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SYSTEMATIC REVIEW

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Association of dietary diversity and odds of anemia in children and adolescents: a systematic review and meta-analysis of observational studies

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Abstract

Background Anemia, characterized by a deficiency in red blood cells or hemoglobin, remains a significant public health concern worldwide, particularly among children and adolescents. Inadequate dietary intake, including micronutrient deficiencies, has been associated with anemia. Dietary diversity, characterized by the consumption of a variety of food groups, may contribute to adequate iron intake and a reduced likelihood of anemia. This systematic review and meta-analysis examined the association between dietary diversity and odds of anemia among children and adolescents.

Methods A comprehensive search of electronic databases (PubMed, Web of Science, Scopus) was conducted for observational studies (cross-sectional or case–control) published before April 2024 that assessed the association between dietary diversity and anemia among children and adolescents. The odds of Bias in Non-Randomized Studies of Exposures (ROBINS-E) tool was used to assess the quality of included studies, ensuring a standardized and rigorous evaluation process. Subgroup analyses explored potential variations in this association based on age group, geographic location, and type of anemia.

Results Nineteen studies (18 cross-sectional and 1 case–control) examined the association between dietary diversity and anemia in children under 5 years old. Pooled analysis revealed a significant association between lower dietary diversity and higher odds of anemia among children aged 0 to 5 years (OR = 1.96; 95% CI: 1.57, 2.45; $I^2 = 83.6\%$, $\tau 2 = 0.38$ $P < 0.001$). Ten studies examined the relationship in children and adolescents aged 6–18 years, showing a similar pattern (OR = 1.73; 95% CI: 1.27, 2.36; $I^2 = 87\%$, $\tau 2 = 0.44$; $P < 0.001$). Subgroup analyses suggested that the association varied across specific geographic regions.

Conclusions This meta-analysis indicates a significant association between lower dietary diversity and higher odds of anemia in children and adolescents. These findings underscore the importance of dietary diversity as a potential factor related to anemia prevalence. Future research should focus on standardizing dietary diversity assessment methods and incorporating detailed dietary quality measurements.

Keywords Anemia, Dietary diversity, Children, Adolescents, Meta-analysis

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Introduction

Micronutrient deficiencies are prevalent globally and are associated with child mortality in some poor and less developed countries and regions such as sub-Saharan Africa [1, 2]. Anemia is a micronutrient deficiency disorder with significant public health implications worldwide [3]. It is commonly observed among children and has been linked to health and development [4]. These impacts include higher rates of growth retardation, reduced immunity and cognitive abilities, and potential adverse effects on health extending into adulthood. Also, anemia can lead to a cascade of detrimental health consequences, including fatigue, decreased physical work capacity, significantly impacting a child's overall well-being and developmental trajectory [5, 6].

Iron deficiency anemia (IDA), characterized by a lack of red blood cells or hemoglobin, remains a significant public health concern worldwide [7, 8]. This condition disproportionately affects children and adolescents, particularly those residing in low- and middle-income countries [9, 10]. In addition to iron deficiency, anemia has been associated with other nutritional inadequacies such as protein, B vitamins, and zinc deficiencies [11–13].

According to the World Health Organization (WHO), anemia is defined by hemoglobin levels < 11.0 g/dL for children under 5 years, < 11.5 g/dL for children 5–11 years, and < 12 g/dL for children 12–14 years [14]. Notably, while anemia can occur across the lifespan, young children under two years old are particularly vulnerable [13, 15, 16]. This heightened susceptibility is attributed to rapid physical and mental development that increases dietary demands. Global estimates suggest that a staggering 269 million children suffered from anemia in 2019 [17, 18]. This burden is not evenly distributed, with approximately two-thirds of these cases concentrated in Asia and Africa. Furthermore, sub-Saharan Africa exhibits the most concerning prevalence rates, with childhood anemia affecting an estimated 46% to 66% of the population [17, 19].

Dietary diversity, defined as the consumption of a variety of food groups and micronutrients, plays a crucial role in ensuring adequate intake of vitamins and minerals [20]. A diet with greater diversity has been linked to higher micronutrient intake, which may contribute to improved iron status and lower odds of anemia [8, 21–23]. Conversely, limited dietary variety can lead to micronutrient deficiencies, especially iron deficiency, increasing susceptibility to anemia [24, 25].

