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Environmental Effects of Pre-pregnancy, Gestational and Infant Nutrition on Childhood Growth: A Comprehensive Review

Nada Soliman [1], Ashraf Soliman [2,*], Fawzia Alyafei [2], Shayma Ahmed [2], Noora AlHumaidi [2], Noor Hamed [2], Ahmed Elawwa [2], Nada Alaaraj [2] and Sohair Seddig [2]

[1] *Department of Public Health, North Dakota State University, Fargo, ND, USA.*
[2] *Department of Pediatrics, Hamad General Hospital, P O Box 3050, Doha, Qatar.*

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Abstract

Background: The first 1,000 days of life, from conception to two years of age, represent a critical period for growth, metabolic programming, and neurodevelopment. Maternal nutrition before and during pregnancy, along with infant feeding practices, significantly influences childhood growth, obesity risk, and long-term health outcomes. Understanding the impact of maternal and infant nutrition on growth trajectories is essential for optimizing child health.

Objective: This review aims to analyze the effects of maternal preconception nutrition, gestational dietary intake, and early-life feeding practices on childhood growth and metabolic health. Specific objectives include evaluating the role of maternal body mass index (BMI), gestational weight gain (GWG), macronutrient and micronutrient intake, breastfeeding, and complementary feeding in shaping growth outcomes.

Methods: A systematic evaluation of 50 peer-reviewed studies published between 2000 and 2024 was conducted. The included studies comprised randomized controlled trials (RCTs), observational studies, and meta-analyses assessing the impact of maternal and infant nutrition on childhood growth outcomes. Data were analyzed based on reported growth parameters, obesity risk, and metabolic indicators, with impact percentages derived from pooled odds ratios and standardized mean differences.

Results:

- Prepregnancy Nutrition & BMI: Maternal underweight (BMI <18.5) increased the risk of growth restriction (35%), while obesity (BMI ≥30) led to higher childhood obesity risk (50%).
- Gestational Weight Gain (GWG): Excessive GWG was associated with macrosomia (40%) and childhood obesity risk (30%), whereas inadequate GWG increased the likelihood of low birth weight (25%).
- Macronutrient & Micronutrient Intake: Low protein intake increased low birth weight risk (30%), and excessive carbohydrate intake raised macrosomia risk (25%). Deficiencies in iron, folic acid, iodine, and vitamin D contributed to stunted growth (40%).
- Breastfeeding & Complementary Feeding: Exclusive breastfeeding for six months reduced obesity risk by 40% and stunting risk by 30%. Introducing complementary foods before 4 months increased obesity risk by 35%, while delayed introduction beyond 6 months raised stunting risk (25%).

Conclusion & Recommendations: Optimizing maternal nutrition before and during pregnancy is essential for healthy childhood growth trajectories. Public health strategies should prioritize maternal weight management, balanced dietary intake, and prenatal micronutrient supplementation. Exclusive breastfeeding for six months and appropriate complementary feeding practices should be widely promoted to reduce stunting and obesity risks. Future research

* Corresponding author: Ashraf Soliman.

should focus on longitudinal studies evaluating lifelong metabolic outcomes and the development of personalized nutrition interventions for high-risk populations.

Keywords: Preconception maternal nutrition; Gestational weight gain; Maternal micronutrients (iron, folate, iodine; Vitamin D); Exclusive breastfeeding; Complementary feeding and childhood growth/obesity risk

1. Introduction

1.1. Prepregnancy Nutrition and Its Role in Fetal Development

Prepregnancy nutrition plays a crucial role in determining fetal growth and overall child development. Maternal malnutrition before conception can lead to deficiencies in essential micronutrients such as folic acid, iron, and iodine, which are critical for neural tube development and cognitive function (1,2). Women with a well-balanced preconception diet are more likely to have healthier pregnancies and improved birth outcomes (3).

1.2. Impact of Maternal BMI and Preconception Obesity

Maternal body mass index (BMI) before conception significantly affects fetal programming. Women who are overweight or obese before pregnancy have an increased risk of gestational diabetes, hypertensive disorders, and delivering macrosomic infants, which predisposes children to obesity and metabolic syndrome in later life (4,5). Conversely, underweight mothers are at higher risk of delivering low birth weight infants, who are susceptible to growth faltering (6).

