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The impact of early nutritional interventions on growth and development in infants- Meta-analysis

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Abstract

Early childhood nutrition is critical for long-term growth, cognitive development, and overall health. This meta-analysis evaluates the impact of nutritional interventions on growth outcomes in children under 8 years, focusing on BMI-for-age, weight-for-height, height-for-age, and weight-for-age z-scores. A systematic search of PubMed, Embase, and Cochrane Library databases identified 429 studies, with 8 randomized controlled trials (n = 6,645 children) meeting inclusion criteria. Pooled mean differences (MDs) and 95% confidence intervals (CIs) were calculated for growth outcomes, with subgroup analysis by intervention duration. Heterogeneity was assessed using I^2 statistics. Nutritional interventions showed no significant effects on BMI-for-age (MD = 0.12, 95% CI: −0.07, 0.30) or height-for-age (MD = 2.45, 95% CI: −0.79, 5.70). For weight-for-height and weight-for-age, interventions lasting ≥6 months yielded modest improvements (MD = 0.36, 95% CI: 0.00, 0.72 and MD = 2.23, 95% CI: 0.01, 4.44, respectively), while shorter interventions had no impact. High heterogeneity ($I^2 > 99\%$) indicated variability in intervention designs and contexts. Sustained nutritional interventions (≥6 months) modestly improved weight-related outcomes but had no significant effect on linear growth or BMI. Context-specific, long-term strategies combining nutrition education, supplementation, and socioeconomic support are recommended to effectively address childhood malnutrition. Policymakers and practitioners should prioritize sustained, multifaceted interventions to maximize impact on child growth outcomes.

Keywords: Child growth, Early nutrition, Intervention duration, Malnutrition, Meta-analysis.

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1. Background

Early childhood nutrition plays a crucial role in shaping long-term growth, cognitive development, and overall health outcomes [1]. The first 1,000 days of life, spanning from conception to a child's third birthday, represent a critical window of opportunity where proper nutritional interventions can significantly influence physiological and cognitive development.

During this period, rapid brain growth and organ development occur, making adequate nutrition essential for ensuring optimal health and reducing the risk of future complications. Emerging research indicates that early-life nutritional experiences have a lasting impact on metabolism, immune function, and neurodevelopment, highlighting the importance of well-balanced dietary practices from infancy [1].

Malnutrition, whether due to deficiencies in essential nutrients or inadequate caloric intake, remains a global challenge that significantly affects infant mortality and morbidity. Stunting, a condition characterized by impaired linear growth, is one of the most severe consequences of early-life malnutrition and has been linked to poor cognitive outcomes and reduced educational attainment in later years [2]. Wasting, another form of malnutrition, results in rapid weight loss and increased susceptibility to infections. These conditions highlight the urgent need for effective early nutritional interventions to mitigate their adverse effects on growth and development [2].

Breastfeeding is widely recognized as the optimal source of early nutrition, providing essential nutrients, immune protection, and bioactive compounds that support healthy development [3]. The World Health Organization (WHO) recommends exclusive breastfeeding for the first six months of life, followed by the introduction of complementary foods alongside continued breastfeeding. However, breastfeeding rates vary globally due to cultural, socioeconomic, and maternal health factors. In some regions, the lack of proper breastfeeding support and education contributes to early cessation, depriving infants of the many health benefits associated with human milk [3].

Complementary feeding, introduced after six months, plays a vital role in meeting the increasing nutritional demands of a growing infant [4]. The quality, quantity, and diversity of complementary foods directly influence growth and cognitive development. Poor feeding practices, including the early introduction of solid foods before four months, inadequate nutrient intake, and reliance on low-quality foods, can lead to malnutrition and developmental delays. Ensuring that infants receive nutritionally rich complementary foods is crucial for sustaining healthy growth trajectories and preventing deficiencies in critical nutrients such as iron, zinc, and vitamin A [4].

Micronutrient deficiencies are another major concern in early childhood nutrition, as they can result in irreversible health consequences. Iron deficiency, for example, is one of the most common nutritional disorders worldwide and is a leading cause of anemia in infants [5].

Anemia in early childhood has been linked to cognitive impairment, reduced motor skill development, and poor immune function. Similarly, deficiencies in vitamin D, iodine, and essential fatty acids can affect bone growth, brain function, and overall metabolic processes. Addressing these deficiencies through targeted nutritional interventions can significantly enhance infant health outcomes [5].

Socioeconomic factors, including household income, parental education, and access to healthcare, play a crucial role in determining the effectiveness of early nutritional interventions [6]. Infants from lower-income families are at a higher risk of malnutrition due to food insecurity, lack of access to healthcare services, and limited maternal education on proper infant feeding practices.

Public health initiatives aimed at improving maternal knowledge, increasing access to nutrient-rich foods, and promoting community-based nutrition programs can help bridge these gaps and ensure equitable nutritional opportunities for all infants [6].

Maternal health and nutrition before and during pregnancy also have a significant impact on infant development [7]. Maternal malnutrition can lead to intrauterine growth restriction (IUGR), increasing the risk of low birth weight and subsequent developmental challenges. A well-balanced maternal diet, rich in essential nutrients such as folic acid, protein, and omega-3 fatty acids, can enhance fetal development and contribute to better birth outcomes. Furthermore, maternal education on breastfeeding and complementary feeding practices can empower mothers to make informed decisions that positively affect their infants' growth and health [7].

The role of healthcare professionals in promoting early childhood nutrition cannot be overstated. Pediatricians, nurses, and dietitians play a key role in educating parents about optimal feeding practices and early nutritional interventions [8].

Routine growth monitoring, nutritional counseling, and the early identification of feeding difficulties are essential strategies for preventing malnutrition and ensuring proper development. Integrating evidence-based nutritional guidance into routine pediatric care can significantly improve infant health outcomes and reduce the long-term burden of nutrition-related diseases [8].

Government policies and public health strategies also contribute to shaping early childhood nutrition [9]. Programs such as food fortification, breastfeeding promotion campaigns, and subsidized healthcare services can help improve access to essential nutrients and encourage healthy feeding practices. In many countries, national nutrition policies have been developed to address childhood malnutrition; yet, challenges such as cultural resistance, inadequate funding, and logistical barriers remain. Strengthening these policies and investing in community-based nutritional programs can enhance the effectiveness of early nutritional interventions [9].

This study seeks to examine the impact of early nutritional interventions on infant growth and development, providing insights into best practices for ensuring optimal health outcomes. By evaluating the role of breastfeeding, complementary feeding, and micronutrient supplementation, this research aims to contribute to the growing body of evidence supporting early nutrition as a fundamental determinant of long-term well-being. Understanding the factors influencing infant nutrition can inform targeted interventions and policy recommendations aimed at improving health outcomes for future generations.