While previous studies have explored the association between dietary diversity and anemia in children, the existing evidence comes from individual studies with potentially limited generalizability. Furthermore, the relationship between dietary diversity and anemia might vary depending on factors like age group, geographic location, and socioeconomic status. There is a need for a more comprehensive analysis to elucidate these connections.

This systematic review and meta-analysis aimed to address this gap in knowledge. By systematically searching and analyzing data from multiple observational studies, we aimed to provide a more robust understanding of the relationship between dietary diversity and anemia in children and adolescents.

Method

Data source and search strategy

The present study was performed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered in Prospero database.

(CRD42024545540). We carried out a comprehensive systematic search from inception to April 2024 in electronic databases including PubMed, Web of Science, and Scopus without any date or language restrictions. Dietary diversity, Dietary diversity score, Anemia, and Iron Deficiency Anemia (Supplementary Table 1) were used in the search approach. In addition, the reference lists of the retrieved articles, google scholar and related review studies were manually searched.

Eligibility criteria

- Population (P): Children and adolescents aged 0–18 years.
- Intervention (I): Assessment of dietary diversity as an exposure factor.
- Comparison (C): Higher dietary diversity vs. lower dietary diversity.
- Outcome (O): Odds of anemia, including iron deficiency anemia.
- Study Design (S): Observational studies (cross-sectional and case–control studies).

Studies meeting these criteria were included in the systematic review and meta-analysis. Exclusion criteria comprised studies focusing on adults, maternal or paternal dietary diversity, lack of anemia outcome data, and study designs such as editorials, commentaries, conference papers, reviews, letters to the editor, unpublished studies, or abstracts. A detailed summary of inclusion and exclusion criteria is provided in Supplementary Table 2.

Study selection

Two independent reviewers (MR and SPM) screened the eligible articles. At first, title/abstract of articles were scanned, publications that were irrelevant were excluded.

Then, remaining records were assessed for eligibility using full text. Any disagreement was resolved by consensus with a third investigator (NGh).

Data collection

The following information were extracted from each included study by two independent investigators (MR and SPM): the first author's last name, research publication year, study country of origin, study design, sample size, participants'gender and age range, dietary measurement, relevant effect estimates, anemia case count, outcome assessment method, and any adjusted analyses. Disagreements were resolved by a third reviewer (NGh). We used the adjusted measure if both adjusted and unadjusted effect sizes were reported.

Quality assessment

The quality of included studies was assessed using the ROBINS-E tool, which evaluates study quality based on bias domains, including confounding, selection, classification, missing data, measurement, and reporting bias. Studies were categorized as having low, moderate, or high risk of bias based on their ROBINS-E scores.

Confounding

Most studies adjusted for common confounders, such as age, sex, socioeconomic status, and physical activity. However, residual confounding remained a significant concern, particularly in cross-sectional studies, which cannot fully control for all potential confounders. In many studies, the adjustments for confounding were incomplete or inadequately addressed, resulting in a classification of some concern or high risk of bias for confounding.

Selection bias

Selection bias was evaluated based on the sampling methods used in each study. Many studies relied on convenience sampling, which may lead to a non-representative sample. In studies where the sample was more randomly selected or better matched, the risk was rated as some concern. However, due to the common use of convenience sampling in cross-sectional designs, some studies were rated as high bias in this domain.

Classification of exposure

Exposure classification in many studies relied on self-reported dietary intake, often using a single 24-h recall, which is prone to recall bias and measurement error. As a result, studies relying on this method were rated as high or very high bias in this domain. Studies that used multiple 24-h recalls or more accurate exposure assessment methods (e.g., food diaries) were rated with some concern for bias.

Deviation from intended interventions

Since the studies included in this review were observational, this domain was not applicable. No interventions were planned or administered, and as such, there was no deviation from intended interventions.

Missing data

Missing data was a concern in some studies, with incomplete participant data or a high rate of drop-out. Some studies provided clear information on how missing data were handled or imputed, they were rated as low bias. Studies without proper handling of missing data were rated as having some concern or high bias.

Outcome measurement

Outcome measurement was evaluated based on whether the outcome assessors were blinded to exposure status and whether standardized and validated measurement tools were used. In many studies, it was unclear whether assessors were blinded, and some studies used unvalidated or subjective outcome measures. As a result, the majority of studies were rated as having some concern or high bias in this domain.