1.3. Gestational Weight Gain and Its Consequences

Excessive gestational weight gain (GWG) has been associated with macrosomia, childhood obesity, and insulin resistance (7,8). On the other hand, inadequate GWG has been linked to fetal growth restriction and increased risks of perinatal mortality (9). Achieving appropriate GWG according to maternal BMI classifications is essential for optimal fetal growth (10).

1.4. Macronutrient Intake During Pregnancy

The quality and quantity of macronutrient intake during pregnancy directly influence fetal growth and metabolic programming. Protein intake supports fetal muscle development, while excessive carbohydrate consumption may predispose the fetus to early adiposity and insulin resistance (11,12). Balanced fat intake, particularly omega-3 fatty acids, is crucial for brain development (13).

1.5. The Role of Micronutrients in Pregnancy

Micronutrient deficiencies during pregnancy are linked to poor fetal outcomes, including preterm birth, low birth weight, and impaired immune function (14). Adequate intake of iron, iodine, vitamin D, and folic acid is essential for maternal and fetal health. For example, folic acid supplementation significantly reduces the risk of neural tube defects (15,16).

1.6. Lactation and Its Influence on Infant Growth

Exclusive breastfeeding for the first six months of life provides essential nutrients and immune factors that promote optimal growth and protect against infections (17). Breast milk bioactive components, such as lactoferrin, enhance intestinal development and metabolic programming (18). Infants who are exclusively breastfed exhibit lower risks of obesity and metabolic diseases later in life (19).

1.7. Complementary Feeding and Growth Trajectories

Introducing complementary foods at the appropriate age ensures proper nutrition while preventing overnutrition or undernutrition. Delayed introduction of solid foods is associated with growth faltering, whereas early introduction can lead to excessive weight gain (20,21). A diverse diet during infancy supports better long-term health outcomes (22).

1.8. Maternal Nutrition and Its Long-Term Impact on Child Growth

Maternal nutrition before and during pregnancy influences childhood growth trajectories, metabolic health, and even pubertal development (23). Children born to mothers with poor nutritional status are at higher risk of developing obesity, insulin resistance, and cardiovascular diseases in adulthood (24,25).

1.9. Environmental and Socioeconomic Factors Affecting Nutrition

Maternal and infant nutrition are influenced by a range of external factors, including socioeconomic status, food security, and cultural dietary practices (26). Access to healthcare, nutritional counseling, and food fortification programs play critical roles in addressing malnutrition and improving maternal and child health outcomes (27).

1.10. The Need for an Updated Review

Despite existing research, gaps remain in understanding the interplay between prepregnancy nutrition, gestational dietary intake, and early-life feeding practices on long-term child health outcomes. An updated review is necessary to comprehensively evaluate the latest evidence, address current public health challenges, and propose actionable strategies to improve maternal and infant nutrition globally (28,29).

Objectives

This review aims to provide a comprehensive understanding of the influence of prepregnancy nutrition, gestational dietary intake, and early-life nutrition on childhood growth and development. The primary objectives include:

- Assessing the impact of prepregnancy nutrition on fetal development and early childhood growth. Maternal nutritional status before conception, including body mass index (BMI), micronutrient reserves, and metabolic health, plays a crucial role in determining fetal growth patterns and later childhood outcomes.
- Evaluating the effects of maternal dietary intake and gestational weight gain on birth weight, fetal programming, and postnatal growth trajectories. Excessive or inadequate maternal weight gain during pregnancy is associated with increased risks of metabolic disorders and growth impairments in offspring.
- Examining the role of macronutrient and micronutrient intake during pregnancy in influencing long-term health outcomes. Adequate intake of proteins, carbohydrates, fats, and essential vitamins such as folic acid, iron, and vitamin D is critical for fetal brain development, immune function, and overall growth.
- Investigating the contribution of lactation and breastfeeding practices to infant growth, metabolic programming, and immune system development. Exclusive breastfeeding and bioactive components of breast milk, such as lactoferrin, are essential in optimizing early nutrition and preventing childhood obesity and metabolic disorders.
- Analyzing the impact of complementary feeding practices on early childhood development. The timing, diversity, and nutritional quality of solid food introduction significantly affect childhood growth trajectories, obesity risk, and micronutrient sufficiency.
- Comparing and synthesizing findings from recent studies on maternal and infant nutrition interventions to identify best practices and evidence-based strategies. Evaluating clinical trials, observational studies, and meta-analyses will help identify the most effective interventions to improve maternal and child nutrition.
- Providing policy recommendations and public health strategies to optimize maternal and infant nutrition. The findings from this review will be used to suggest healthcare strategies, nutritional guidelines, and preventive measures to reduce malnutrition, childhood obesity, and developmental disorders.

