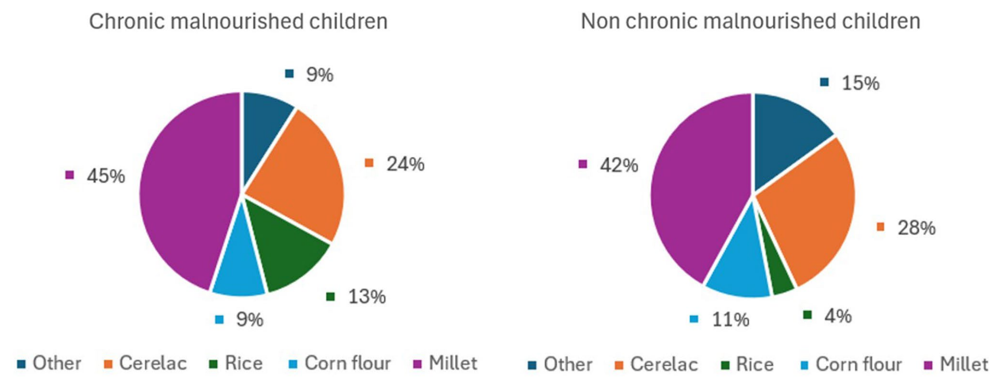

FIGURE 3
Distribution of the type of flour used in the first food in the two groups (M and NM).

TABLE 6 WHO indicators for the evaluation of childhood feeding practices in cases (M) and controls (NM).

WHO indicators	M		NM		*p-value*
	% values	sample size	% values	sample size	
2-exclusive breastfeeding under 6 months	57%	56	53%	47	0.69
3-continued breastfeeding at 1 year	74%	53	79%	43	0.53
4-introduction of solid, semisolid, or soft foods	70%	56	72%	47	0.76
5-minimum dietary diversity	38%	48	47%	36	0.37
6-minimum meal frequency	78%	55	83%	46	0.58
7-minimum acceptable diet	33%	49	41%	37	0.45
9-children ever breastfed	17%	47	40%	40	**0.02**
10-continued breastfeeding at 2 years	6%	17	10%	21	0.68
11-age-appropriate breastfeeding	20%	46	51%	39	**0.00**
13-duration of breastfeeding	12 months		12 months		0.86
14-bottle feeding	26%	43	34%	38	0.40
15-milk feeding frequency for non-breastfed children	28%	40	42%	26	0.21

Cow's milk was introduced to one child in the control group at a median age of 13.5 months, and to three children in the case group at a median age of 12 months.

In both cases and controls, salt, sugar, spices, and soft drinks were, in most cases, introduced before 1 year of age.

At the time of the survey, children ate a median of 3 meals a day in M and 3.5 in NM ($p = 0.6$) and used a dedicated plate in 70 and 65%, respectively (p-value 0.58).

Finally, among the WHO indicators for the evaluation of childhood feeding practices, statistically significant differences were found in relation to indicators 9 and 11: the percentages of children who were ever breastfed and had breast milk during the introduction of CF were found higher in controls than in cases (Table 6).

Factors associated with chronic malnutrition

From the multivariable logistic regression, it emerged that risk factors for chronic malnutrition were HIV infection of both mother and child (OR: 7.50, CI: 1.6–35.09, $p = 0.01$) and the initiation of CF without awareness (OR: 4.35, CI: 1.45–13.05, $p = 0.01$). Instead, early and frequent consumption of dairy products (OR: 0.09, CI: 0.02–0.56, $p = 0.01$) and breastfeeding during CF (OR: 0.34, CI 0.10–1.14, $p = 0.08$) were found to be protective factors (Table 7).

Discussion

Chronic malnutrition early in life is considered a public health problem since it exposes the rapidly growing child to often irreversible adverse outcomes in the short- and long-term periods, such as neurodevelopmental disorders (17, 18), increased susceptibility to infections (19–23) and, in adulthood, metabolic disorders and related diseases (17).

Based on these assumptions, the aim of our study was to analyze the nutritional practices in the first year of life in a group of children in a low-resource setting and to evaluate the adherence to international guidelines. A secondary objective was to study the nutritional practices in a group of M versus NM children.

TABLE 7 Results from the third multivariate analysis: event = chronic malnutrition ($p < 0.001$).

	Coefficient	Odds ratio (OR)	Confidence interval OR	Significance
Intercept	−0.20	–	–	0.762
HIV				
"Mother only"	0.24	1.27	0.36–4.50	0.714
"Both"	2.02	7.50	1.60–35.09	**0.010**
"Nobody"	–	1	–	–
C3_T3				
"≤8 months and ≥7 times/ week"	−2.37	0.09	0.02–0.56	**0.010**
"Other"	−0.56	0.57	0.19–1.74	0.323
"Never"	–	1	–	–
Reason: crying	1.47	4.35	1.45–13.05	**0.009**
Still breastfeeding (yes vs no)	−1.09	0.34	0.10–1.14	**0.081**

Relative to breastfeeding practice, among the study population, breastfeeding lasted less than recommended (14).

International societies recommend promoting exclusive breastfeeding for the first 6 months of life (24, 25) or for at least the first 4 months (i.e., 17 weeks, the beginning of the 5th month), while still considering it a desirable goal to continue exclusive breastfeeding until 6 months of age (13). Nonetheless, even after the start of CF, it is recommended that the child continue breastfeeding until 2 years of the child's life, especially in low-resource countries, as it is a protective factor for health status (13, 24, 25). The WHO global goal for 2025 is to reach breastfeeding for 6 months at least 50% (26), which is in line with our results; nonetheless, it would be extremely important, and it is suggested to continue breastfeeding until 2 years or beyond.

The median age of breastmilk cessation (12.5 months), in fact, deviates from these suggestions (13, 24, 25), and this finding takes on particular importance considering that Mozambique is a low-income country, where poverty also results in poor access to quantitatively and qualitatively adequate food. It is precisely in these cases, in fact, that continuing breastfeeding until at least 2 years of age is important to help meet the child's caloric and nutritional needs, decreasing the risk of developing malnutrition (13).

Furthermore, we found that only 29% of mothers used boiled water for milk replenishment, and only 29% sterilized their baby's bottles. Considering the tropical climate and the high prevalence of infectious diseases in Mozambique, the lack of proper hygiene practices contributes to an increased risk of infectious diseases, which, on the one hand, predisposes to a higher risk of developing chronic malnutrition, and on the other hand is inherently more frequent in M individuals, as they are generally immunocompromised.

Concerning CF, we found that while the introduction of CF occurred at a median age of 6 months, there were wide ranges (min 2, max 9 months). Early introduction at 2 or 3 months was motivated by maternal agalactia or erroneous family beliefs. According to a study by Lutter et al. (27), this is associated with several potential risks: incomplete and inadequate infant development to consume food, increased morbidity due to gastrointestinal illnesses if water or food were contaminated, and potential risk of malnutrition since in low-resource countries complementary foods often have a lower nutritional quality than breast milk (24, 27). On the other hand, when the first food was introduced late, parents justified the decision by stating that the child seemed to be satisfied with breastfeeding alone. Late introduction of CF is associated with the inadequate introduction of nutrients essential for growth and development, especially iron, increased risk of food allergies, and decreased likelihood that the child will later accept a wide range of flavors and foods (27, 28).

In our study, mothers' reasons for initiating CF denoted a lack of education in nutritional requirements. In fact, the main reason for introduction was baby's crying (61%, or 56 children), as also reported in some studies (29, 30).

From our results, Mozambican children's first food is 'gruel', a soft consistency food composed mainly of flour and water. To make this gruel, most mothers (43%) used millet flour. It is not known whether the choice to use gluten-free flour was made on purpose or was merely due to its availability. In contrast to other traditions, where fruit puree is often the first food (31), the study found that, in Mozambique, the median age of fruit introduction was 7 months.

Considering the composition of the first baby food, it is possible to identify the first two inadequate feeding practices: in the study, in fact, the median age of introduction of sugar and salt was 6 months. In contrast, international societies suggest that neither sugar nor salt should be added to baby's food (13) and, indeed, their introduction should be delayed to at least 2 years and 1 year, respectively. However, it is important to consider that sugar is a low-priced and readily available food even in low-resource countries. Thus, it could be hypothesized that although there is evidence that, in the long term, high-sugar consumption may have adverse health effects (32), it was introduced for the reasons just mentioned.

At the time of the survey, children were taking a median of 3 (3–4) meals per day and were using a dedicated plate in 68% of cases. Confirming this, the WHO indicator number 6 (14) on minimum meal frequency was positive in 80% of cases. On the other hand, the indicator of minimally acceptable diet [the WHO indicator number 7 (14)] was present in only 36% of the sample, and the indicator of minimal dietary diversity [number 5 (14)] was satisfied in only 42% of cases. In fact, at the time of the survey, the entire group of children with a median age of 19 months had already introduced fruits and vegetables, but the same cannot be said for protein sources. The reasons for all children's failure to introduce the various protein sources may be a lack of food availability/ affordability or a lack of mother's knowledge about how the family diet should be composed in order to be nutritionally complete. Our results confirm what has been described among the risk factors for chronic malnutrition: even in cases where caloric needs are met, various other factors can contribute to the onset of this condition, including a diet that is qualitatively poor, not very varied, or with low consumption of animal foods (17).