Selective reporting

Selective reporting of outcomes was assessed by examining whether all pre-specified outcomes were reported. Some studies selectively reported outcomes or failed to report all planned outcomes, leading to some concern or high-risk ratings in this domain. A detailed bias assessment for each study across these domains is provided in Supplementary Table 3.

Statistical analysis

Statistical analyses were performed with STATA (version 14; Stata Corporation, College Station, TX). To assess the association between dietary diversity and anemia, the estimates for anemia and IDA were pooled. The pooled odds of anemia among the children and adolescents was calculated using log OR and 95% CI were estimated using a DerSimonian and Laird weighted random effects model methods. To assess the heterogeneity across the included studies, we used the I^2 statistic, which quantifies the percentage of total variation across studies due to heterogeneity, and tau-squared (τ^2), which provides an absolute measure of variance in true effect sizes. I^2 values of 0–25%, 25–50%, 50–75%, and 75–100% were considered to represent low, moderate, high, and very high heterogeneity, respectively. Tau-squared values were derived from a random-effects model using STATA version 14.

In addition to confidence intervals, we calculated 95% prediction intervals (PI) to provide an estimate of the expected range of effect sizes in future studies, incorporating between-study variance. Prediction intervals were computed using the following formula:

$$PI = \text{Pooled Effect } \pm 1.96 \times \sqrt{r^2 + SE_{pooled}^2}$$

where τ2 represents the between-study variance, and SE_pooled is the standard error of the pooled effect size, estimated from the confidence intervals.

To improve clinical interpretability, we also calculated absolute risk increases (ARI) for each population group, based on estimated baseline anemia prevalence. ARI was calculated using the formula:

$$\text{ARI} = \text{Baseline Risk } \times (\text{OR} - 1)$$

where Baseline odds were derived from WHO estimates and included study data. Certainty of the evidence was assessed using the GRADE approach, starting at'low'due to the observational nature of the included studies. We systematically considered five domains—risk of bias, inconsistency, indirectness, imprecision, and publication bias—for possible downgrading. Although some effect sizes were moderate to large, we did not apply any upgrades due to the high risk of bias, substantial heterogeneity, and lack of dose–response assessment across studies. The overall certainty of evidence was rated as'low'for both age groups.

To identify the sources of heterogeneity, subgroup analyses were conducted based on continent (Africa, and Asia), type of anemia (anemia, Iron deficiency anemia), sex and ROBINS-E score (Low odds of bias vs. high odds of bias). Publication bias was assessed by using the Egger's regression test and Begg's test (significance point at $P < 0.05$, for all). Sensitivity analysis was conducted to examine the influence of each study on the overall effect size. In addition to Egger's and Begg's tests for publication bias, we compared the results of the random-effects model with the fixed-effects model as an exploratory analysis to evaluate the presence of small-study effects. A substantial difference in effect estimates between the two models may suggest small-study effects. Egger's test was conducted using a p-value threshold of 0.05, which is a more conservative approach compared to the original threshold of 0.1. However, considering the observed visual asymmetry in the funnel plot, we performed additional sensitivity analyses to further explore potential publication bias.

Results

Characteristics of the included studies

The process of study selection is demonstrated in PRISMA flow diagram (Fig. 1). The initial literature search yielded 898 studies. After excluding duplicate records, 519 publications remained. Then, the title and abstract of these studies was screened and 473 article were excluded based on the study inclusion criteria. The full-text of 46 articles were reviewed to confirm eligibility. Of these, leading to the exclusion of 17 articles due to various reasons (Supplementary Table 2). Finally, 29 studies were included in the current systematic review and meta-analysis [24, 10, 26–52].

The detailed characteristics of the included studies are summarized in Table 1. Of 29 included observational studies, 28 were cross-sectional in design [24, 26–44, 10, 46–52], and only 1 was case–control [45]. Studies were published between 2015 and 2024, with a sample size ranging from 210 to 14,669 participants. Seventeen studies conducted in Ethiopia [10, 27–33, 35, 40, 41, 43, 47–51], and the rest were performed in India ($n = 4$) [34, 36, 38, 44], Tanzania ($n = 2$) [39, 46], Nepal ($n = 1$) [37], Chad ($n = 1$) [52], Burkina Faso ($n = 1$) [42], Indonesia ($n = 1$) [26], Ghana ($n = 1$) [45], South Africa ($n = 1$) [24]. Some studies were conducted on both genders [24, 34–36, 10, 38–49, 51–54], while other studies were performed on girls only [26, 31, 33, 37, 50]. Dietary assessment was done with various methods including, 24-h recall [28, 30, 31, 33–37, 39, 42, 43], 7-day recall [52], 24 h and 7 days' child food frequency recall [10], FFQ + 24-h recall [27, 32], 2-day 24-h recall [26], 3-day 24-h recall [24], and 30 days- FFQ [40, 41, 44]. Five studies did not report the dietary assessment method [29, 36, 38, 46, 49]. To assess dietary diversity, most of the studies used dietary diversity score (DDS) [24, 32–40, 42–45, 47–52], one study determined dietary diversity based on principal component analyses [41], and one study did not report the dietary diversity assessment method [46]. Anemia, and iron deficiency anemia were identified based on WHO reference values (2011).