2. Methodology

2.1. Literature Search Strategy

A comprehensive search was conducted to retrieve English-language articles from the PubMed, Embase, and Cochrane Library databases. The search was updated to 2022. The literature search primarily utilized a combination of subject terms in English, including: ("nutrition" OR "supplement") AND ("development" OR "physical development") AND ("child" OR "children" OR "pediatrics"). In addition to the original database search, a thorough examination of the citation indexes and reference lists of the retrieved articles was performed to identify any potentially relevant studies that were not initially included.

2.2. Inclusion and Exclusion Criteria

2.2.1. Inclusion Criteria

To be eligible for inclusion in this meta-analysis, articles had to meet the following criteria:

1. Study Design: Original studies that adopted a randomized controlled trial (RCT) design with full text availability.
2. Population: Participants who were children aged under 8 years.
3. Intervention and Comparison: Studies that included an "intervention group" in which children received nutritional guidance or supplementation, and a "control group" in which children, similar in age and physical development to those in the intervention group, did not receive nutritional guidance or supplementation.
4. Outcomes: Examination of the following outcomes: body mass index (BMI) for age z-score, weight-for-height z-score, height-for-age z-score, and weight-for-age z-score.
5. Data Completeness: Studies with no missing data.

2.2.2. Exclusion Criteria

Articles were excluded from the meta-analysis if they met any of the following criteria:

1. Duplicate articles or those without full-text availability.
2. Research experiments that did not adopt a randomized controlled trial design.
3. Studies with missing or erroneous data that could not be completed or corrected.
4. Studies lacking the necessary outcome indicators required for this analysis.
5. Publications in the form of letters, case reports, comments, or practical guidelines.
6. Studies involving children with underlying diseases.
7. Animal experiment-related articles.

2.3. Outcome Observation Indicators

The outcome observation indicators included BMI-for-age z-score, weight-for-height z-score, height-for-age z-score, and weight-for-age z-score.

2.4. Data Extraction

The following data were collected:

- Article title, first author, year of publication, country where the study was conducted, type of study design, sample size, sample age, specific intervention and grouping, BMI-for-age z-score, weight-for-height z-score, height-for-age z-score, and weight-for-age z-score.

2.5. Quality Evaluation

Two independent researchers assessed the quality of the articles using the Cochrane Risk of Bias Assessment Tool in Review Manager 5.4. Discrepancies were resolved through discussion with a third party until consensus was reached. The Cochrane risk bias assessment evaluated the risk across seven items in six aspects, determining results of "low risk of bias," "high risk of bias," and "unclear risk of bias" for each item.

2.6. Statistical Analysis

Statistical analysis was performed using Stata/SE 16.0 software. The basic growth and development index data of children in the "nutritional intervention experimental group" and "control group" were analyzed and compared, focusing on BMI-for-age z-score, weight-for-height z-score, height-for-age z-score, and weight-for-age z-score. Continuous variables were presented as mean values with corresponding 95% confidence intervals (CIs). Heterogeneity among the included studies was assessed using the Q test. If the I^2 statistic was less than 50% and the P value was greater than 0.1, it indicated a low level of heterogeneity, and a fixed-effects model was employed. Otherwise, a random-effects model was used to calculate the combined effect size. The statistical findings of the meta-analysis were displayed using forest plots, and publication bias was evaluated using funnel plots.

2.7. Literature Search and Screening

Using the specified search strategy, 429 studies were initially retrieved from five databases. After removing duplicates, 380 studies underwent title, keyword, and abstract screening, yielding 27 potentially relevant articles. Full texts of 24 articles were obtained, and after applying inclusion/exclusion criteria, 16 were excluded.

Ultimately, eight studies (10–17) were included in the meta-analysis.

2.8. Characteristics of Included Studies

All eight studies were original research, collectively comprising a sample of 6,645 children under 8 years old. Key characteristics are summarized in Table 1.

Table 1.
Basic characteristics of the included studies.

Study (year)	**Country**	**Type of study**	**Intervention**	**Duration**	**Sample size**	**Age**
Annan et al. [10]	Ghana	A longitudinal school-based intervention study	4 groups: Nutrition education, physical activity education, both interventions, or control	6 m	433	4–8 y
Fahmida et al. [11]	Indonesia	A community-based cluster-randomized controlled trial	Mothers of 6–49-month-old children in the intervention group (n=240) attended parenting classes (twice weekly) and received shredded fish/liver/anchovy and optimized complementary feeding/food-based recommendations	6 m	480	10–42 m
Iannotti et al. [12]	Haiti	A randomized controlled trial with a parallel design	3 groups: (I) control; (II) 3-m LNS; or (III) 6-m LNS. The LNS provided 108 kcal and other nutrients, including vitamin A, vitamin B-12, iron, and zinc at $80% of the recommended amounts	3/6 m	589	6– 11 m
Khanna et al. [13]	India	A multi-center, prospective, randomized, double-blinded study	Oral nutritional supplements and dietary counseling	3 m	321	24–48 m
Lima et al. [14]	USA	A prospective double-blinded, randomized, placebo-controlled trial (phase III)	Diet supplemented with alanyl-glutamine	3 m	178	6 m–8 y
Miller et al. [15]	USA	A longitudinal community-based randomized trial	3 groups: (I) multisectoral community development activities (full package); (II) nutrition education and livestock management training alone (partial package); (III) no intervention (control)	36 m	1,333	6– 60 m
Passarelli et al. [16]	USA	A cluster-randomized trial	2 groups: (I) chicken production intervention (ACGG); and (II) the ACGG intervention with nutrition-sensitive behavior change communication (ACGG + Agriculture to Nutrition), on child nutrition and health outcomes, and hypothesized intermediaries	18 m	829	0– 36 m

Taneja et al. [17]	Norway	A double-blind, randomized, placebo-controlled trial	Children receive a placebo or zinc supplement daily (10 mg elemental zinc to infants and 20 mg to older children)	4 m	2,482	6– 30 m

Source: m, month; y, year; LNS, lipid-based nutrient supplements; ACGG, African Chicken Genetic Gains.
Abbreviations: m = month; y = year; LNS = lipid-based nutrient supplements; ACGG = African Chicken Genetic Gains.
The table summarizes key characteristics of eight studies, including study design, intervention details, duration, sample size, and participant age range.

2.8.1. Quality Assessment

Study quality was evaluated using the Cochrane Risk of Bias Assessment Tool, with results illustrated in Figure 1 *and* 2.