Considering the age of introduction of various foods, international guidelines (24) do not provide a fixed and precise timing but suggest considering traditions, culture, and ethical or religious choices (13). In addition, usually, it was recommended that cow's milk should not be used before 12 months of age as it is poor in iron; however, the WHO says that introducing non-human milk after 6 months could be a safe choice if accompanied by complementary foods since the occult blood losses in infants 6–11 months of age are very minor and not likely to affect iron status (33). Gluten should be introduced between 4 and 12 months of age, avoiding large amounts (13). According to the guidelines, allergenic foods can also be introduced after 4 months (17 weeks), without distinguishing between other complementary foods (13, 34–36). Finally, it is interesting to note that 43% of children at the time of the interview had already introduced spices, probably due in part to traditional cooking.

In our study, another important error in feeding concerns soft drinks: although water was properly introduced at a median age of 6 months, that is, in parallel with the start of CF, sugary and carbonated soft drinks were introduced at a median age of 9 months although guidelines advise against their intake at any age but, in particular, during CF. At this age, in fact, the child develops a preference for the tastes to which he or she is most exposed (13).

This second part of the study then involved a comparative analysis between children with chronic malnutrition and children with normal nutritional status. Considering the percentages of both sexes within the groups, it appears that the number of males is higher in cases (52%) than in controls (43%), and the opposite can be said for females. This finding does not reach statistical significance but seems to be in agreement with articles in the literature suggesting a higher prevalence of chronic malnutrition in males (37).

Analysis of anthropometric data at birth shows that the percentiles of cases were statistically lower than controls. In fact, while the median weight of children with chronic malnutrition was 2,800 g with a median percentile of 23, in the healthy, the median values were 3,095 g and a median percentile of 42. The same result was reported for length. The same conclusions could not be drawn for head circumference, as the number of subjects reporting it was too small to allow for the assessment of statistical significance. As expected, considering instead the measurements made at the time of the survey, the differences between the two groups become more pronounced.

The study outlined the higher prevalence of malnutrition in HIV-infected children, an infection that had a prevalence of 7.3% in 2022 in Mozambique (38). In fact, HIV and malnutrition often have a two-way relationship (39–44), where each condition interacts with and exacerbates the other, increasing vulnerability to infection and further worsening health status (43). HIV can be transmitted from mother to child during pregnancy, childbirth and/or breastfeeding (44, 45). In order to protect the health of both mother and child, in 2016, the WHO published guidelines on this issue (24), which emphasized that pharmacologically treated HIV infection is not a contraindication to pregnancy or even breastfeeding and, indeed, that breastfeeding is recommended even up to 2 years of age or at least until supplementary feeding alone can provide sufficient amounts of energy, macro- and micronutrients to the child. In case the mother is HIV-positive, to prevent transmission of the infection to the child, the child is given drugs from birth until 6 weeks of age if the mother is taking antiretroviral therapy or until 1 week after breastfeeding stops if the mother is not taking the therapy (46).

Considering breastfeeding and CF practices, it is interesting to note that the comparative analysis did not show statistically significant differences in most of the variables investigated, with the exception of two WHO indicators (14) for the evaluation of feeding practices. The first indicator relates to the percentage of children under 2 years of age who always received breast milk, and the second indicator relates to the adequacy of breast milk intake in relation to other foods in children under 2 years of age. Both indicators were significantly lower in the case group, which seems to imply that among the protective factors toward chronic malnutrition, breastfeeding carried out in a continuous and prolonged manner may also be considered. In this regard, although studies available in the literature have drawn conflicting conclusions (47–51), the WHO maintains that it is good practice to breastfeed exclusively during the first 6 months, continuing until 12 months and hopefully until 24 months or as long as breastfeeding is agreeable and safe for both baby and mother (13). The rationale for these recommendations lies in the innumerable benefits that seem to be associated with breastfeeding for both mother and baby. For example, benefits for the baby include protection from infections [especially gastrointestinal (24), respiratory, and ear (52, 53)], improved intestinal microflora (54), and the resulting decrease in mortality from all causes, from diarrhea (55), that among M infants (24), and, if breastfeeding within an hour of birth, even neonatal mortality in general (24, 56). The same benefits have also been found with complementary breastfeeding, although obviously to a lesser extent than with exclusive breastfeeding (19). Despite this, exclusive breast milk intake is still suboptimal, so much so that one of the WHO goals for 2025 is to increase the percentage of exclusive breastfeeding to at least 50% (57).

No significant differences were found in any of the WHO indicators (55) related to CF, probably because of the low numerosity of the sample, but, nevertheless, in the group of children with chronic malnutrition, the percentages concerning minimal dietary diversity, minimal food frequency (indicator number 6) and minimally acceptable diet are lower. Children with chronic malnutrition have a less varied and adequate diet and consume fewer meals during the day; these data need to be taken into consideration. Statistically significant differences in CF practices were detected in the frequency of weekly consumption of dairy products, which was higher in controls than cases. It can be inferred that this is due to the good nutritional values of milk and dairy products: these provide protein, minerals, vitamins, and fatty acids and, in the case of yogurt, also probiotics, which are protective against infections (58). However, it should be considered that milk and dairy products are not typical Mozambican products, so they may be available only to those with greater economic resources or greater awareness regarding the beneficial effects.

Compared to the data in the literature, this study confirmed low-birth-weight percentile as a risk factor (59, 60) for chronic malnutrition. Nonetheless, regarding low birth weight, applying multivariate logistic regression, a weight of less than 10 percentile exposes a 3.56 times higher risk of chronic malnutrition than subjects with normal anthropometric parameters (OR: 3.56). However, it is very interesting that although statistical significance is not reached, those born with a weight percentile between 11 and 25, and less considered, are also exposed to an increased risk of chronic malnutrition (2.5 times).

Our study outlines that low birth weight is thus one of the major risk factors for the development of chronic malnutrition (59, 60) and that being under 25° percentile could be a risk factor. Nutritional deficits during fetal life increase the risk of maintaining this issue throughout life. This appears to be related to the nutritional status of the mother during the gestational period: pregnant women with chronic malnutrition generate offspring with lower birth weight (61–63). Children suffering from HIV together with their mother had a risk of 7.5 times being M, as those with a birth weight below 10° percentile (3.26 times) and having a mother not prepared to start CF (4.25 times). In contrast, the mother's age of less than 20 years, often associated with an increased risk of malnutrition (46), was not found to be a risk factor in this study.

The start of CF due to infant crying increased the risk by more than 4-fold. Therefore, this underscores the need to intensify nutrition educational projects and counseling. The introduction of dairy products <8 months is instead a protective factor. Interestingly, the WHO stated that infants 6–11 months of age fed milk other than breast milk, either milk formula or animal milk, can be fed (conditional, low-certainty evidence). This, in fact, could be due to the consideration that the risk of malnutrition would overcome the risk of anemia, which is also reduced in children >6 months (33).

It would be useful to consider implementing nutritional interventions in pregnancy and once the baby is born in order to improve the nutritional status of pregnant women and also to increase awareness of the importance of breastfeeding and nutrition in the first years of life (in particular, during CF).

Our study has some limitations; in particular, the limited number of patients could not have allowed us to find more statistically significant differences between chronic M and NM children, though this was a secondary objective. Another limit could be the self-reporting of some of the responses.

Conclusion

In our population, while complementary nutrition started at an adequate age, there was a wide range in the timing of introduction. Furthermore, the percentage of children with a minimally acceptable diet was low, feeding with human milk could be increased, and CF mistakes (early introduction of sugar/salt and soft drinks introduction) should be corrected.

Our findings highlight the need to raise awareness of the importance of timely and appropriate CF composition and that in order to prevent malnutrition, human milk feeding should be expanded. The attention on children suffering from HIV, with lower birth weight, and with less breastfeeding and dairy product consumption should be increased to prevent malnutrition.

Additional interventions focusing on nutritional practices and maternal education will help us establish practices that improve children's nutritional status.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Direction of the Beira Central Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

SC: Investigation, Supervision, Writing – original draft, Writing – review & editing. IA: Investigation, Writing – original draft, Writing – review & editing. AV: Investigation, Writing – original draft, Writing – review & editing. AZ; —. CG: Methodology, Writing – original draft, Writing – review & editing. BC: Writing – review & editing. AM: Writing – review & editing. IR: Data curation, Methodology, Writing – review & editing. LD: Conceptualization, Supervision, Writing – review & editing. PG: Supervision, Validation, Writing – review & editing. GV: Conceptualization, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The authors declare that no Gen AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2025.1553572/full#supplementary-material

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Prevalence, spatial distribution, and determinants of wasting among children under five in Senegal: spatial and multilevel analyses of the 2023 Senegal Demographic and Health Survey

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Introduction: Child undernutrition remains a persistent public health challenge across sub-Saharan Africa. Wasting, which is characterized by severe muscle wasting and heightened vulnerability to morbidity and mortality, poses a particularly grave concern in the region. Recently, Senegal's children faced a number of socioeconomic challenges, including the lingering effects of the COVID-19 pandemic, disruptions caused by the war between Russia and Ukraine, persistent security threats from the Sahel crisis, and internal socio-political tensions. Hence, this study aimed to assess the prevalence, spatial distribution, and determinants of wasting among children under five in Senegal.