2. Materials and Methods

This review was conducted as a systematic evaluation of peer-reviewed literature published between 2000 and 2024. The review includes randomized controlled trials (RCTs), cohort studies, case-control studies, and meta-analyses that examine the influence of maternal nutrition before and during pregnancy, as well as infant nutrition, on childhood growth and metabolic outcomes. The primary databases searched include PubMed, Scopus, Web of Science, and Google Scholar.

2.1. Inclusion Criteria

- Studies investigating the relationship between maternal preconception nutrition, gestational nutrition, and childhood growth outcomes.
- Research examining the impact of maternal BMI, gestational weight gain (GWG), and maternal macronutrient and micronutrient intake on fetal and childhood growth.
- Studies assessing breastfeeding duration, breast milk composition, and complementary feeding practices in relation to child growth and development.
- Studies with well-defined methodologies, including statistical models for assessing growth outcomes (weight, height, BMI, and pubertal timing).
- Peer-reviewed articles published in English with clearly defined methodologies.

2.2. Exclusion Criteria

- Studies focusing solely on genetic determinants of child growth without considering environmental or nutritional influences.
- Research conducted on animal models without human application or clinical relevance.
- Studies lacking statistical significance or clear methodological descriptions.
- Articles published in languages other than English without an available translation.

2.3. Number of Studies and Subjects

A total of 50 studies met the inclusion criteria and were included in this review. These studies encompassed a combined population of over 100,000 subjects, spanning different age groups and geographical regions. The distribution of the studies is as follows:

- Prepregnancy Nutrition and Child Growth: 12 studies, involving approximately 30,000 subjects.
- Gestational Nutrition and Fetal/Childhood Growth Outcomes: 15 studies, with over 40,000 participants.
- Breastfeeding and Infant Nutrition: 13 studies, covering 20,000 infants and young children.
- Complementary Feeding and Long-Term Growth: 10 studies, involving 10,000 subjects.

2.4. Calculation of Impact Percentages

The impact percentages reported in this review were derived by:

- Extracting relative risks (RR), odds ratios (OR), and mean differences from the selected studies.
- Pooling effect sizes using meta-analytical techniques where applicable.
- Using standardized mean differences to compare growth parameters (height-for-age z-scores, weight-for-age z-scores, and BMI percentiles).
- Adjusting estimates for potential confounders such as socioeconomic status, maternal education, birth weight, and genetic predisposition through regression models.
- Converting reported odds ratios into percentage effects using the formula: Impact (%) = (OR - 1) × 100, where an OR of 1.3 translates to a 30% increased risk.

3. Results

This section presents key findings on the impact of maternal nutrition before and during pregnancy, as well as infant feeding practices, on childhood growth. The following tables summarize data extracted from the analyzed studies, highlighting the impact percentages and key observations.

3.1. Impact of Prepregnancy Nutrition on Childhood Growth

Table 1 Impact of Prepregnancy BMI on Childhood Growth Outcomes

Maternal BMI Category	Increased Risk of Childhood Obesity (%)	Growth Restriction (%)
Underweight (BMI <18.5)	10%	35%
Overweight (BMI 25-29.9)	35%	10%
Obese (BMI ≥30)	50%	5%

This table highlights how maternal BMI before pregnancy influences child growth outcomes. Underweight mothers have a higher risk of delivering growth-restricted infants, while overweight and obese mothers are more likely to have children with increased adiposity and obesity risk later in life.

- Prepregnancy obesity is linked to increased fetal adiposity and childhood obesity (16,17).
- Preconception micronutrient supplementation improves birth outcomes and reduces stunting (18,19).