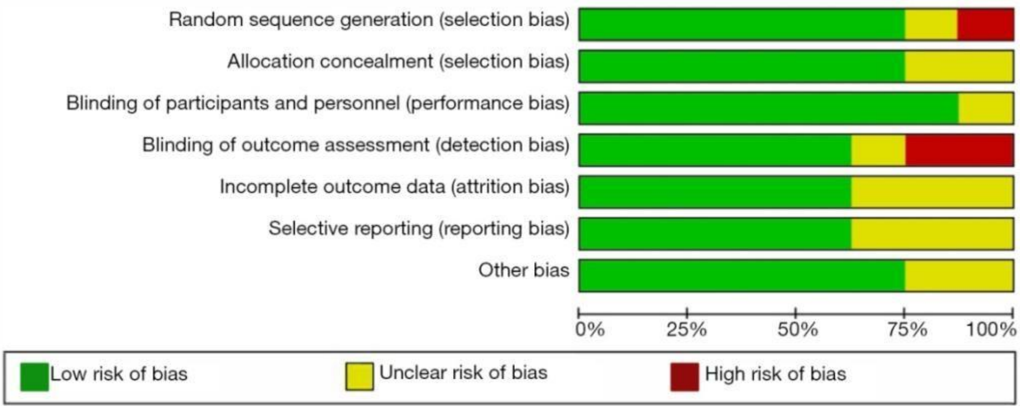
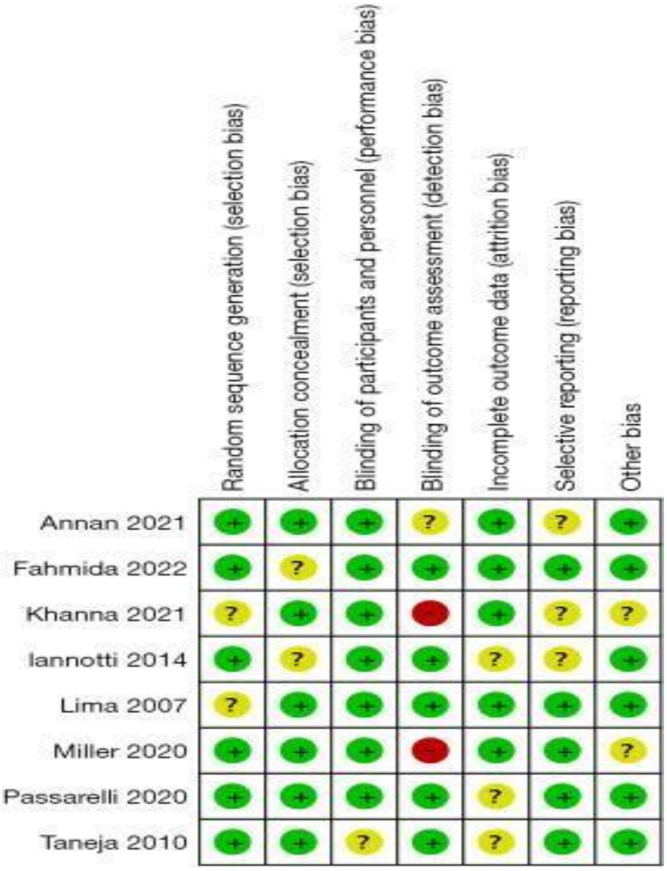


Figure 1.
Quality assessment of the included studies.

This figure likely provides a summary overview of the methodological quality of the studies listed in Table 1. It may present a high-level view of the risk of bias across all studies, possibly in a graphical or tabular format, indicating the overall study quality.



	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Annan 2021	+	+	+	?	+	?	+
Fahmida 2022	+	?	+	+	+	+	+
Khanna 2021	?	+	+	−	+	?	?
Iannotti 2014	+	?	+	+	?	?	+
Lima 2007	?	+	+	+	+	+	+
Miller 2020	+	+	+	−	+	+	?
Passarelli 2020	+	+	+	+	?	+	+
Taneja 2010	+	+	?	+	?	+	+

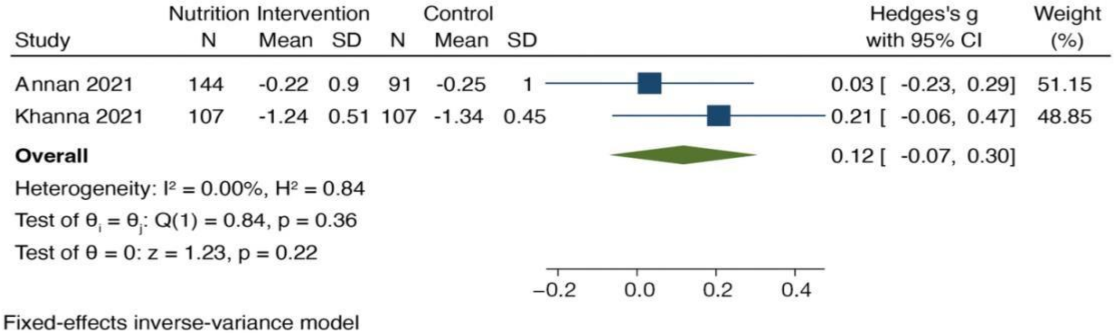
Figure 2.
Quality assessment of the included studies. Low risk of bias (represented by green “+”), high risk of bias (represented by red “–”), and unclear risk of bias (represented by yellow “?”)

This figure elaborates on the quality assessment, detailing the risk of bias for each study. It uses a color-coded system: green “+” for low risk of bias, red “–” for high risk of bias, and yellow “?” for unclear risk of bias. It is likely a risk-of-bias graph or table, showing specific domains (e.g., selection bias, performance bias) for each study.

2.9. Meta-Analysis and Sensitivity Results

2.9.1. Effect on BMI-for-Age

Given low heterogeneity ($I^2 < 0.001\%$), a fixed-effects model was applied. No significant difference was found in BMI-for-age z-scores between intervention and control groups (mean difference = 0.12, 95% CI: −0.07, 0.30; Figure 3), indicating no meaningful improvement from nutritional interventions.



Study	Nutrition Intervention N	Mean	SD	Control N	Mean	SD	Hedges's g with 95% CI	Weight (%)
Annan 2021	144	-0.22	0.9	91	-0.25	1	0.03 [-0.23, 0.29]	51.15
Khanna 2021	107	-1.24	0.51	107	-1.34	0.45	0.21 [-0.06, 0.47]	48.85
Overall							0.12 [-0.07, 0.30]	