Method: A secondary analysis of the 2023 Senegal Demographic and Survey dataset was conducted. A total weighted sample of 4,392 children under the age of 5 years was included in the analysis. ArcGIS 10.7 and Stata 17 were utilized for spatial analysis and multilevel regression, respectively. The fixed effect was evaluated by calculating the adjusted odds ratio with a 95% confidence interval. We considered the association between explanatory variables and outcomes to be significant when the p-value was less than the predetermined level of significance (0.05).

Result: The prevalence of wasting among children under the age of five in Senegal was 10.29% at a 95% CI of 9.42 to 11.24%. Childhood wasting exhibited a clustered pattern across regions of Senegal. The hot spot clusters of elevated wasting prevalence were found to be concentrated in the Diourbel, Tambacounda, and Matam regions of Senegal. Small birth size, poor household wealth index, rural residence, and region were significant determinants of wasting among children under 5 years old.

Conclusion: Childhood wasting remains a significant public health concern in Senegal, with a prevalence much higher than the global 2025 target. Spatial clustering of high wasting prevalence in the Diourbel, Tambacounda, and Matam regions highlights the need for targeted interventions in these high-risk areas. The identified risk factors, including small birth size, poor household wealth, rural residence, and regional disparities, should guide the design and implementation of effective nutritional programs and policies. Addressing the underlying determinants of childhood wasting is crucial to improve child health and development outcomes in Senegal.

KEYWORDS

prevalence, spatial distribution, determinants, wasting, children, Senegal

Introduction

Child undernutrition remains a persistent public health challenge across sub-Saharan Africa. Wasting, the acute manifestation of malnutrition characterized by severe muscle wasting and heightened vulnerability to morbidity and mortality, poses a particularly grave concern in the region (1, 2). In 2023, an estimated 13.6 million children under five in sub-Saharan Africa were affected by wasting, accounting for over half the global burden of this life-threatening condition (3). For children under the age of five, wasting is defined as having a weight-for-height ratio that is more than 2 standard deviations below the median value in the World Health Organization (WHO) Child Growth Standards (4).

Senegal, a West African nation, has made notable progress in reducing child mortality and improving nutritional outcomes in recent decades (5–7). However, in 2023, Senegal's children faced a number of socioeconomic challenges, including the lingering effects of the COVID-19 pandemic, disruptions caused by the war between Russia and Ukraine, persistent security threats from the Sahel crisis, and internal socio-political tensions (8). While Senegal's economic growth rate exceeded the sub-Saharan African average, high inflation continued to impact families and children, leading to an increase in the prevalence of severe acute malnutrition from 8% in 2019 to 10.2% in 2023 (8).

Prior research has identified several factors associated with childhood wasting, including socioeconomic status, maternal education, access to healthcare, sanitation, and food security (7, 9–12). Despite these insights, gaps persist in our understanding of the regional and contextual factors underlying the ongoing public health challenge of persistent wasting across Senegal.

This study aimed to leverage the 2023 Senegal Demographic and Health Survey (SDHS) to conduct a comprehensive spatial and multilevel analysis of the prevalence, geographic patterning, and multilevel predictors of wasting among children under five in Senegal. Previous studies have primarily focused on national-level estimates, often overlooking subnational variations and the complex interplay of factors at different levels (13, 14). The 2023 SDHS provides a unique and comprehensive dataset that includes detailed geographic and multilevel data, making it particularly suited for this type of analysis. By integrating spatial epidemiological analysis with multilevel modeling techniques, this study builds on previous research by offering a more nuanced understanding of the spatial and multilevel determinants of wasting (14, 15).

Abbreviations: AOR, Adjusted odds ratio; AIC, Akaike's Information Criterion; BIC, Bayesian Information Criterion; CI, Confidence interval; DHS, Demographic and Health Survey; FDR: ICC, Intra-class correlation coefficient; MOR, Median odds ratio; LL, Log likelihood; LLR, log likelihood ratio; PCV, Proportional change in variance; RR, Relative risk; SDHS, Senegal Demographic and Health Survey; WHO, World Health Organization.

Spatial analysis allows us to identify and visualize the geographic distribution of wasting at a subnational level, revealing regional hotspots and patterns that may be masked in national-level analyses. This geographic perspective is crucial for understanding the spatial heterogeneity of wasting and for designing targeted interventions that address specific regional needs. Multilevel analysis, on the other hand, enables us to examine the complex interplay of factors at different levels—individual and community—that influence a child's nutritional status. By considering these multiple levels simultaneously, we can uncover how broader contextual factors, such as community socioeconomic status or access to healthcare, interact with individual and household characteristics to impact wasting. This comprehensive approach provides a deeper understanding of the determinants of wasting and helps identify leverage points for multisectoral strategies. The insights gained can inform the design of targeted, context-specific interventions and multisectoral strategies to address the underlying determinants of this pressing public health issue.

Methods

Data, sampling, and population

A secondary analysis of the 2023 Senegal Demographic and Survey dataset aimed to assess the prevalence, spatial distribution, and determinants of wasting among children under five. The DHS Program provides access to a wide range of datasets from surveys conducted across many countries. The available datasets can be accessed through their website at https://www.dhsprogram.com/data/available-datasets.cfm. The DHS data were made accessible to researchers and analysts through a formal request process managed by the MEASURE DHS program. Users can browse the available datasets and request access as needed for their research.

The Demographic and Health Survey (DHS) utilizes a robust sampling methodology to ensure the data are nationally representative. First, the country is divided into distinct strata based on relevant characteristics, such as urban/rural location or geographic regions. Within each stratum, the primary sampling units (clusters) are randomly selected, with these clusters typically comprising multiple households. In the second stage of sampling, a sample of households is drawn from within each selected cluster, using either a systematic or random approach.

Our study population consisted of all children under the age of 5 years who were residing in the sampled households. However, we excluded children who were missing key anthropometric data necessary for assessing their wasting status.

Variables of the study

The study's primary outcome was childhood wasting, which was assessed using the World Health Organization's (WHO) Child Growth

Standards (4). Specifically, children under 5 years of age were classified as experiencing wasting if their weight-for-height z-score was below −2 standard deviations (SD) from the WHO median (4). This measure, commonly referred to as childhood wasting, was used to evaluate the prevalence of this nutritional status indicator.

In terms of handling missing values, the researchers followed the guide to the Demographic and Health Survey (DHS) statistics. Children who were not weighed and measured, as well as those with missing weight and height values, were excluded from both the denominators and numerators. Furthermore, children flagged for out-of-range or invalid z-scores were also excluded from the denominators and numerators. This approach ensured that the analysis of childhood wasting was based on valid and reliable anthropometric data, and that the study's findings were representative of the target population.

In this study, the researchers considered explanatory variables at two levels: individual or household variables (first level) and community (cluster) level variables (second level). The first-level variables included the child's age, gender, birth size, maternal age, maternal educational status, maternal occupation, paternal educational status, paternal occupation, household size, wealth index, birth interval, antenatal care (ANC) visits, media exposure, type of birth, source of drinking water, and type of toilet facility. These variables were selected based on their relevance to the study's objectives and their consistent identification in previous research as significant predictors of childhood wasting. At the second level, the researchers examined community-related factors, such as the place of residence, community illiteracy rate, community media exposure, community poverty level, and region. These variables were selected based on their potential to capture broader contextual influences on a child's nutritional status. For instance, the place of residence (urban vs. rural) can significantly impact access to healthcare and nutritional resources. Community illiteracy rate and media exposure reflect the overall educational and informational environment, which can influence health behaviors and practices. Community poverty level indicates the economic conditions of the area, which can affect food security and access to services. The region was included to account for geographic variations in cultural, economic, and environmental factors.

Data management

The analysis utilized the children's recode (KR) datasets from the MEASURE DHS archive, which were extracted and loaded into Stata 17 for the formal statistical analysis. Prior to conducting the analysis, a thorough data cleaning process was undertaken. This involved checking for any duplicate records, as well as identifying and removing any implausible or invalid anthropometric measurements.

The analysis results were reported using weighted prevalence estimates and frequencies, presented in tables and bar charts. To account for the complex survey design of the DHS data, the analysis methodology incorporated the sampling weights provided in the dataset. Additionally, the standard errors of the regression coefficients were adjusted to reflect the probability of sample selection and the multistage cluster sampling approach. This ensures that the analysis estimates are representative of the target population and the statistical inferences drawn are valid.

Spatial analysis

To investigate the spatial dependency of zero-dose childhood immunization in Ethiopia, the researchers used spatial autocorrelation techniques. Specifically, they utilized an optimized hot spot analysis method to identify statistically significant spatial clusters of high (hot spots) and low (cold spots) rates of zero-dose children.

The optimized hot spot analysis, an extension of the traditional hot spot analysis (Getis-Ord Gi* statistic), was used to detect spatial clustering patterns. This technique examines the distribution of features and their surrounding neighbors to determine if there are any statistically significant aggregations (16). Additionally, it applies the false discovery rate (FDR) correction method to adjust the results for multiple testing and spatial dependence (16, 17).