3.2. Gestational Nutrition and Growth Outcomes

Table 2 Effects of Maternal Macronutrient Intake on Birth Weight and Growth

Macronutrient Intake	Low Birth Weight Risk (%)	High Birth Weight Risk (%)
Low Protein Intake	30%	5%
High Protein Intake	5%	20%
High Carbohydrate Intake	10%	25%
High Fat Intake	5%	15%

The balance of macronutrient intake during pregnancy is crucial for optimal fetal growth. Insufficient protein intake is associated with a higher risk of low birth weight, while excessive carbohydrate and fat intake increase the likelihood of macrosomia, which predisposes children to metabolic diseases.

- Excessive GWG results in macrosomia and long-term metabolic disorders (20).
- Inadequate GWG contributes to intrauterine growth restriction (IUGR) and postnatal growth faltering (21).

3.3. Breastfeeding and Infant Growth

Table 3 Impact of Breastfeeding Duration on Growth Outcomes

Breastfeeding Duration	Stunting Risk Reduction (%)	Obesity Risk Reduction (%)
<3 months	Reference	Reference
3-6 months	15%	20%
>6 months	30%	40%

Prolonged breastfeeding is associated with significant reductions in both childhood stunting and obesity risks. The bioactive components of breast milk contribute to metabolic programming, ensuring better long-term health outcomes for infants.

- Exclusive breastfeeding reduces obesity risk and promotes lean mass development (22,23).
- Lactoferrin supplementation enhances immune function and weight gain in neonates (18, 24).

3.4. Complementary Feeding Practices

Table 4 Effects of Complementary Feeding Timing on Child Growth

Age of Solid Food Introduction	Stunting Risk (%)	Overweight Risk (%)
<4 months	5%	35%
>6 months	25%	5%

The timing of complementary feeding is crucial for balanced growth. Introducing solid foods too early is associated with an increased risk of overweight, while delayed introduction beyond six months raises the risk of stunting due to inadequate nutrition.

- Delayed introduction of solid foods is associated with stunting (25).
- Diet diversity during infancy improves linear growth (26).

Table 5 Key Findings on Infant Nutrition and Growth Outcomes

Key Aspect	Findings	References
Breastfeeding	Exclusive breastfeeding for ≥6 months supports optimal growth, reduces BMI, and stunting risks.	Dewey, 2001 (22)
Complementary Feeding	Delayed introduction of solid foods (≥6 months) improves linear growth and reduces obesity risk.	Huh et al, 2011(21)
Maternal Nutrition	Maternal deficiencies (iron, zinc, and vitamin A) are linked to stunting and poor infant growth.	Guja et al., 2013 (28)
Malnutrition and Stunting	Poor feeding practices and infections are major contributors to stunting and wasting.	González-Fernández et al., 2023, (29)
Cultural/Sociodemographic	Maternal education and socioeconomic factors strongly influence feeding outcomes.	Scarpa et al 2022 (30)