Included studies were reported their results as adjusted ORs and considered confounders such as child's age [24, 26–30, 35–37, 40, 42, 43, 46–48, 50, 51], grade of child [29, 37], child's sex [24, 28, 34–36, 42, 43, 51], mother's education [29, 35–37, 40, 42, 43, 10, 48, 50, 51], mothers' age [27, 28, 36, 40], father's education [10, 29, 37, 42], father's occupation [28, 37, 40], education of adolescent [26], knowledge on anemia [37], knowledge on weekly iron folic acid supplementation [37], iron folate utilization [41, 47, 48], iron intake [26], vitamin A rich food [52], dairy/egg intake [52], number of under five children within household [40], family size [28, 31, 47, 50], wealth index [31, 42, 43, 47, 51], monthly income [27, 30,

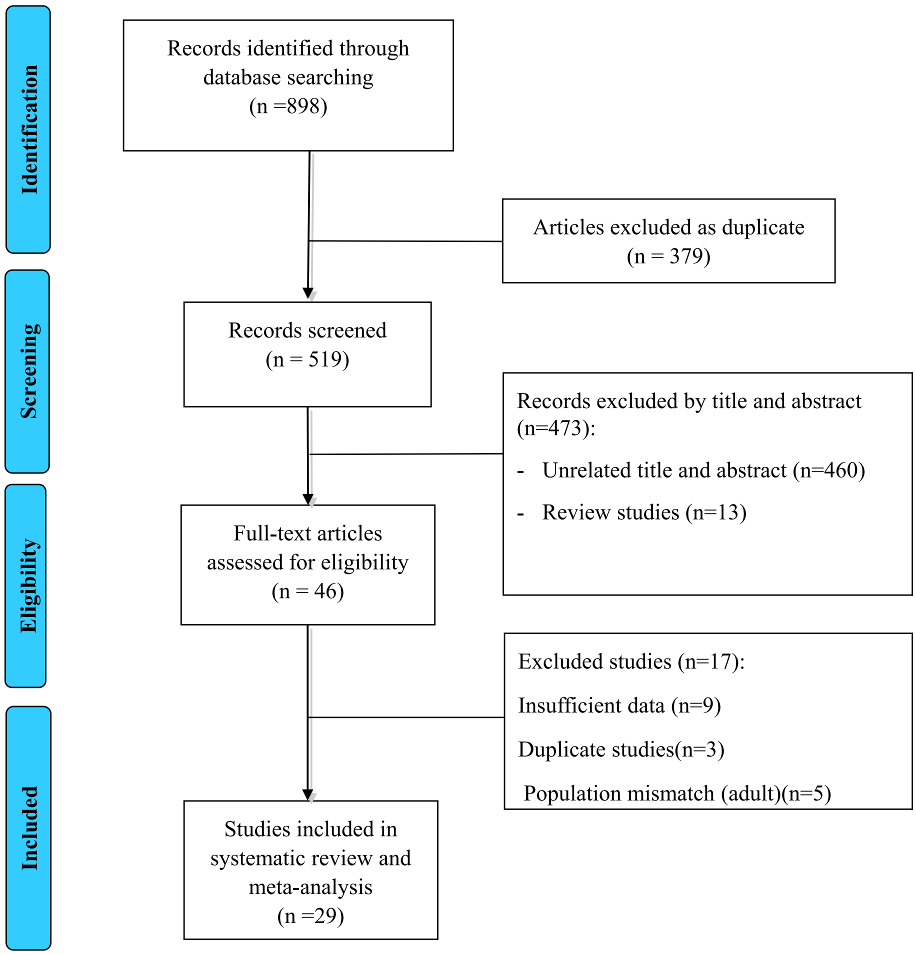

Fig. 1 PRISMA flowchart of the studies examined and included in the meta-analysis