Furthermore, the researchers utilized the spatial SaTScan statistics method, which involves scanning the study area using a circular window. The geographic coordinate data, including the cases (zero-dose children) and controls (non-zero dose children), were fitted to the Bernoulli model. For each potential cluster, the researchers calculated the log likelihood ratio (LLR), relative risk (RR), and *p*-values to assess whether the observed number of cases within the cluster was significantly higher than expected. Finally, the researchers used an interpolation technique called kriging to predict the rates of zero-dose childhood immunization in unsampled areas of Ethiopia, based on the observed data from the sampled areas.

Multilevel modeling

This study utilized data from the DHS, which contains information at both the household and cluster levels. To address the issue of non-independent observations, which is a requirement for standard logistic regression, we used mixed-effects models with a binary outcome variable. We fitted four different model specifications: a null model to assess the random effect and determine the appropriateness of multilevel regression, Model I, which included the outcome variables and first-level control variables, Model II, which incorporated the outcome variables and second-level control variables, and a final comprehensive Model III, which included all outcome variables, first-level controls, and second-level controls. By using this multilevel modeling approach, we accounted for the hierarchical structure of the DHS data and more effectively investigated the determinants of childhood wasting. The multilevel regression model was equated as follows (18):

$$\log\left(\frac{\Pi ij}{1-\Pi ij}\right) = \beta 0 + \beta 1x1ij + \ldots + \beta nxnij + \gamma 0 + \gamma 1z1ij + \ldots + \gamma mzmij + uoij$$

where πij represents the probability of wasting for the i^{th} child in the j^{th} cluster, while (1-πij) denotes the probability of the i^{th} child in the j^{th} cluster not experiencing wasting. The intercept term β0 characterizes the baseline of the regression equation. The coefficients β1 to βn are linked to the level 1 variables x1ij to xnij, which exert an influence on the response variable at the individual level. The intercept γ0j captures the random effect at level 2, while the coefficients γ1 to γm are associated with the level 2 variables z1ij to zmij, reflecting cluster-level effects. Finally, the error term eij accounts for the random error or residual within the model.

The researchers evaluated both the fixed and random components of the mixed-effects models. The random effect was assessed using the variance, intra-class correlation coefficient (ICC), median odds ratio (MOR), and proportional change in variation (PCV). The fixed effect was evaluated by calculating the adjusted odds ratio (AOR) with a 95% confidence interval (CI). We considered the association between explanatory variables and outcomes to be significant when the *p*-value was less than the predetermined level of significance (0.05). For model comparison, the researchers utilized the log likelihood, deviance, Akaike's Information Criterion (AIC), and Bayesian Information Criterion (BIC). To address multicollinearity, which can occur when two or more independent variables in a regression model are highly correlated, the researchers calculated the variance inflation factor (VIF) for each variable and found that VIF values were below five, indicating that multicollinearity was not a significant concern. Additionally, the researchers used multivariable regression techniques to control for potential confounding factors, which are variables that might be associated with both the independent and dependent variables and could influence the observed relationship. This approach allowed the researchers to isolate the effect of each independent variable on the dependent variable while accounting for other relevant factors.

Results

Descriptive statistics of the study

A total weighted sample of 4,392 children under the age of 5 years was included in the analysis of this study (52.55% male children and 47.45% female children). Out of 2,308 male and 2,084 female children, 253 (11.29%) male children and 187 (9.20%) female children were wasted. Additionally, 11.06% of the 810 children born with a small size had wasting. Furthermore, 11.93% of children born to mothers with no formal education were positive for wasting. Moreover, 322 (12.36%) of the 2,684 children who were rural residents included in this study were identified as having acute malnutrition (wasting). Notably, childhood wasting was highest in the Matam region (23.13%) and lowest in the Dakar region (5.19%) of Senegal (Table 1).

The chi-square association testing of this study revealed that a total of nine variables were distinctly associated with wasting (Table 1). These variables were size at birth, maternal education, type of toilet facility, source of drinking water, residence, community illiteracy rate, community poverty level, and region.

Prevalence of wasting among children under five in Senegal

The national prevalence of wasting among children under the age of five in Senegal was 10.29% at a 95% confidence interval of 9.42 to 11.24% (Figure 1).

Spatial autocorrelation

The spatial autocorrelation analysis showed a positive Moran's Index of 0.216211, indicating a degree of positive spatial autocorrelation. In other words, the high positive Z-score of 6.732605 suggests that the observed spatial clustering of wasting among children is significantly different from what would be expected under a random distribution. Furthermore, the very low *p*-value of less than 0.0001 confirms the statistical significance of this spatial clustering. These results demonstrate that childhood wasting is not randomly distributed across the region, but rather exhibits a clustered pattern. This means that areas with similar wasting prevalence tend to be located in proximity to one another (Figure 2).

Hot spot analysis of wasting among children under the age of five in Senegal

The hot spot analysis conducted as part of this study identified the locations of high-risk "hot spot" clusters and low-risk "cold spot" clusters for childhood wasting across Senegal. As shown in Figure 3, the red points on the map indicate the areas where hot spot clusters of wasting were detected, while the green points denote the locations of cold spot clusters.

Specifically, the hot spot clusters of elevated wasting prevalence were found to be concentrated in the Diourbel, Tambacounda, and Matam regions of Senegal. This suggests that these geographic areas are experiencing particularly high levels of childhood wasting compared to other parts of the country. In contrast, the cold spot clusters, representing regions with significantly lower wasting rates, were observed in the Dakar, Thies, and western Saint-Louis areas. These regions can be considered relatively "low-risk" zones for childhood wasting within Senegal.

SaTScan analysis of wasting among children under the age of five in Senegal

The SaTScan spatial cluster analysis, which was conducted using 30% of the total population, identified two statistically significant cluster windows for childhood wasting in Senegal—one primary cluster and one secondary cluster.

The most likely (primary) cluster window was located at 14.749142°N latitude and 15.701673°W longitude, with a radius of 18.72 km. The children living within this primary cluster window were found to have a 3.88 times higher risk of wasting compared to children outside the cluster. Additionally, a secondary cluster window was detected at 15.030375°N latitude and 13.659316°W longitude, with a larger radius of 191.77 km. The children residing within this secondary cluster window had a 2.20 times higher risk of wasting relative to those outside the cluster (Table 2).

While the primary cluster window encircled areas in the eastern parts of the Diourbel region and the northeast border of the Fatick region, the secondary cluster window encompassed the entire Matam, Tambacounda, and southeastern portions of the Kaffrine, Louga, and Saint-Louis regions (Figure 4).

Spatial interpolation

The ordinary kriging interpolation map shown in Figure 5 displays the predicted spatial distribution of childhood wasting across Senegal.

TABLE 1 Descriptive statistics of the study (n = 4,392).

Variables		Weighted frequency (%)	Wasting status		*P*-value
			Wasted [*n* (%)]	Not wasted [*n* (%)]	
Age	Under 24 months	1,853(42.19)	181 (10.01)	1,629 (89.99)	0.93
	24 months or more	2,539 (57.81)	258 (10.50)	2,199 (89.50)	
Gender	Male	2,308 (52.55)	253 (11.29)	1985 (88.71)	0.128
	Female	2084 (47.45)	187 (9.20)	1843 (90.80)	
Birth size	Large	579 (21.17)	37 (6.66)	518 (93.34)	0.001
	Average	1,346 (49.22)	133 (10.19)	1,172 (89.81)	
	Small	810 (29.61)	88 (11.06)	706 (88.94)	
Birth interval	Less than 2 years	520 (15.81)	60 (12.01)	439 (87.99)	0.303
	Two years or more	2,767 (84.19)	265(9.81)	2,432 (90.19)	
Child is twin	Single	4,223 (96.15)	423 (10.31)	3,678 (89.69)	0.867
	Multiple	169 (3.85)	17 (9.93)	151 (90.07)	
Had diarrhea recently	No	3,388 (77.15)	341 (10.38)	2,941 (89.62)	0.867
	Yes	1,004 (22.85)	99 (10.00)	887 (90.00)	
Maternal age	15–19	190 (4.33)	23 (12.20)	165 (87.80)	0.366
	20–34	2,954 (67.26)	302 (10.53)	2,567 (89.47)	
	35–49	1,248 (28.41)	114 (9.44)	1,096 (90.56)	
Maternal education	No education	2,508 (57.10)	290 (11.93)	2,144 (88.07)	0.003
	Primary	859 (19.56)	66 (7.79)	780 (92.21)	
	Secondary or higher	1,025 (23.34)	83 (8.41)	905 (91.59)	
Maternal occupation	No working	2,900 (66.04)	312 (11.08)	2,505 (88.92)	0.064
	Working	1,491 (33.96)	127 (8.77)	1,323 (91.23)	
Paternal education	Education	3,013 (72.39)	318 (10.85)	2,611 (89.15)	0.138
	Primary	451 (10.83)	43 (9.69)	397 (90.31)	
	Secondary or higher	698 (16.78)	54 (7.99)	625 (92.01)	
Paternal occupation	Unemployed	986 (23.69)	83 (8.65)	877 (91.35)	0.490
	Employed	3,176 (76.31)	332 (10.74)	2,756 (89.26)	
ANC	No visits	324 (12.88)	31 (9.75)	287 (90.25)	0.165
	Had visits	2,194 (87.12)	210 (9.88)	1915 (90.12)	
Type of toilet facility	Improved	3,236 (73.68)	298 (9.47)	2,850 (90.53)	0.012
	Unimproved	1,156 (26.32)	141 (12.60)	978 (87.40)	
Family size	2–5	375 (8.54)	43 (11.64)	328 (88.36)	0.790
	6 or more	4,017 (91.46)	396 (10.16)	3,501 (89.84)	
Wealth index	Poorest	1,018 (23.18)	133 (13.47)	856 (86.53)	0.001
	Poorer	972 (22.12)	107 (11.36)	835 (88.64)	
	Middle	913 (20.79)	99 (11.03)	798 (88.97)	
	Richer	792 (18.04)	54 (7.02)	710 (92.98)	
	Richest	697 (15.87)	46 (6.87)	629 (93.13)	
Media exposure	No	1,544 (35.16)	173 (11.50)	1,330 (88.50)	0.352
	Yes	2,847 (64.84)	266 (9.64)	2,498 (90.36)	
Source of drinking water	Improved	3,646 (83.02)	334 (9.42)	3,212 (90.58)	0.040
	Unimproved	746 (16.98)	105 (14.59)	616 (85.41)	
Residence	Urban	1,708 (38.89)	118 (7.07)	1,549 (92.93)	0.004
	Rural	2,684 (61.11)	322 (12.36)	2,280 (87.64)	