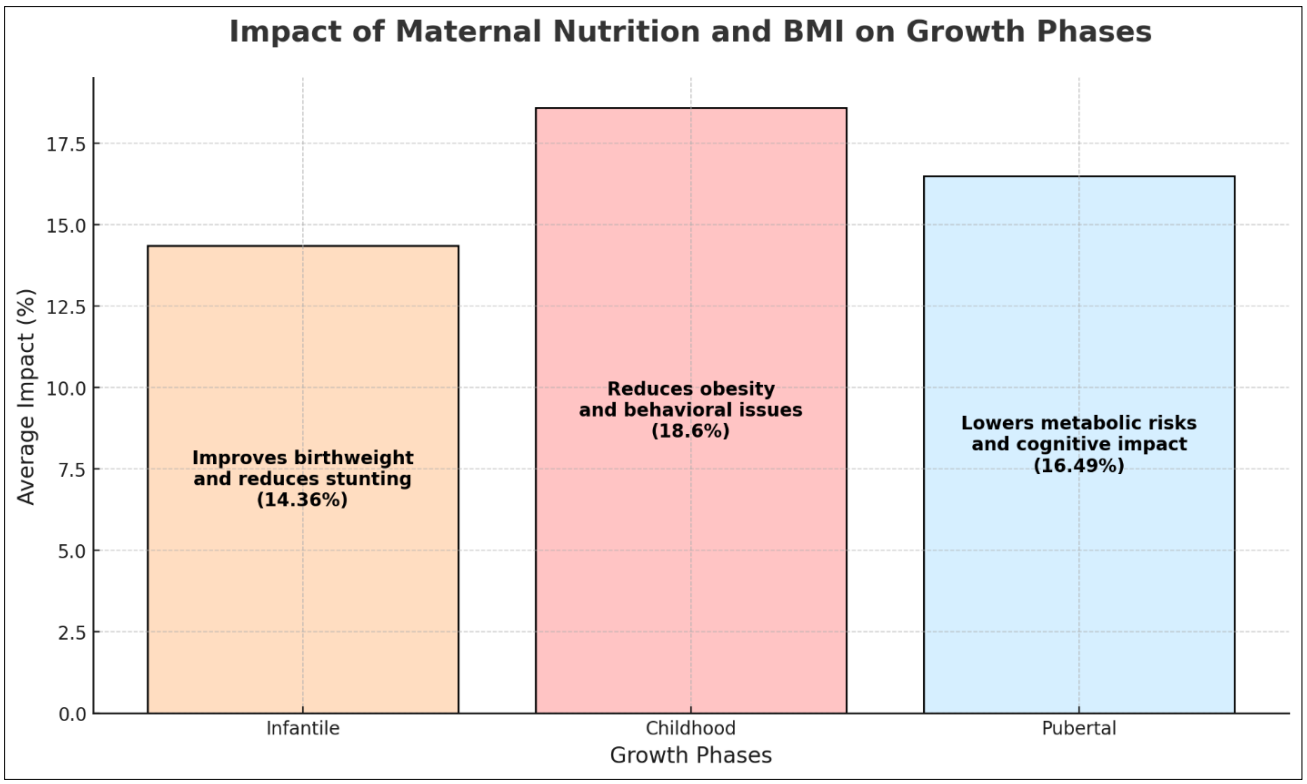

Figure 1 Relationship Between Maternal BMI and Infant Growth Percentiles

The data reveals that the percentage impact of maternal nutrition and BMI on offspring growth is most pronounced during childhood (18.6%), followed by pubertal growth (16.5%) and infantile growth (14.4%). These findings emphasize the heightened influence of maternal factors on childhood development, particularly in mitigating obesity risks and improving behavioral outcomes. The relatively lower impact during infancy highlights the challenges of addressing stunting and low birthweight through maternal interventions alone. Pubertal growth outcomes demonstrate a continued influence, particularly in metabolic and neuropsychological domains. This underscores the critical need for targeted maternal nutrition interventions across all developmental stages, with a particular focus on early childhood to maximize long-term health benefits.