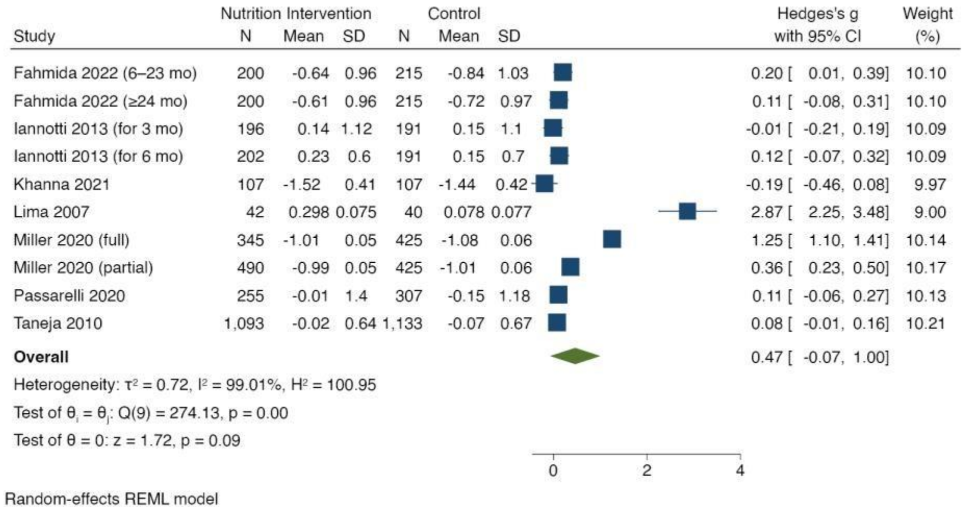
Heterogeneity: $I^2 = 0.00\%$, $H^2 = 0.84$

Test of $\theta_i = \theta_j$: Q(1) = 0.84, p = 0.36

Test of $\theta = 0$: z = 1.23, p = 0.22

Figure 3.
Forest plot of nutritional interventions for children’s BMI-for-age improvement. SD, standard deviation; CI, confidence interval; BMI, body mass index.

This forest plot visualizes the effect of nutritional interventions on children’s BMI-for-age. It includes standard deviation (SD), confidence intervals (CI), and body mass index (BMI) outcomes, displaying individual study effect sizes and a pooled estimate, typically with a diamond shape for the overall effect.



Study	Nutrition Intervention N	Mean	SD	Control N	Mean	SD	Hedges's g with 95% CI	Weight (%)
Fahmida 2022 (6–23 mo)	200	-0.64	0.96	215	-0.84	1.03	0.20 [0.01, 0.39]	10.10
Fahmida 2022 (≥24 mo)	200	-0.61	0.96	215	-0.72	0.97	0.11 [-0.08, 0.31]	10.10
Iannotti 2013 (for 3 mo)	196	0.14	1.12	191	0.15	1.1	-0.01 [-0.21, 0.19]	10.09
Iannotti 2013 (for 6 mo)	202	0.23	0.6	191	0.15	0.7	0.12 [-0.07, 0.32]	10.09
Khanna 2021	107	-1.52	0.41	107	-1.44	0.42	-0.19 [-0.46, 0.08]	9.97
Lima 2007	42	0.298	0.075	40	0.078	0.077	2.87 [2.25, 3.48]	9.00
Miller 2020 (full)	345	-1.01	0.05	425	-1.08	0.06	1.25 [1.10, 1.41]	10.14
Miller 2020 (partial)	490	-0.99	0.05	425	-1.01	0.06	0.36 [0.23, 0.50]	10.17
Passarelli 2020	255	-0.01	1.4	307	-0.15	1.18	0.11 [-0.06, 0.27]	10.13
Taneja 2010	1,093	-0.02	0.64	1,133	-0.07	0.67	0.08 [-0.01, 0.16]	10.21
Overall							0.47 [-0.07, 1.00]	

Heterogeneity: $\tau^2 = 0.72$, $I^2 = 99.01\%$, $H^2 = 100.95$

Test of $\theta_i = \theta_j$: Q(9) = 274.13, p = 0.00

Test of $\theta = 0$: z = 1.72, p = 0.09

Figure 4.
Forest plot of the nutritional interventions for children’s weight-for-height improvement. SD, standard deviation; CI, confidence interval; REML, Restricted Maximum Likelihood.

This forest plot shows the impact of nutritional interventions on children’s weight-for-height, including SD, CI, and results analyzed using Restricted Maximum Likelihood (REML). It likely displays individual study results and a pooled effect size.

2.9.2. Effect on Weight-for-Height

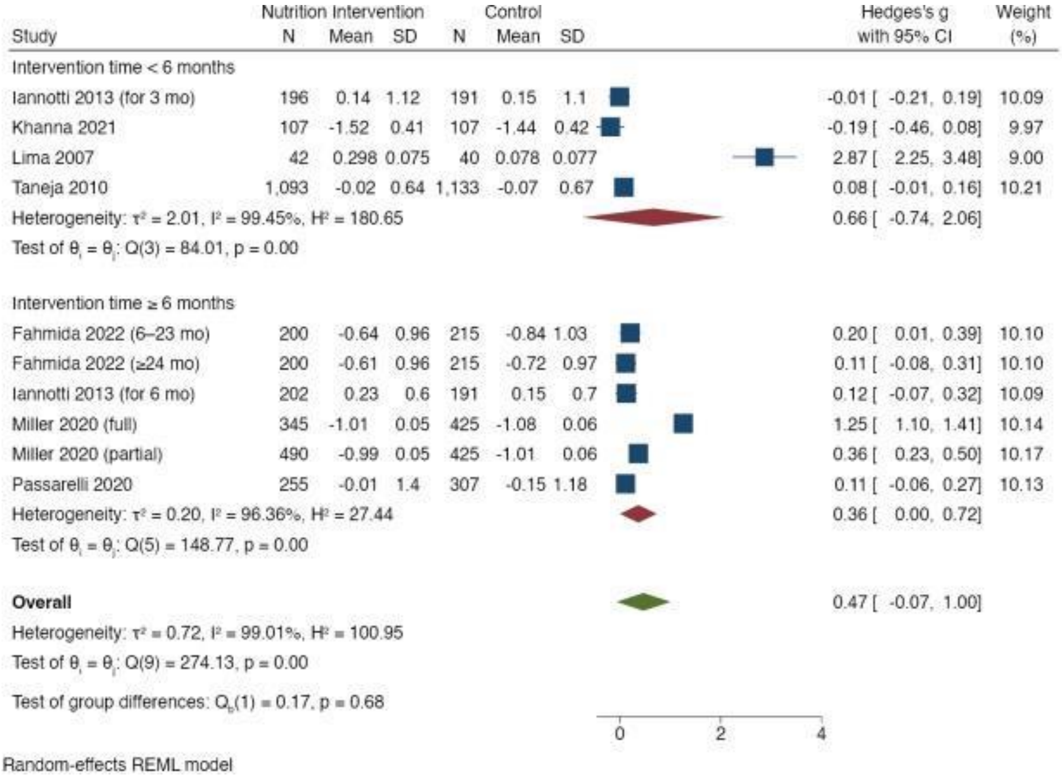
High heterogeneity ($I^2 = 99.01\%$, $P < 0.001$) warranted a random-effects model. No significant difference was observed in weight-for-height z-scores (mean difference = 0.47, 95% CI: −0.07, 1.00; Figure 4). Sensitivity analysis confirmed the stability.