(Continued)

TABLE 1 (Continued)

Variables		Weighted frequency (%)	Wasting status		P-value
			Wasted [n (%)]	Not wasted [n (%)]	
Community illiteracy rate	Low	2,192 (49.91)	159 (7.46)	1976 (92.54)	0.001
	High	2,200 (50.09)	280 (13.13)	1852 (86.87)	
Community media utilization	Low	2,022 (46.05)	205 (10.48)	1752 (89.52)	0.129
	High	2,369 (53.95)	234 (10.13)	2077 (89.87)	
Community poverty level	Low	2,505 (57.03)	196 (8.03)	2,241 (91.97)	0.001
	High	1,887 (42.97)	244 (13.30)	1,587 (86.70)	
Region	Dakar	835 (19.01)	43 (5.19)	784 (94.81)	0.001
	Ziguinchor	133 (3.02)	8 (5.88)	125 (94.12)	
	Diourbel	522 (11.89)	88 (17.82)	404 (82.18)	
	Saint-Louis	361 (8.22)	29 (8.32)	322 (91.68)	
	Tambacounda	215 (4.89)	39 (18.65)	168 (81.35)	
	Kaolack	340 (7.75)	32 (9.72)	297 (90.28)	
	Thies	588 (13.39)	36 (6.36)	533 (93.64)	
	Louga	251 (5.72)	27 (11.09)	213 (88.91)	
	Fatick	278 (6.34)	32 (11.83)	238 (88.17)	
	Kolda	221 (5.03)	22 (9.90)	196 (90.10)	
	Matam	195 (4.43)	43 (23.13)	141 (76.87)	
	Kaffrine	257 (5.86)	22 (8.67)	234 (91.33)	
	Kedougou	58 (1.31)	5 (7.94)	53 (92.06)	
	Sedhiou	138 (3.13)	16 (11.53)	119 (88.47)	

ANC, antenatal care.

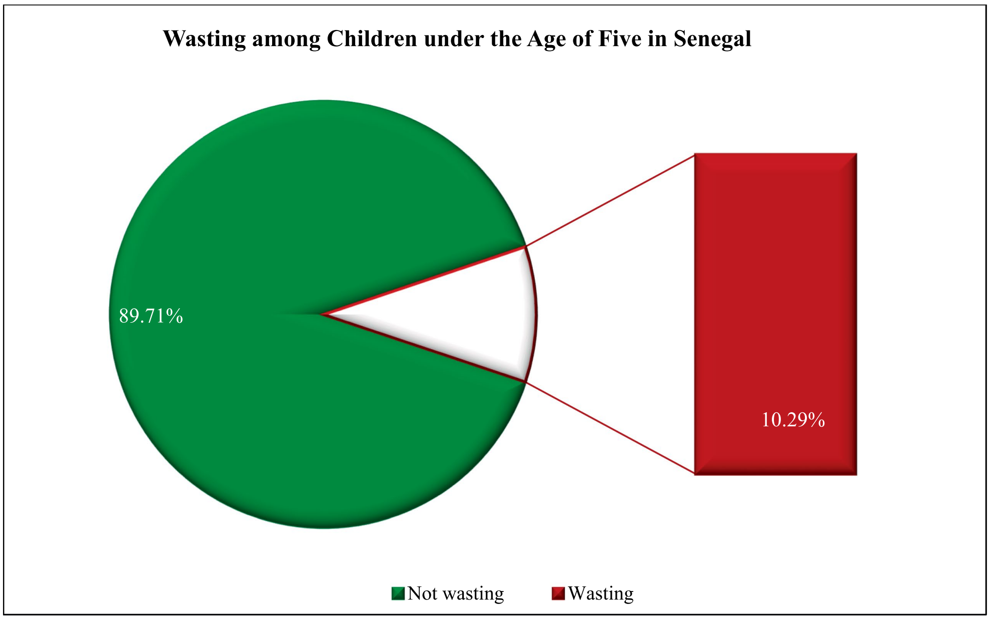

FIGURE 1
Prevalence of wasting among children under the age of five in Senegal, DHS 2023.

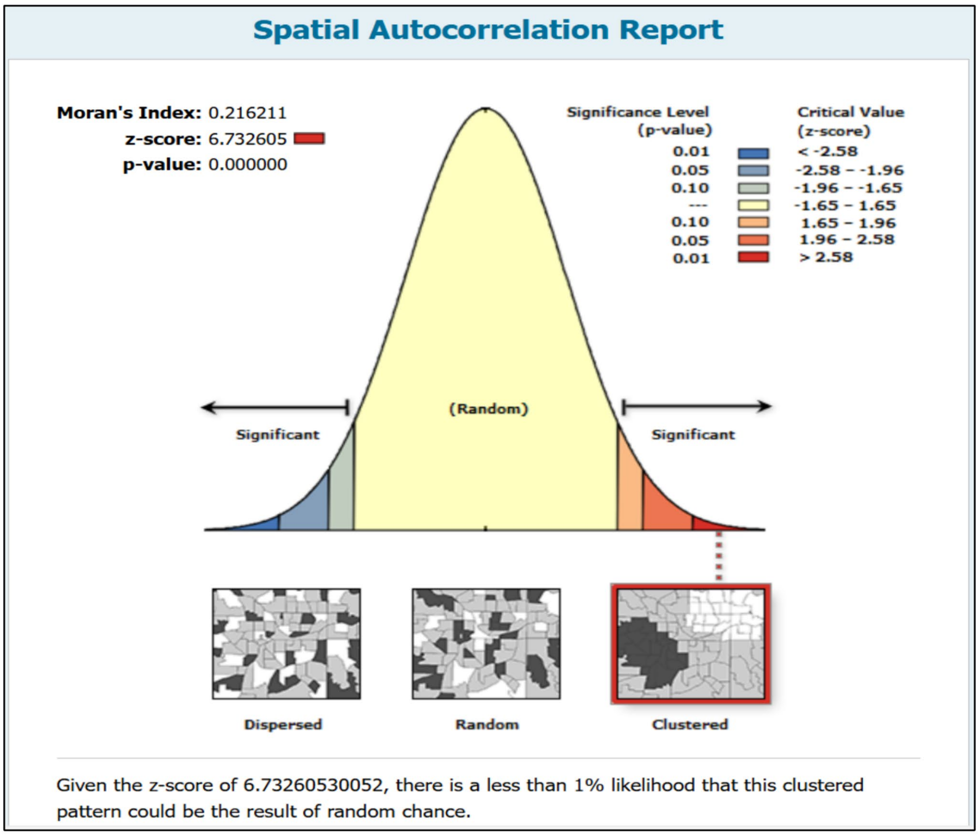

FIGURE 2
Spatial autocorrelation of wasting among children under the age of five in Senegal, DHS 2023.

The red shaded areas on the map indicate regions with high predicted values of wasting prevalence, while the green areas correspond to locations with lower predicted wasting proportions. Based on the kriging analysis, it was found that the majority of the Matam region and the western portion of the Ziguinchor region were predicted to have high proportions of wasting among children under 5 years of age (Figure 5).

Random effect (measures of variation) and model fitness

The results from your multilevel models examining the prevalence, spatial distribution, and determinants of wasting among children under 5 years old in Senegal provide valuable insights. Decreasing random effect variance from the null Model 0 to the full Model III indicates that the inclusion of explanatory variables in the subsequent models helps explain a substantial portion of the between-cluster (community) variability in the risk of child wasting. This reduction in random effect variance from Model 0 to Model III is 67.53%, suggesting that the variables included in the final Model III account for a large proportion of the initial unexplained between-cluster heterogeneity in child wasting. Additionally, the intra-class correlation (ICC) decreases from 10.72% in the null Model 0 to 3.75% in the full Model III, implying that a smaller proportion of the total variance in child wasting is attributable to between-cluster differences after accounting for the explanatory variables in the model. Such a finding suggests that the individual- and cluster-level factors included in the models help explain a significant portion of the contextual influences on child wasting.