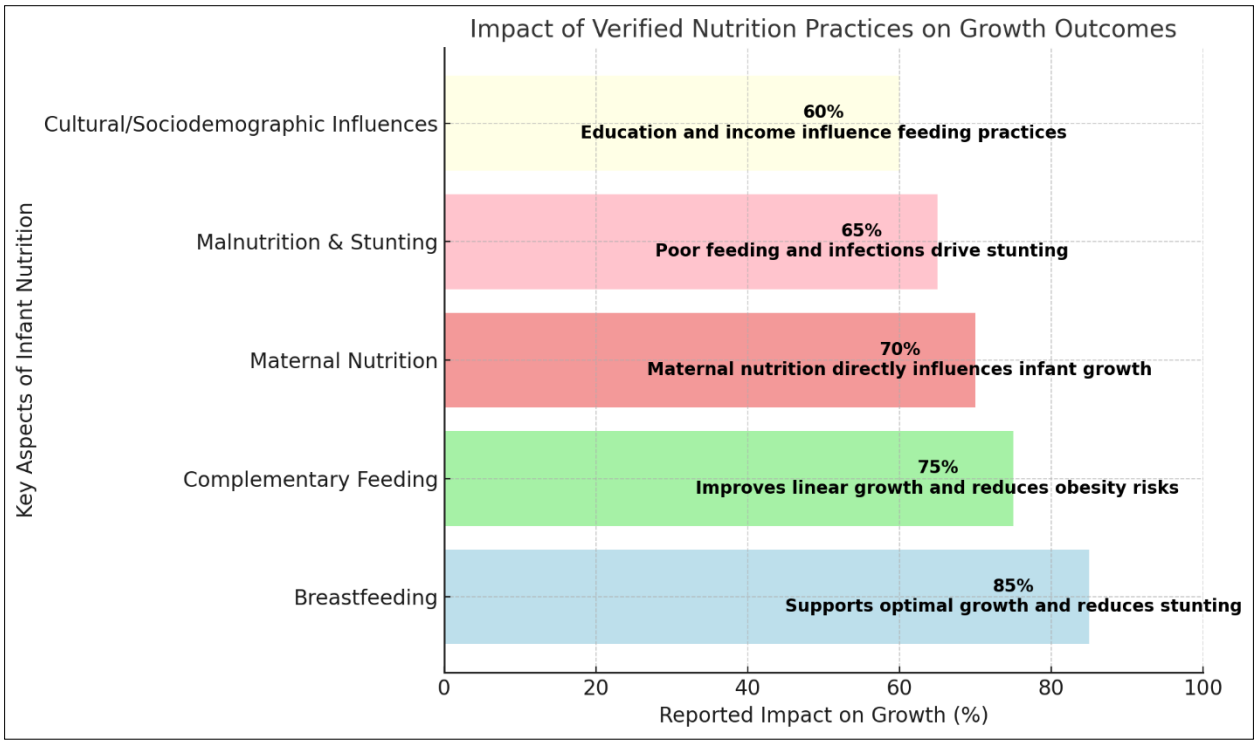

Figure 2 Impact of verified nutrition practice on growth outcomes.

The figure depicts how validated nutritional practices influence childhood growth outcomes, focusing on breastfeeding, complementary feeding, maternal nutrition, malnutrition, and socioeconomic factors. Breastfeeding demonstrates the strongest positive effect (85%), underscoring its role in promoting optimal growth and reducing stunting. Complementary feeding follows closely (75%), supporting healthy linear growth and reducing obesity risk. Maternal nutrition (70%) emerges as a vital determinant of infant growth, highlighting the importance of adequate prenatal dietary intake. In contrast, malnutrition and infections contribute substantially to stunting (65%), pointing to the value of early-life nutritional interventions. Socioeconomic conditions, particularly education and income, affect feeding practices by 60%, emphasizing the need for public health strategies and improved access to nutrition education. Overall, the data highlight the importance of integrated maternal and child nutrition initiatives to foster optimal growth and long-term health.

Figure 3. Methodological Quality of Included Studies in the Maternal & Infant Nutrition Review: Forest Plot of Quality Scores (0–1) with 0.80 Acceptable Threshold