48], household food insecurity [27, 28, 33, 34, 41, 43, 47, 48], introduction time of complementary feeding [27, 28, 40, 41, 43, 47, 51], exclusive breast feeding [30], stunting [32, 43, 47, 48, 51], underweight [32, 43, 46, 48], diarrhea in the last 2 months [30, 43, 48, 51], growth monitoring service utilization [43, 48], birth interval [43], stool disposal [46], meal frequency of child [10, 31, 43], frequency of meat consumption in child [50], meal frequency of mother [28], intestinal parasites [27], menses status [31, 50], frequency of changed pad [31], duration of menses [31], Tea/coffee intake within 30 min after meal [29, 32, 50], wasting [29, 31, 50], receiving anti-helminthic drug [28], mother's smoking, [49] source of drinking water [33, 40], and use of social media by adolescent [26]. One study not reported adjusted variables [45]. In 3 investigations, no adjustments for potential confounders were done [38, 39, 44].

The odds of bias ratings by ROBINS-E domain are presented in Supplementary Table 3. Except four studies that had some concerns, others studies rated with high bias (19 studies) and very high bias (6 studies). Most studies had high or very high odds of bias due to reliance on single 24-h recalls, which may introduce measurement error and misclassification bias. Also, residual confounding was a common issue, as many studies did not adjust for all key factors such as socioeconomic status and household food security. Moreover, few studies used validated dietary assessment tools, increasing the odds of exposure misclassification.

Dietary diversity and odds of anemia among 0 to 5 years old children

Nineteen studies with 19 effect size were evaluated the association between dietary diversity and odds of anemia. Based on pooled results, there was a significant correlation between inadequate dietary diversity and odds of anemia among the children under 5 years old (OR $=1.96$; 95% CI: 1.57, 2.45; $I^2 = 83.6\%$, $\tau^2 = 0.38$ $P < 0.001$) (Fig. 2). The 95% prediction interval was [0.57, 6.70], suggesting that future studies might observe varying effect

Table 1 Characteristics of studies included in the systematic review and meta-analysis

First author (year)	Location, data collection period, study name	sample size, age, sex	Dietary assessment tool	Comparison	OR (95% CI)	Number of Anemia Cases	Overall Quality
Khanal (2024) [38]	Kathmandu, Nepal, 2014–2016	n 602 10 to 19 years (100% F)	24 h recall	DDS ≥ 5 food groups vs. DDS < 5 food groups	Anemia risk: 13.8 (4.20, 22.6)	245	High bias
Kumar (2023) [39]	data of a collaborative project of the Ministry of Health and Family Welfare India, 2016–2018	n 14,669 10 to 19 years (49.9% M, 50.1% F)	Not reported	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 1·06 (0.95, 1.19)	5126	Very high bias
Zavala (2023) [54]	SMART surveys, Chad, 2016 to 2019 and 2021	n 2170 n 2349 Under 5 years (mixed)	7 day recall	DDS ≥ 5 food groups vs. DDS < 5 food groups	Anemia risk: 1.53 (1.08, 2.17) Anemia risk: 1.53 (1.16, 2)	846	Some concerns
Sodde (2023) [49]	Atnago, Ethiopia, 10 to June 25, 2022	n 309 2 to 5 years (48.3% M, 51.7% F)	24 h recall	DDS ≥ 5 food groups vs. DDS < 5 food groups	Anemia risk: 1.70 (1.02, 3.07)	134	High bias
Fentaw (2023) [31]	Kombolcha town, Ethiopia, February 15 to May 14, 2020	n 395 Under 5 years (53.9% M, 46.1% F)	24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 2.61 (1.55, 4.38)	178	High bias
Kathuria (2023) [37]	Rohtak town, India, 2018,2019	n 166 Under 5 years (41.7% M, 58.3% F)	Not reported	DDS ≥ 5 food groups vs. DDS < 5 food groups	Anemia risk: 1.70 (1.01, 3.01)	53	High bias
Mank (2022) [43]	Ouagadougou, Burkina Faso, 2021	n 1059 11 to 15 years (43% M, 57% F)	24 h recall	DDS ≥ 5 food groups vs. DDS < 5 food groups	Anemia risk: 0.91 (0.76, 1·09)	312	Some concerns
Lweno (2022) [40]	Dar es Salaam, Tanzania, 2004–2005	n 2522 n 1177 Under 2 years (51% M, 49% F)	24 h recall	DDS ≥ 5 food groups vs. DDS < 5 food groups	IDA: 0.99 (0.84, 1.19) IDA: 1.21 (0.76, 1.53)	732	Very high bias
Tegegne (2022) [50]	Bale zone, Ethiopia, 1 to 30 June 2021	n 770 Under 2 years (50.5% M, 49.5% F)	24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 2.74 (1.97,2.08)	369	High bias
Hiruy (2021) [36]	three Ethiopia Demographic and Health Surveys, 2005, 2011,2016	n 5638 Under 2 years (mixed)	24 h recall	DDS ≥ 5 food groups vs. DDS < 5 food groups	Anemia risk: 1.49 (0.96, 2.32)	2762	High bias
Said (2021) [48]	Three Tanzania Demographic and Health Surveys, 2005,2010,2015	n 1173 Under 5 years (mixed)	Not reported	Not reported	Anemia risk: 0.61 (0.37, 0.98)	382	High bias
Orsango (2021) [10]	Southern Ethiopia, 2018	n 107 2 to 5 years (48% M, 52% F)	24 h and 7 days child food frequency recall	DDS ≥ 6 food groups vs. DDS ≤ 3 food group	IDA risk: 0.5 (0.17, 1.75)	49	High bias
Alamneh (2021) [28]	Ethiopia, 2018–2020,	n 310 Under 5 years (52.3% M, 47.3% F)	FFQ + 24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 2.30 (1.12, 5.14)	167	High bias
Molla (2020) [44]	Debre Berhan Town, Ethiopia, 1 February to 2 March, 2018	n 531 Under 2 years (49% M, 51% F)	24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 2.5 (1.40, 4.3)	219	High bias