Furthermore, the decreasing median odds ratio (MOR) from 1.82 in the null Model 0 to 1.41 in the full Model III indicates that the unexplained between-cluster heterogeneity in the log odds of child wasting is reduced by the inclusion of the explanatory variables. This means that, on average, the child's odds of wasting would increase by a factor of 1.41 if they were to move from a cluster (community) with a lower risk to a cluster with a higher risk, after accounting for the individual- and cluster-level factors in the final Model III. Finally, the improvements in model fit statistics, such as the increasing log-likelihood (LL) values, decreasing deviance, and lower AIC and BIC values from the null Model 0 to the full Model III, further confirm that the inclusion of the explanatory variables significantly enhances the model's ability to explain the determinants of wasting among children under 5 years old in Senegal (Table 3).

Measures of association (fixed effect)

In our multivariable multilevel regression analysis, we aimed to construct a parsimonious model that captured the key determinants of the outcome variable, wasting. To achieve this, we first conducted a preliminary bivariable regression analysis to identify factors that had a p-value less than 0.25. This less stringent p-value threshold was chosen to ensure that potentially important variables were not

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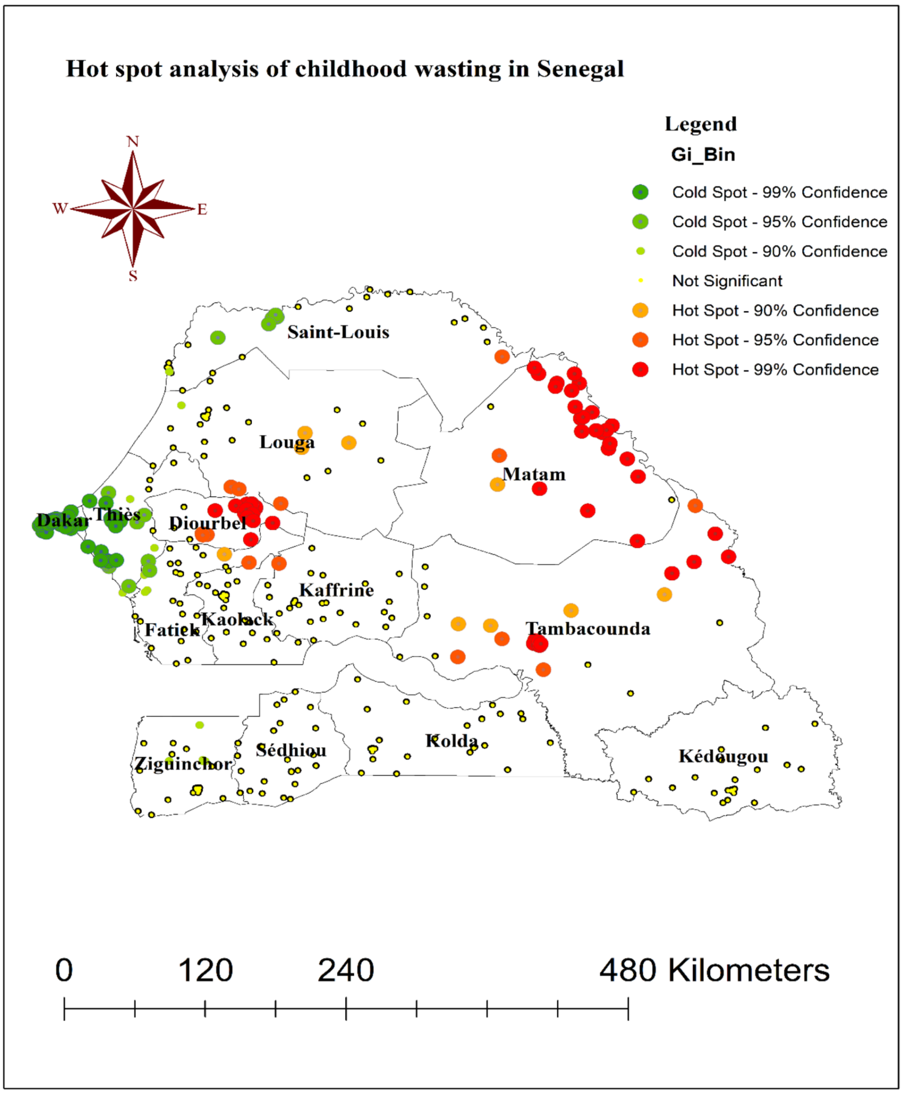

FIGURE 3
Hot spot analysis of wasting among children under the age of five in Senegal, DHS 2023.

TABLE 2 **SaTScan analysis of wasting among children under the age of five in Senegal, DHS 2023.**

Cluster	N	Latitude	Longitude	Radius (km)	Population	Cases	RR	LLR	*p*-value
Primary	4	14.749142 N	15.701673 W	18.72	104	39	3.88	27.85	<0.001
Secondary	69	15.030375 N	13.659316 W	191.77	595	116	2.20	26.51	<0.001

prematurely excluded from the multivariable modeling stage. Notably, we found that only factors that had demonstrated statistically significant associations with wasting in the initial chi-square tests had *p*-values below 0.25 in the bivariable regressions. This suggested that these variables were indeed strongly associated with the outcome of interest and merited inclusion in the multivariable model.

Accordingly, the findings from the fixed effects portion of the multilevel regression analysis revealed that birth size, household wealth index, place of residence, and region were significant determinants of wasting among children under 5 years old in Senegal.

The odds ratio of 1.55 (95% CI: 1.16, 2.08) for the "small birth size" variable indicates that children with a small birth size had 55% higher odds of being wasted compared to children with an average birth size, after accounting for other factors in the model. Similarly, the odds ratio of 2.28 (95% CI: 1.20, 4.36) for the "poorest household wealth index" category shows that children from the poorest households have more than two times the odds of being wasted compared to their counterparts from wealthier households.

Furthermore, the odds ratio of 1.20 (95% CI: 1.05, 1.92) for "rural residence" suggests that children living in rural areas have 20% higher odds of being wasted relative to their urban counterparts.

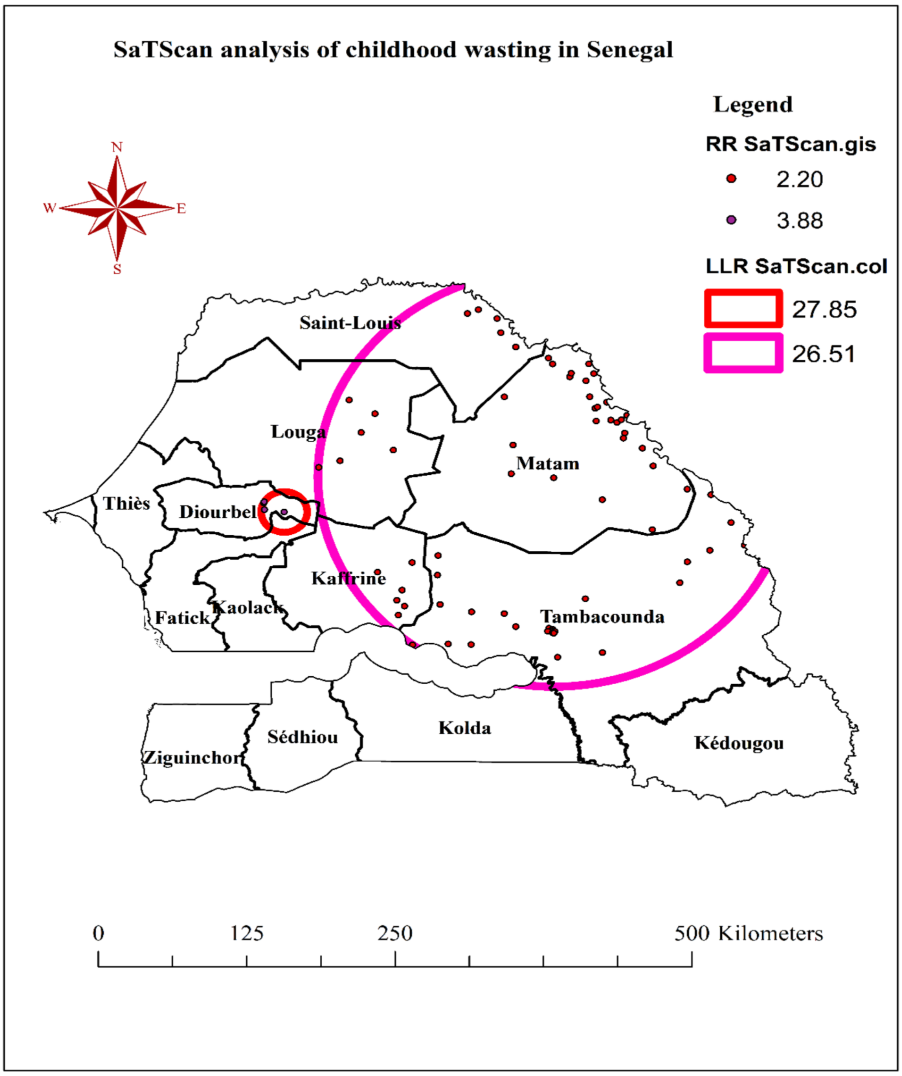

FIGURE 4
SaTScan analysis of wasting among children under the age of five in Senegal, DHS 2023.