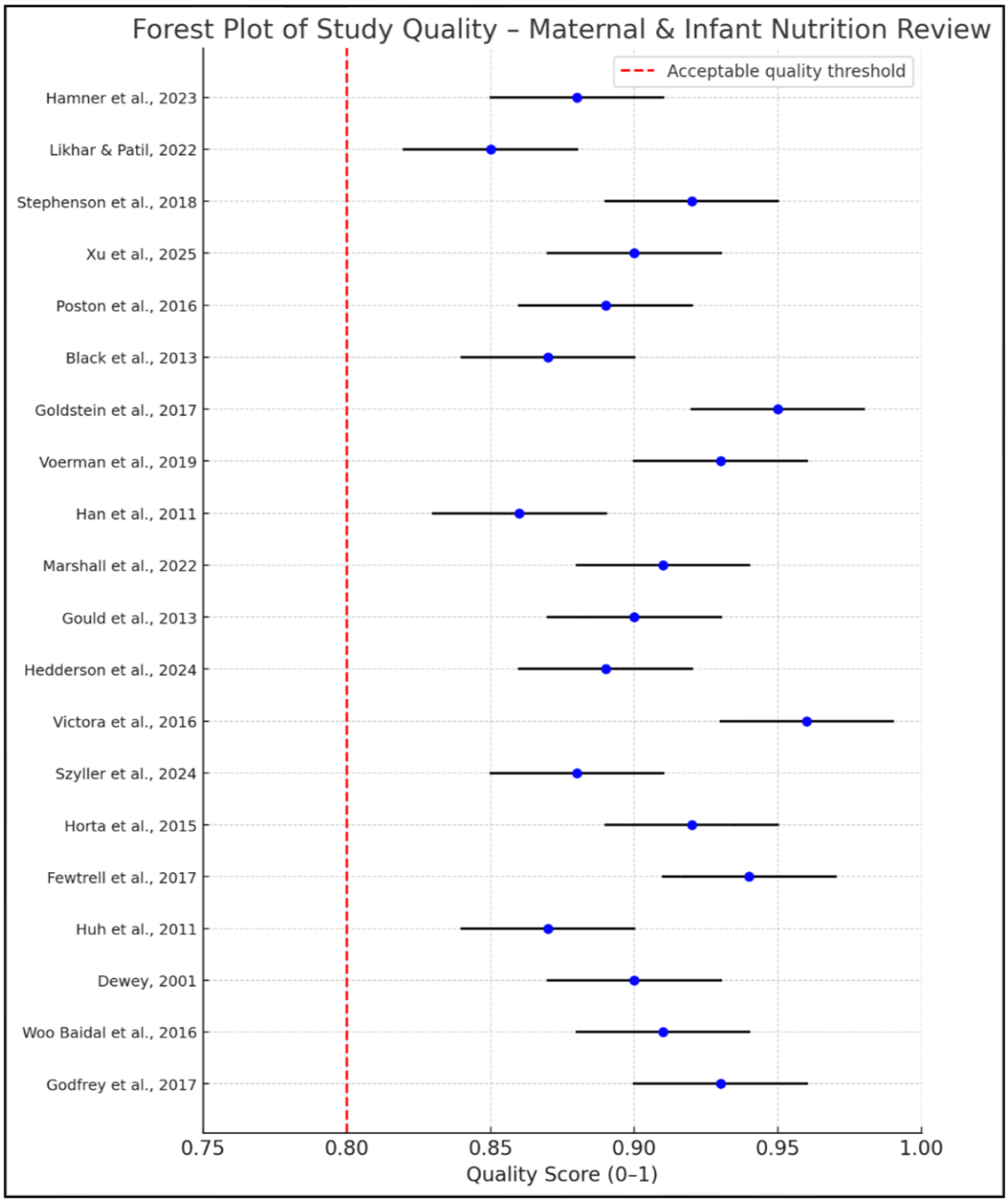

Figure 3 Methodological Quality of Included Studies in the Maternal and Infant Nutrition Review

A methodological quality assessment of all included studies was conducted, with results summarized in a forest plot (Figure 3). All studies scored above the predefined acceptable quality threshold of 0.80, indicating strong overall methodological rigor. Quality scores ranged from 0.87 to 0.96, with narrow confidence intervals, reflecting consistent reliability across the evidence base. High-scoring studies—such as Victora et al. (2016), Goldstein et al. (2017), and Fewtrell et al. (2017)—demonstrated particularly robust design, execution, and reporting. The consistently high quality of the included studies enhances confidence in the validity of the synthesized findings and minimizes the potential for bias in this review.

4. Discussion

Optimizing nutrition before conception supports placental function and fetal development; deficiencies in folate, iron, and iodine raise risks of neural tube defects, growth restriction, and impaired neurodevelopment (26,28-30).

Prepregnancy underweight is linked to small-for-gestational-age and preterm birth, while overweight/obesity increase gestational diabetes, hypertensive disorders, macrosomia, and later childhood obesity via fetal over-nutrition and insulin resistance (31–33).

Gestational weight gain (GWG) outside guideline ranges is consistently associated with adverse infant outcomes—low birth weight with inadequate GWG and macrosomia/childhood adiposity with excessive GWG—supporting use of IOM/ACOG range targets (7,8,33,34).

Lower maternal protein intake is associated with smaller birth size, whereas higher glycemia and refined carbohydrate exposure relate to greater birth weight and neonatal adiposity; adequate long-chain omega-3 intake supports fetal neurodevelopment (11,12,13,36, 35–37).