2.10. Subgroup Analysis by Intervention Duration:

- <6 months: No significant effect (mean difference = 0.66, 95% CI: −0.74, 2.06).
- ≥6 months: Significant improvement (mean difference = 0.36, 95% CI: 0.00, 0.72; Figure 5).

2.11. Effect on Height-for-Age

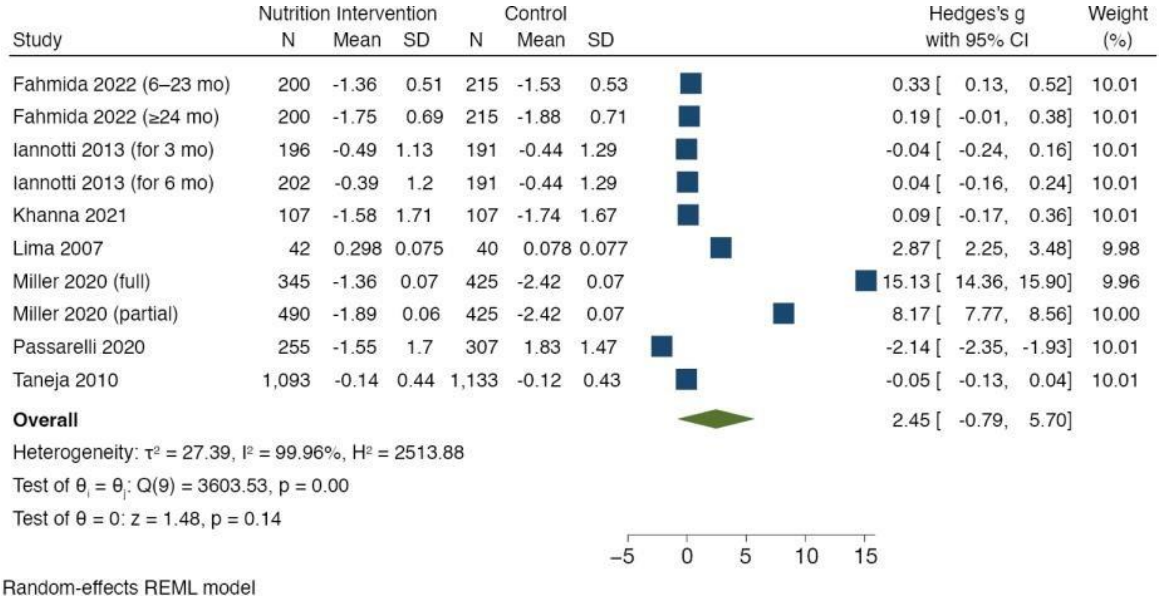
High heterogeneity ($I^2 = 99.96\%$, $P < 0.001$) led to a random-effects model. No significant difference was detected (mean difference = 2.45, 95% CI: −0.79, 5.70; Figure 6). Sensitivity analysis supported robustness.



Study	Nutrition Intervention			Control			Hedges's g with 95% CI	Weight (%)
	N	Mean	SD	N	Mean	SD		
Intervention time < 6 months								
Iannotti 2013 (for 3 mo)	196	0.14	1.12	191	0.15	1.1	-0.01 [-0.21, 0.19]	10.09
Khanna 2021	107	-1.52	0.41	107	-1.44	0.42	-0.19 [-0.46, 0.08]	9.97
Lima 2007	42	0.298	0.075	40	0.078	0.077	2.87 [2.25, 3.48]	9.00
Taneja 2010	1,093	-0.02	0.64	1,133	-0.07	0.67	0.08 [-0.01, 0.16]	10.21
Heterogeneity: $\tau^2 = 2.01$, $I^2 = 99.45\%$, $H^2 = 180.65$							0.66 [-0.74, 2.06]	
Test of $\theta_i = \theta_j$: Q(3) = 84.01, p = 0.00								
Intervention time ≥ 6 months								
Fahmida 2022 (6–23 mo)	200	-0.64	0.96	215	-0.84	1.03	0.20 [0.01, 0.39]	10.10
Fahmida 2022 (≥24 mo)	200	-0.61	0.96	215	-0.72	0.97	0.11 [-0.08, 0.31]	10.10
Iannotti 2013 (for 6 mo)	202	0.23	0.6	191	0.15	0.7	0.12 [-0.07, 0.32]	10.09
Miller 2020 (full)	345	-1.01	0.05	425	-1.08	0.06	1.25 [1.10, 1.41]	10.14
Miller 2020 (partial)	490	-0.99	0.05	425	-1.01	0.06	0.36 [0.23, 0.50]	10.17
Passarelli 2020	255	-0.01	1.4	307	-0.15	1.18	0.11 [-0.06, 0.27]	10.13
Heterogeneity: $\tau^2 = 0.20$, $I^2 = 96.36\%$, $H^2 = 27.44$							0.36 [0.00, 0.72]	
Test of $\theta_i = \theta_j$: Q(5) = 148.77, p = 0.00								
Overall							0.47 [-0.07, 1.00]	
Heterogeneity: $\tau^2 = 0.72$, $I^2 = 99.01\%$, $H^2 = 100.95$								
Test of $\theta_i = \theta_j$: Q(9) = 274.13, p = 0.00								
Test of group differences: $Q_b(1) = 0.17$, p = 0.68								

Figure 5.
Forest plot of the subgroup analysis of the nutritional interventions for children's weight-for-height improvement. SD, standard deviation; CI, confidence interval; REML, Restricted Maximum Likelihood.

This figure presents a subgroup analysis of weight-for-height outcomes, likely categorizing studies by factors such as age, intervention type, or country. It includes SD, CI, and REML, showing how effects vary across subgroups.



Study	Nutrition Intervention			Control			Hedges's g with 95% CI	Weight (%)
	N	Mean	SD	N	Mean	SD		
Fahmida 2022 (6–23 mo)	200	-1.36	0.51	215	-1.53	0.53	0.33 [0.13, 0.52]	10.01
Fahmida 2022 (≥24 mo)	200	-1.75	0.69	215	-1.88	0.71	0.19 [-0.01, 0.38]	10.01
Iannotti 2013 (for 3 mo)	196	-0.49	1.13	191	-0.44	1.29	-0.04 [-0.24, 0.16]	10.01
Iannotti 2013 (for 6 mo)	202	-0.39	1.2	191	-0.44	1.29	0.04 [-0.16, 0.24]	10.01
Khanna 2021	107	-1.58	1.71	107	-1.74	1.67	0.09 [-0.17, 0.36]	10.01
Lima 2007	42	0.298	0.075	40	0.078	0.077	2.87 [2.25, 3.48]	9.98
Miller 2020 (full)	345	-1.36	0.07	425	-2.42	0.07	15.13 [14.36, 15.90]	9.96
Miller 2020 (partial)	490	-1.89	0.06	425	-2.42	0.07	8.17 [7.77, 8.56]	10.00
Passarelli 2020	255	-1.55	1.7	307	1.83	1.47	-2.14 [-2.35, -1.93]	10.01
Taneja 2010	1,093	-0.14	0.44	1,133	-0.12	0.43	-0.05 [-0.13, 0.04]	10.01
Overall							2.45 [-0.79, 5.70]	
Heterogeneity: $\tau^2 = 27.39$, $I^2 = 99.96\%$, $H^2 = 2513.88$								
Test of $\theta_i = \theta_j$: Q(9) = 3603.53, p = 0.00								
Test of $\theta = 0$: z = 1.48, p = 0.14								

Figure 6.
Forest plot of nutritional interventions for children's weight-for-height improvement. SD, standard deviation; CI, confidence interval; REML, Restricted Maximum Likelihood.