The regional differences in child wasting are quite pronounced. Compared to the reference category of the Dakar region, children living in the Diourbel, Tambacounda, and Matam regions have substantially higher odds of wasting, with odds ratios of 4.06 (95% CI: 1.60, 10.29), 3.35 (95% CI: 1.31, 8.52), and 4.92 (95% CI: 1.95, 12.40), respectively (Table 4).

Discussion

Child undernutrition remains a persistent public health challenge across sub-Saharan Africa. Wasting, the acute manifestation of malnutrition characterized by severe muscle wasting and heightened vulnerability to morbidity and mortality, poses a particularly grave concern in the region. Recently, Senegal's children faced a number of socioeconomic challenges, including the lingering effects of the COVID-19 pandemic, disruptions caused by the war between Russia and Ukraine, persistent security threats from the Sahel crisis, and internal socio-political tensions. Hence, this study revealed the prevalence, spatial distribution, and determinants of wasting among children under five in Senegal.

The prevalence of wasting, a form of acute undernutrition, among children under five in Senegal is alarmingly high at 10.29%, with a 95% confidence interval ranging from 9.42 to 11.24%. This finding is consistent with the reported prevalence of severe acute malnutrition among children in Senegal in 2023, which was 10.2%, according to UNICEF (8). This indicates that approximately 10 out of every 100 children in Senegal are affected by wasting, a critical situation when compared to neighboring countries. For instance, the Gambia reported a wasting prevalence of 5.9% in its 2019–2020 Demographic and Health Survey (DHS) (19), while a systematic review in 2019 found a pooled wasting prevalence of 6.1% in Guinea-Bissau (20). Looking at a broader African context, Nigeria's 2018 DHS showed a wasting prevalence of 6.5% among children under five (21).

Furthermore, Senegal's wasting prevalence is significantly higher than the global average of 6.8% (22) and the sub-Saharan African regional average of 7.09% (23), underscoring the country's struggle

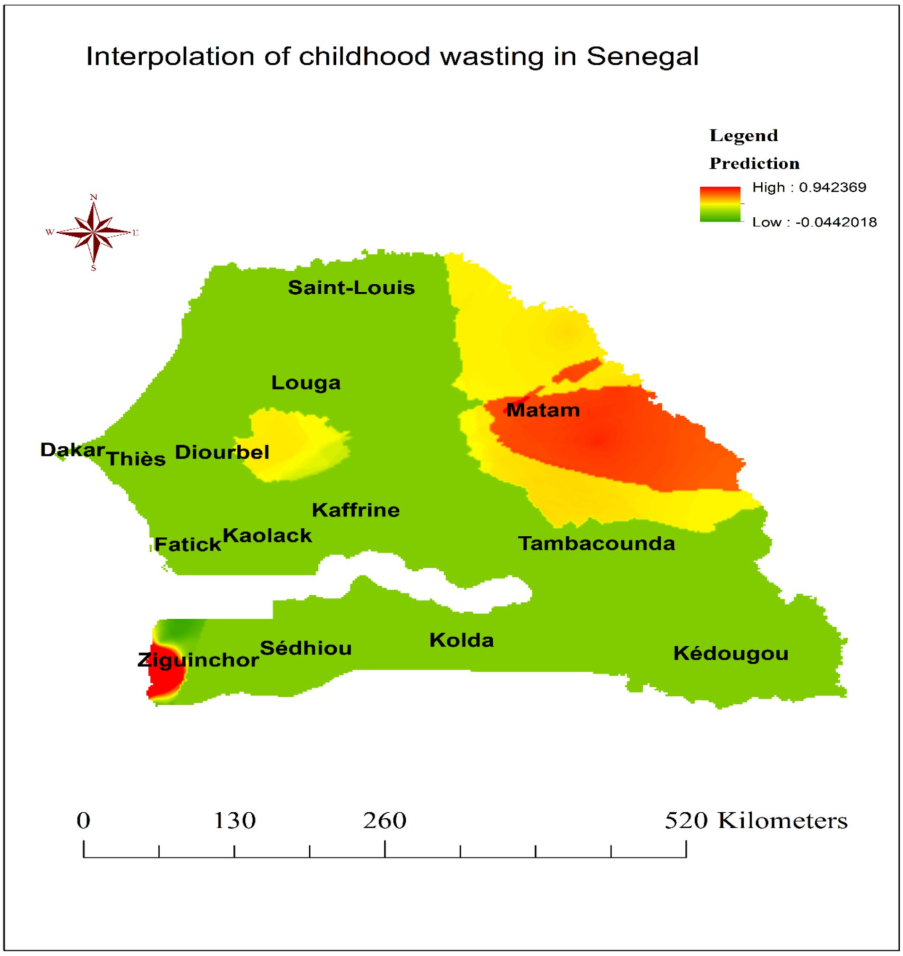

FIGURE 5
Kriging interpolation of wasting among children under the age of five in Senegal, DHS 2023.

TABLE 3 Random effect and model fitness of wasting among children under the age of five in Senegal, DHS 2023.

Parameters	Model 0	Model I	Model II	Model III
Random effect				
Variance	0.3951249	0.3258096	0.1490077	0.1282953
ICC	0.1072254	0.0901102	0.0433303	0.0375
MOR	1.82	1.72	1.44	1.41
PCV	Reference	17.54%	62.29	67.53%
Model comparison				
LL	−1548.27	−903.30	−1506.19	−879.09
Deviance	3,096.54	1,806.60	3,012.38	1,758.18
AIC	3100.54	1830.602	3048.38	1814.192
BIC	3113.35	1980.07	3163.74	1901.69

AIC, Akaike's Information Criterion; BIC, Bayesian Information Criterion; ICC, intra-class correlation coefficient; MOR, median odds ratio, LL, log likelihood; PCV, proportional change in variance.

with childhood undernutrition. This challenge is a reflection of Senegal's challenging economic landscape, where food scarcity is a grim reality for many families (1). Cultural dietary practices, which may not always align with the nutritional needs of children, could also contribute to the issue of undernutrition in the country (24). Additionally, poor sanitation and hygiene can exacerbate health problems, leading to a vicious cycle of disease and malnutrition (25). The finding also emphasizes the need for continuous monitoring and evaluation of both the prevalence of wasting and the effectiveness of intervention programs in Senegal. International aid, when effectively managed, can play a crucial role in supplementing the country's efforts to improve the nutritional status of its children (26).

The observation that childhood wasting is not randomly distributed but exhibits a clustered pattern is an important finding. This suggests that there are underlying geographic, socioeconomic, or environmental factors that contribute to the spatial heterogeneity of wasting, prevalence. Previous studies have also shown that the distribution of malnutrition, including wasting, is often spatially correlated (27, 28). Additionally, the identification of hot spot clusters of elevated wasting prevalence in the Diourbel, Tambacounda, and Matam regions of Senegal is particularly noteworthy. This could indicate the presence of region-specific risk factors that contribute to higher rates of wasting in these areas. Some potential factors that have been linked to spatial clustering of wasting in other contexts include access to healthcare services,

TABLE 4 Measures of association of wasting among children under the age of 5 years in Senegal, DHS 2023.

Factors		Model I AOR at 95% CI	Model II AOR at 95% CI	Model III AOR at 95% CI
Birth size	Large	0.67 (0.46, 0.97)		0.70 (0.48, 1.01)
	Average	1.00		1.00
	Small	1.47 (1.10, 1.96)		**1.55 (1.16, 2.08)** *
Maternal education	No education	1.22 (0.86, 1.72)		1.05 (0.73, 1.51)
	Primary	1.10 (0.73, 1.67)		1.11 (0.74, 1.68)
	Secondary or higher	1.00		1.00
Type of toilet facility	Improved	1.00		1.00
	Unimproved	1.31 (0.95, 1.83)		1.22 (0.87, 1.69)
Wealth index	Poorest	2.38 (1.26, 4.52)		**2.28 (1.20, 4.36)** *
	Poorer	2.36 (1.24, 4.51)		1.92 (0.97, 3.79)
	Middle	1.94 (1.01, 3.72)		1.76 (0.91, 3.40)
	Richer	1.62 (0.81, 3.22)		1.62 (0.81, 3.22)
	Richest	1.00		1.00
Source of drinking water	Improved	1.00		1.00
	Unimproved	1.25 (0.91, 1.72)		1.18 (0.84, 1.65)
Residence	Urban		1.00	1.00
	Rural		1.22 (1.08, 1.95)	**1.20 (1.05, 1.92)** *
Community illiteracy rate	Low		1.00	1.00
	High		1.27 (0.98, 1.64)	1.26 (0.79, 1.99)
Community poverty level	Low		1.00	1.00
	High		1.30 (0.96, 1.75)	1.26 (0.79, 1.99)
Region	Dakar		1.00	1.00
	Ziguinchor		1.25 (0.53, 2.97)	1.44 (0.46, 4.53)
	Diourbel		3.41 (1.70, 6.84)	**4.06 (1.60, 10.29)** *
	Saint-Louis		1.59 (0.76, 3.32)	1.42 (0.52, 3.88)
	Tambacounda		3.41 (1.71, 6.82)	**3.35 (1.31, 8.52)** *
	Kaolack		1.78 (0.85, 3.72)	1.81 (0.66, 5.00)
	Thies		1.33 (0.63, 2.82)	1.55 (0.58, 4.10)
	Louga		2.22 (1.08, 4.55)	2.13 (0.81, 5.64)
	Fatick		2.24 (1.10, 4.55)	2.45 (0.94, 6.42)
	Kolda		1.73 (0.82, 3.64)	1.69 (0.62, 4.62)
	Matam		5.29 (2.68, 10.46)	**4.92 (1.95, 12.40)** *
	Kaffrine		1.31 (0.63, 2.73)	1.39 (0.52, 3.71)
	Kedougou		1.60 (0.75, 3.44)	1.22 (0.42, 3.49)
	Sedhiou		1.94 (0.93, 4.04)	2.24 (0.83, 6.04)