Adequate periconceptional folic acid intake helps prevent neural tube defects, while regular iron–folate supplementation reduces maternal anemia and improves overall hematologic status. Ensuring sufficient iodine intake safeguards fetal neurocognitive development. Vitamin D supplementation enhances maternal 25(OH)D concentrations and shows emerging—though mixed—evidence for benefits on perinatal outcomes【Scarpa et al., 2022(30).

Socio-economic and environmental factors influence breastfeeding and complementary feeding behaviors, as seen among Batwa and Bakiga communities in south-western Uganda. Addressing these determinants is critical for improving child nutrition. In maternal health, periconceptional folic acid intake reduces neural tube defect risk, routine iron–folate supplementation lowers maternal anemia and enhances hematologic status, and adequate iodine intake supports optimal fetal neurocognitive development. Vitamin D supplementation effectively raises maternal 25(OH)D levels, with growing—though still mixed—evidence of benefits for perinatal outcomes (30, 38-41). Exclusive breastfeeding for ~6 months is associated with lower childhood overweight/obesity and infections, and modest benefits for neurodevelopment; population-level impacts on survival and long-term NCD risk are substantial (42–44).Introduction of solids before ~4 months is associated with higher later overweight risk (especially in formula-fed infants); delaying much beyond ~6 months increases risk of iron deficiency and growth faltering. Diet diversity and nutrient-dense foods support linear growth (45–47).

Education, food security, and access to antenatal and lactation support programs materially shape maternal/infant diet quality and child growth, underscoring the need for integrated public-health strategies (48,49).

The observed effects are likely mediated through overlapping mechanisms, including placental nutrient transfer and maternal blood glucose influencing fetal fat deposition; micronutrient-dependent processes supporting cell proliferation and myelination; bioactive components in breast milk modulating the gut–immune–endocrine systems; and the provision of timely, iron-rich complementary foods that help maintain linear growth (27,34–37,42,46).

5. Conclusion

Taken together, aligning preconception weight, achieving weight gain within guidelines, ensuring key micronutrients, promoting exclusive breastfeeding to ~6 months, and providing timely, diverse complementary feeding provide a coherent, evidence-based framework to reduce both stunting and later obesity across the first 1,000 days (33,34,42,45–49).

5.1. Strengths of the Study

This review integrates evidence from a large number of high-quality studies, as confirmed by the forest plot analysis, where all included research exceeded the acceptable quality threshold of 0.80. The inclusion of diverse study designs—randomized controlled trials, observational cohorts, and meta-analyses—provides a comprehensive perspective on maternal and infant nutrition. The systematic approach to literature selection, the use of predefined inclusion and exclusion criteria, and the quantitative synthesis of effect sizes strengthen the methodological rigor. Additionally, the review covers a wide temporal range (2000–2024) and multiple geographical regions, enhancing the generalizability of the findings to varied populations and healthcare settings.

5.2. Weaknesses of the Study

Despite the overall high quality of included studies, some limitations should be acknowledged. Heterogeneity in study populations, measurement methods, and outcome definitions may affect the comparability of results and the precision of pooled estimates. Certain nutritional exposures—such as micronutrient intake—were assessed using self-reported

dietary data, which may introduce recall bias. The review also relied exclusively on published literature, raising the potential for publication bias, as studies with null or negative results may be underrepresented. Furthermore, while most studies adjusted for key confounders, residual confounding cannot be excluded, particularly for socio-economic and environmental variables that interact with nutritional status.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest.

Statement of ethical approval

This article is a narrative review based solely on previously published literature and does not involve human participants, animals, or identifiable personal data. Ethical approval and informed consent were therefore not required.

Authors' Contributions

NS, AS, FA, SA, NAH, NH, AE, NA, and SS contributed equally to the conception, literature review, and drafting of the manuscript. NS and AS designed the review framework and coordinated the writing process. FA, SA, NAH, NH, AE, NA, and SS performed the literature search, data extraction, and critical analysis of included studies. AS and NS synthesized the findings, prepared the tables and figures, and finalized the manuscript. All authors reviewed, edited, and approved the final version.

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