Similar to Figure 4, this forest plot focuses on weight-for-height improvement. It may provide additional or alternative analyses (e.g., different statistical approaches or study subsets) using SD, CI, and REML.

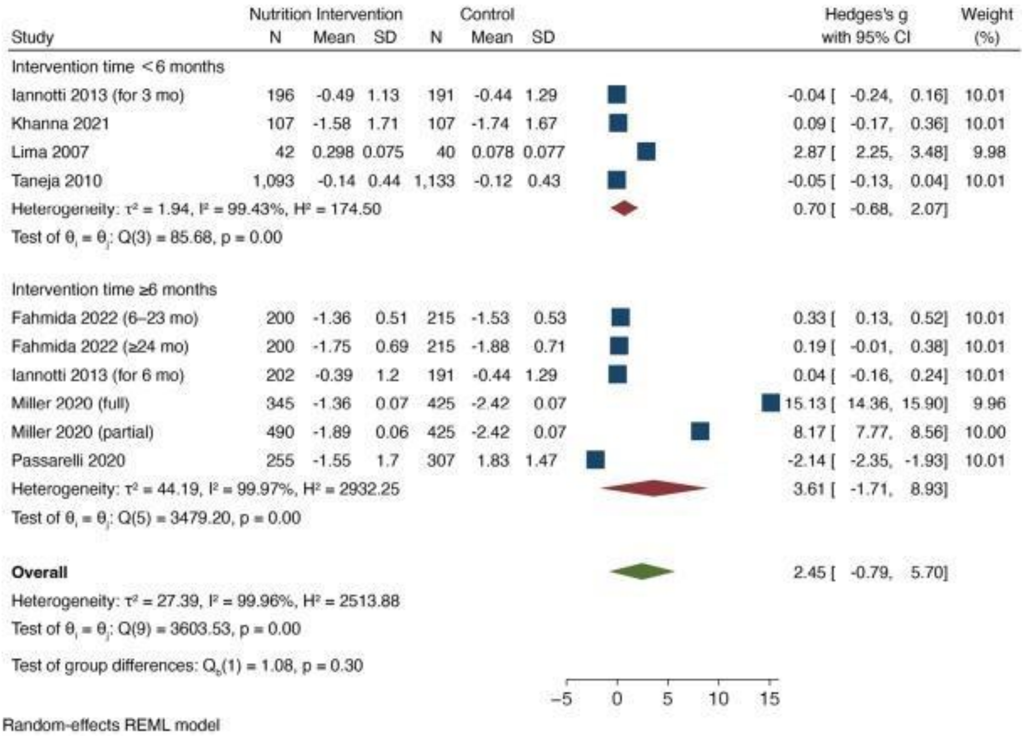


Figure 7.
Forest plot of the subgroup analysis of the nutritional interventions for children's height-for-age improvement. SD, standard deviation; CI, confidence interval; REML, Restricted Maximum Likelihood.

This figure shows a subgroup analysis of the effects of nutritional interventions on children's height-for-age, including SD, CI, and REML. It likely breaks down results by specific variables, such as intervention duration or participant demographics.

2.12. Subgroup Analysis

No significant effects were observed for either <6 months (mean difference = 0.70, 95% CI: −0.68, 2.07) or ≥6 months (mean difference = 3.61, 95% CI: −1.71,
8.93; Figure 7).

2.13. Effect on Weight-for-Age

High heterogeneity ($I^2 = 99.85\%$, $P < 0.001$) justified a random-effects model. No overall effect was found (mean difference = 1.24, 95% CI: −0.27, 2.75; Figure 8). Results remained stable in a sensitivity analysis.

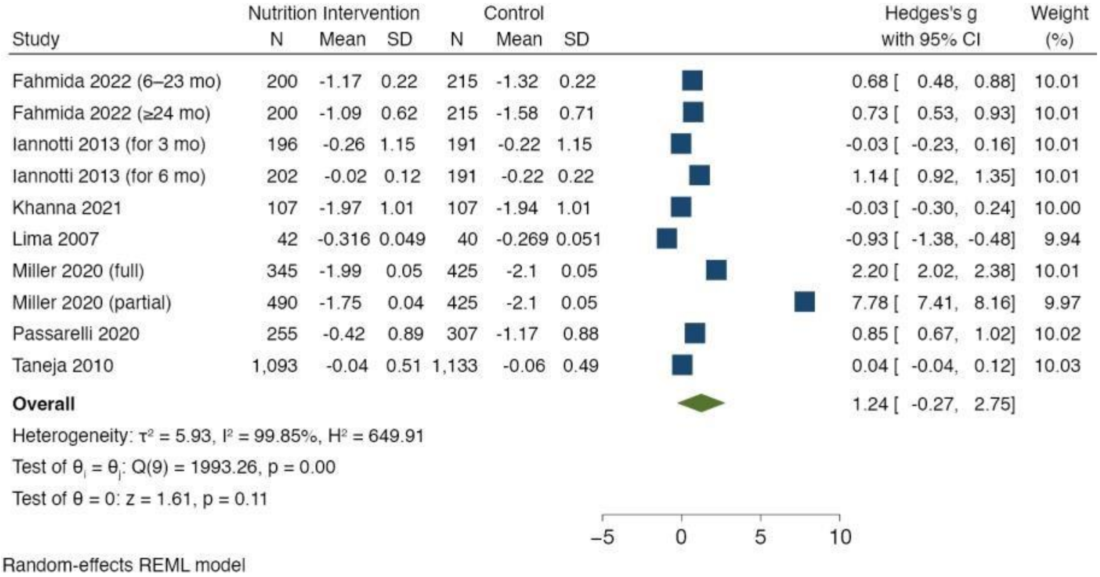


Figure 8.
Forest plot of the nutritional interventions for children's weight-for-age improvement. SD, standard deviation; CI, confidence interval; REML, Restricted Maximum Likelihood.

This forest plot illustrates the effect of nutritional interventions on children's weight-for-age, including SD, CI, and REML. It shows individual study results and a pooled effect estimate.