AOR, adjusted odds ratio; CI, confidence interval; *Statistically significant at *p*-value <0.05.

sanitation and hygiene, food security, and household wealth (29, 30). Moreover, the primary cluster window encircling areas in the eastern Diourbel region and the northeast border of the Fatick region, as well as the secondary cluster window encompassing the Matam, Tambacounda, and southeastern portions of the Kaffrine, Louga, and Saint-Louis regions, provided valuable spatial information to guide targeted interventions. By identifying these high-risk areas, policymakers and public health officials can prioritize resource allocation and tailor prevention and treatment strategies to address the specific needs of these communities (30). Furthermore, the Kriging interpolation, which predicted areas with high proportions of wasting, reinforces the need for a geographically informed approach to addressing childhood wasting in Senegal. This suggests that large swaths of these areas may be experiencing high wasting rates. Kriging interpolation, a geostatistical method, leverages spatial correlations in observed data to estimate the prevalence of conditions like wasting in unsampled areas (31). In this study, the technique revealed elevated wasting rates across much of the Matam region and western Ziguinchor, underscoring the need for prioritized resource allocation in these areas.

While our study provides valuable insights into the determinants of wasting, it is important to acknowledge their nature inherent in its cross-sectional design. This design restricts our ability to infer causality between the observed variables and children's wasting. Consequently, the following associations identified through our analysis should be interpreted with caution, as they may not necessarily reflect causal relationships.

Birth size was identified as a significant predictor of wasting. Children with a small birth size had higher odds of being wasted compared to those with an average birth size, even after accounting for other factors in the model. This aligns with existing evidence that low birth weight and small birth size are strongly associated with an increased risk of acute malnutrition in early childhood (32, 33). Small birth size may be a proxy for intrauterine growth restriction, which can compromise a child's nutrient stores and metabolic programming, predisposing them to wasting (34). The finding that children with a small birth size had higher odds of being wasted underscores the critical importance of maternal and fetal health during the prenatal period. Small birth size can be a marker of intrauterine growth restriction, which can have long-lasting consequences on a child's physical and cognitive development (35). This points to the need for interventions that target the prevention and management of low birth weight and intrauterine growth retardation, such as improving access to quality antenatal care, addressing maternal undernutrition, and promoting optimal maternal nutrition and health behaviors (36).

Household wealth was also a significant determinant, with children from the poorest households having more than twice the odds of being wasted compared to their counterparts from wealthier households. This finding is consistent with a large body of research demonstrating the critical role of household socioeconomic status in child nutritional outcomes (14, 37–39). Poverty is closely linked to food insecurity, inadequate access to healthcare, and suboptimal child care practices, all of which increase the risk of acute malnutrition. Addressing the root causes of household poverty, such as limited access to livelihood opportunities, social protection, and essential services, may be crucial in reducing the burden of acute malnutrition among children from disadvantaged backgrounds.

Furthermore, the analysis revealed a significant rural–urban disparity, with children living in rural areas having 20% higher odds of wasting compared to their urban peers. This aligns with prior studies in sub-Saharan Africa that have identified place of residence as a key determinant of child nutritional status (40, 41). The observed rural–urban disparity in child wasting highlights the persistent geographic inequities in nutrition and health outcomes. This gap likely reflects the complex interplay of factors, including differences in access to nutritious foods, healthcare services, water and sanitation infrastructure, and caregiving practices between rural and urban areas (41). Targeted, context-specific interventions that address the unique challenges faced by rural communities, such as investing in rural infrastructure, strengthening community-based health and nutrition services, and promoting household food security, may help to narrow this divide.

The analysis uncovered pronounced regional variations in child wasting within Senegal. Compared to the Dakar region, children living in Diourbel, Tambacounda, and Matam regions had significantly higher odds of being wasted. These regional disparities underscore the importance of considering subnational differences in the design and implementation of nutrition programs. The disparities may be driven by several socioeconomic factors. Regions such as Diourbel, Tambacounda, and Matam often experience higher levels of poverty, lower household wealth, and limited access to economic opportunities compared to urban areas such as Dakar (42). These economic challenges can lead to food insecurity and inadequate access to nutritious food, contributing to higher rates of wasting (43). Additionally, rural areas may have less access to healthcare services, which can affect the timely diagnosis and treatment of malnutrition (44). Cultural practices and beliefs also play a significant role in regional disparities. In some regions, traditional dietary practices and food taboos may limit the variety and nutritional quality of food available to children (45). For example, certain foods that are rich in essential nutrients might be avoided due to cultural beliefs, impacting the nutritional status of children (43). Furthermore, practices related to infant and young child feeding, such as the duration of breastfeeding and the introduction of complementary foods, can vary significantly across regions and influence wasting rates (45). Variations in climate and agricultural productivity can also contribute to regional disparities. Regions with less favorable climatic conditions may experience lower agricultural yields, leading to food shortages and higher food prices1. This can exacerbate food insecurity and increase the risk of wasting among children. The capacity of local health systems to address malnutrition can vary widely between regions. Areas with limited healthcare infrastructure and resources may struggle to provide adequate nutrition services, such as growth monitoring, nutritional counseling, and treatment for malnutrition (42, 44). Strengthening health systems in these regions is crucial for improving child nutritional outcomes.

Taken together, the findings of this study emphasize the multifaceted and context-specific nature of child undernutrition in Senegal. Addressing this persistent public health challenge will require a comprehensive, multisectoral approach that tackles the individual, household, and community-level drivers of wasting. This may involve integrating nutrition-specific interventions, such as the promotion of optimal infant and young child feeding practices, with nutrition-sensitive approaches that address the broader social, economic, and environmental determinants of child health and wellbeing (1, 46).

The key limitations of this study are related to its cross-sectional design. As a survey conducted at a single point in time, the study is unable to establish causal relationships between the determinants and the prevalence of wasting among children under five in Senegal. The geographical coverage of the survey may also be a limiting factor, as the spatial analysis may not be fully representative of the entire country. Furthermore, the study may not have accounted for all relevant confounding factors that could influence wasting, and the 2023 data may not reflect the current situation, limiting the temporal relevance of the findings. Finally, the generalizability of the results to other contexts outside of Senegal may be limited due to the country-specific nature of the study.

Conclusion

Childhood wasting remains a significant public health concern in Senegal, with a prevalence much higher than the global 2025 target. Spatial clustering of high wasting prevalence in the Diourbel, Tambacounda, and Matam regions highlights the need for targeted interventions in these high-risk areas. The identified risk factors, including small birth size, poor household wealth, rural residence, and regional disparities, should guide the design and implementation of effective nutritional programs and policies. Addressing the underlying determinants of childhood wasting is crucial to improve child health and development outcomes in Senegal. Continued monitoring, multisectoral collaboration, and evidence-based strategies are necessary to effectively reduce the burden of wasting and promote optimal nutrition among children under five, with a priority on addressing the geographic and socioeconomic inequities in wasting prevalence to ensure equitable progress nationwide.

Recommendation

Targeted nutritional interventions

These interventions implement community-based nutritional programs focusing on high-risk regions, such as Diourbel, Tambacounda, and Matam. These programs should include supplementary feeding, growth monitoring, and nutrition education for caregivers.

Economic support initiatives

These initiatives develop and promote income-generating activities and social protection programs to improve household wealth, particularly in rural areas. This can help alleviate poverty and improve access to nutritious food.

Maternal and child health services

These services strengthen antenatal care (ANC) services to ensure early identification and management of at-risk pregnancies and promote maternal education on infant and young child feeding practices.

Water, sanitation, and hygiene (WASH) programs

These programs improve access to clean drinking water and sanitation facilities to reduce the risk of infections that contribute to wasting and implement community-led total sanitation (CLTS) programs to promote hygiene practices.

Multisectoral collaboration

It fosters collaboration between health, agriculture, education, and social protection sectors to address the multifaceted determinants of wasting and establishes a national task force to coordinate efforts and monitor progress.

Monitoring and evaluation

Monitoring and evaluation establish robust monitoring and evaluation systems to track the effectiveness of interventions and adjust strategies as needed and use data from the 2023 SDHS to inform policy decisions and program designs.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://www.dhsprogram.com/data/available-datasets.cfm.

Author contributions

TT: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Writing—original draft, Writing—reviewing and editing. BT: Investigation, Methodology, Software, Validation, Visualization, Writing—reviewing and editing. AA: Data curation, Investigation, Methodology, Software, Validation, Visualization, Writing—reviewing and editing. MW: Data curation, Investigation, Methodology, Software, Validation, Visualization, Writing—reviewing and editing. EM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing—reviewing and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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