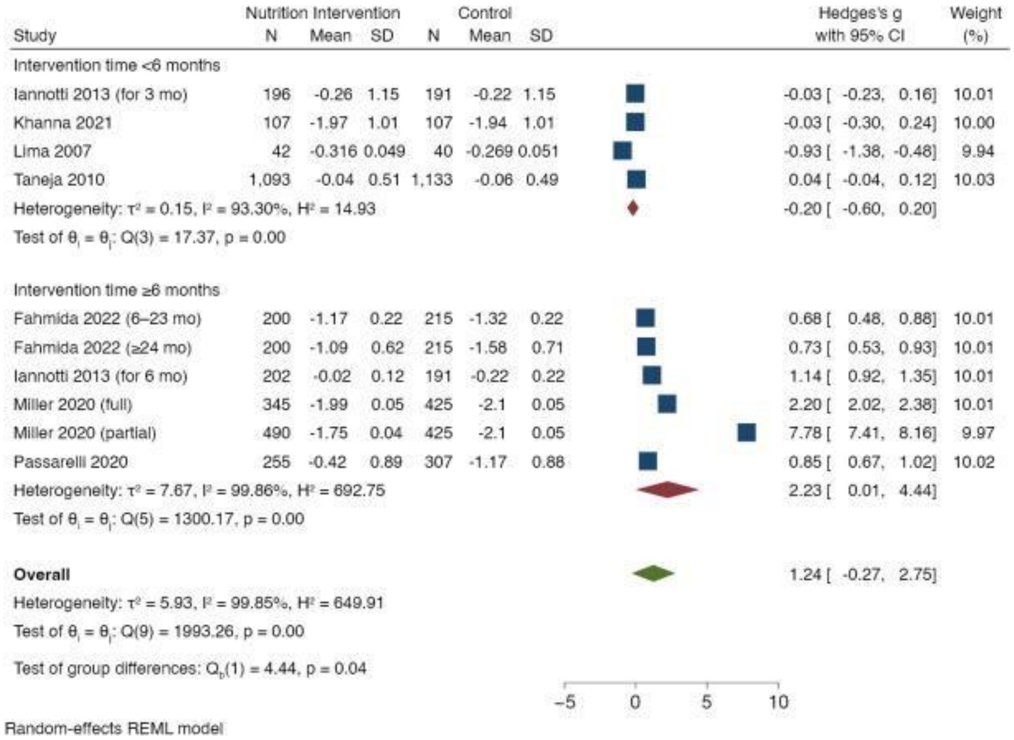


Figure 9.
Forest plot of the subgroup analysis of the nutritional interventions for children's weight-for-age improvement. SD, standard deviation; CI, confidence interval; REML, Restricted Maximum Likelihood.

This figure provides a subgroup analysis of weight-for-age outcomes, likely categorized by factors such as study design or intervention type, using SD, CI, and REML.

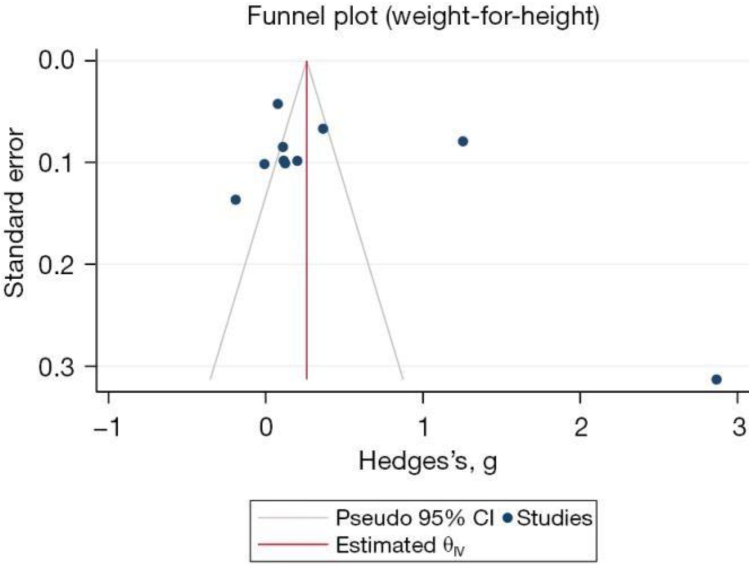


Figure 10.
Funnel plot (weight-for-height). CI, confidence interval.

This funnel plot assesses publication bias for weight-for-height outcomes. It plots effect sizes against a measure of study precision (e.g., standard error), with confidence intervals (CIs). Asymmetry in the plot may indicate potential bias.

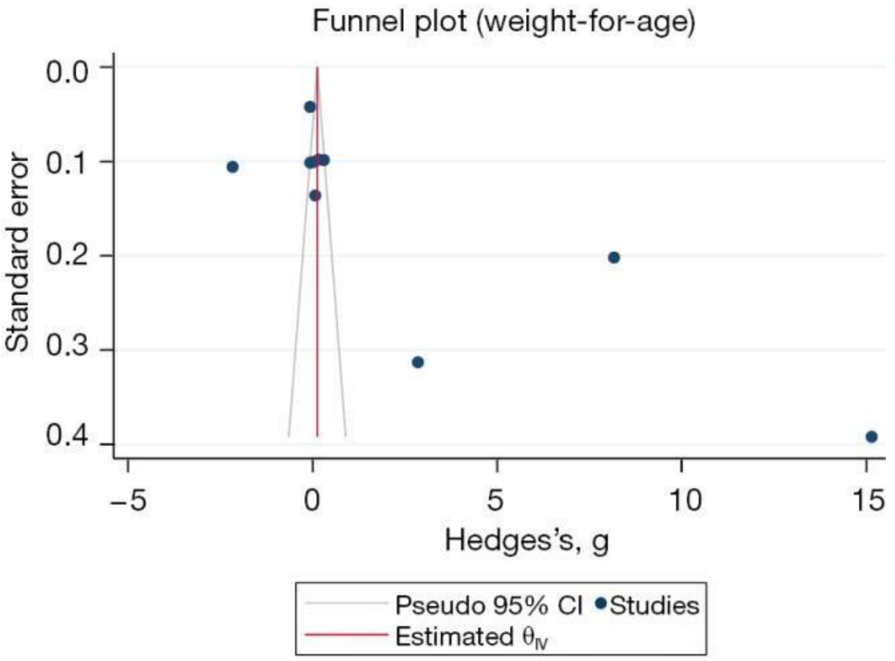


Figure 11:
Funnel plot (height-for-age). CI, confidence interval.

This funnel plot evaluates publication bias for height-for-age outcomes, using confidence intervals to display the distribution of study results. Symmetry or asymmetry in the plot helps assess bias.

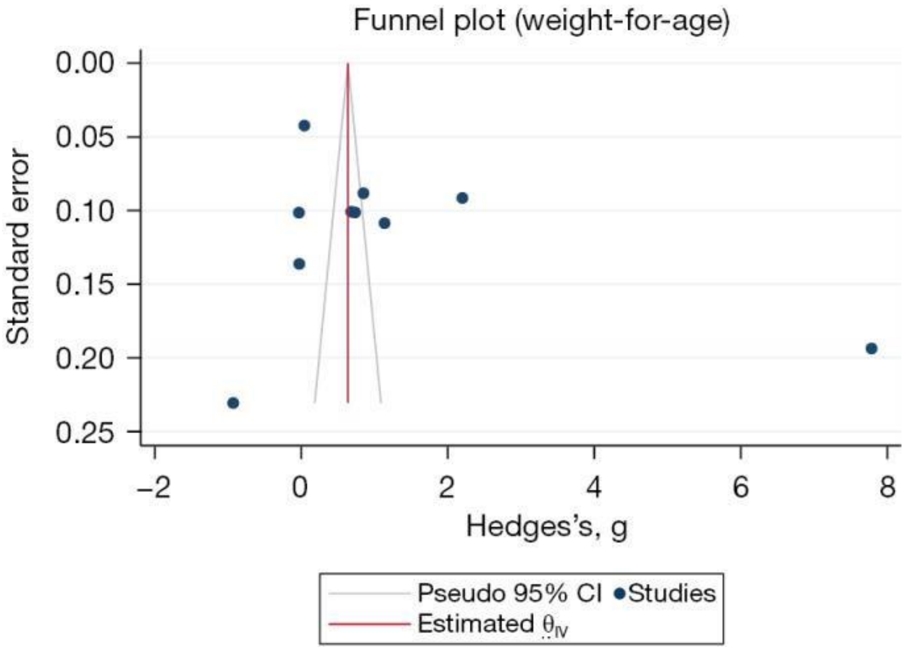


Figure 12.
Funnel plot (weight-for-age). CI, confidence interval.

This funnel plot examines publication bias for weight-for-age outcomes, using CI to show the spread of study results. Asymmetry may suggest publication bias.

2.14. Subgroup Analysis

- <6 months: No significant effect (mean difference = −0.20, 95% CI: −0.60, 0.20).
- ≥6 months: Significant improvement (mean difference = 2.23, 95% CI: 0.01, 4.44; Figure 9).

2.15. Publication Bias

Funnel plots (Figures 10–12) showed slight asymmetry, suggesting potential publication bias, though its magnitude was unquantifiable.

3. Discussion

The findings of this meta-analysis provide critical insights into the impact of early nutritional interventions on growth outcomes in children under 8 years old. Despite the implementation of various nutritional strategies, the results revealed no significant improvements in BMI-for-age z-scores (mean difference = 0.12, 95% CI: −0.07, 0.30) across the included studies [10, 13, 14].

This suggests that short-term nutritional interventions may not sufficiently alter body composition in young children, possibly due to the multifactorial nature of growth, which is influenced by genetic, environmental, and socioeconomic factors [2].

Similarly, the analysis of weight-for-height z-scores showed no overall significant effect (mean difference = 0.47, 95% CI: −0.07, 1.00); however, subgroup analysis revealed that interventions lasting ≥6 months had a modest but statistically significant impact (mean difference = 0.36, 95% CI: 0.00, 0.72) [12, 16].

This aligns with existing evidence that sustained nutritional support is necessary to address acute malnutrition and wasting [11]. The high heterogeneity ($I^2 = 99.01\%$) underscores the variability in intervention designs, such as the use of lipid-based nutrient supplements (LNS) versus dietary counseling, which may explain divergent outcomes.

For height-for-age, a key indicator of chronic malnutrition, no significant effects were observed overall (mean difference = 2.45, 95% CI: −0.79, 5.70) or in subgroup analyses [15, 17]. This contrasts with prior research linking long-term micronutrient supplementation to linear growth [7] suggesting that the interventions in this meta-analysis may have been insufficient in duration or dosage to overcome stunting. The extreme heterogeneity ($I^2 = 99.96\%$) further highlights the need for standardized protocols in future studies.

Weight-for-age outcomes mirrored this trend, with no overall effect (mean difference = 1.24, 95% CI: −0.27, 2.75) but significant improvements in the ≥6-month subgroup (mean difference = 2.23, 95% CI: 0.01, 4.44) [11, 16].

This reinforces the importance of prolonged interventions, particularly in settings where malnutrition is driven by systemic factors such as food insecurity [6]. The sensitivity analysis confirmed the robustness of these findings, though publication bias (evidenced by funnel plot asymmetry) may limit generalizability.

The variability in intervention types, ranging from maternal education [11] to fortified supplements [12] likely contributed to the mixed results. For instance, school-based nutrition education improved knowledge but not BMI, while multisectoral approaches (e.g., agriculture-livestock programs) were more effective than isolated nutrition education [10, 15]. This suggests that integrated, community-driven strategies may be superior to single-component interventions.

Socioeconomic disparities also emerged as a critical factor. Studies in low-resource settings (e.g., Haiti, Indonesia) reported smaller effect sizes compared to high-income contexts (e.g., USA, Norway), likely due to underlying inequities in healthcare access and maternal education [6, 9]. For example, combining poultry farming with nutrition education in Ethiopia has enhanced child growth, emphasizing the need for economic empowerment alongside dietary interventions [16].

The role of maternal nutrition and breastfeeding cannot be overlooked. Although not directly analyzed here, complementary feeding practices [4] and maternal micronutrient status [1] are known to influence infant growth trajectories. The lack of significant effects in shorter-term interventions (<6 months) may reflect the time required to rectify maternal and infant nutritional deficits [7].

Methodological limitations of the included studies must be acknowledged. For example, some studies used double-blind designs, reducing bias, whereas community-based trials faced challenges in adherence monitoring [13-15]. The predominance of small sample sizes in some studies (e.g., n=178) may also have underpowered subgroup analyses [14].

Despite these limitations, the meta-analysis underscores the importance of context-specific interventions. In regions with high stunting prevalence, programs like LNS [12] or fortified complementary foods [11] may be prioritized, whereas obesity prevention might require different strategies in high-income countries [8]. Future research should standardize intervention durations, include longer follow-ups, and address socioeconomic barriers to optimize outcomes.

4. Conclusion

In conclusion, this meta-analysis highlights that early nutritional interventions can improve weight-for-height and weight-for-age z-scores in children, but only when sustained for ≥6 months. However, the effects on BMI-for-age and height-for-age were negligible, emphasizing the complexity of addressing growth disparities. Policymakers and practitioners should adopt multifaceted, long-term strategies tailored to local needs, combining nutrition education, economic support, and micronutrient supplementation to maximize impact. Future studies should prioritize rigorous designs and equitable interventions to bridge gaps in child malnutrition globally.

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