Table 1 (continued)

First author (year)	Location, data collection period, study name	sample size, age, sex	Dietary assessment tool	Comparison	OR (95% CI)	Number of Anemia Cases	Overall Quality
Tura (2020) [52]	Ambo town, Ethiopia, August 5–29, 2018	n 523 10 to 19 years (100% F)	24 h recall	DDS > 6 food groups vs. DDS ≤ 3 food group	Anemia risk: 0.96 (0.61, 1.53)	205	Very high bias
Fentie (2020) [32]	Jimma town, Ethiopia, 2019	n 528 14 to 19 years (100% F)	24 h recall	DDS ≥ 6 food groups vs. DDS ≤ 3 food group	Anemia risk: 3.57 (1.88, 6.76)	312	High bias
Fage (2020) [30]	Haramaya town, Ethiopia, February 1 to 28, 2017	n 493 12 to 19 years (65.1% M, 34.9% F)	Not reported	DDS ≥ 6 food groups vs. DDS ≤ 3 food group	Anemia risk: 2.33 (1.12, 4.86)	267	High bias
Agustina (2020) [27]	Indonesia, 2016–2018, Iron Folate Supplementation Program	n 335 12 to 19 years (100% F)	2-day 24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 1.44 (0.90, 2.29)	173	High bias
Visser (2021) [24]	South Africa, 2009–2012	n 578 5 to 12 years (51% M, 49% F)	3-day 24 h recall	DDS > 4 food groups vs. DDS ≤ 4 food group	Anemia risk: 1.56 (1.45, 2·67) IDA risk: 2.79 (1.77, 4.48)	236	High bias
Malako (2019) [41]	Southern Nation Nationalities and Peoples Region, Ethiopia, April 2017	n 477 Under 2 years (50.9% M, 49.1% F)	FFQ	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 2.95 (1.78, 4.91)	283	Some concerns
Alemayehu (2019) [29]	Wolaita Zone, Southern Ethiopia, 2015	n 990 Under 2 years (56.2% M, 43.8% F)	24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 1.40 (1.03, 1.92)	312	High bias
Parbey (2019) [47]	Hohoe Municipality, Ghana, 2018–2019	n 210 Under 5 years (48·3% M, 51·7% F)	24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 9.15 (3.13, 26.82)	104	High bias
Gonete (2018) [34]	Dembia, Ethiopia, March 1 to April 15/2017	n 462 15 to 19 years (100% F)	24 h recall	DDS ≥ 5 food groups vs. DDS < 5 food groups	Anemia risk: 2.10 (1.30, 3.50)	215	High bias
Gosdin (2018) [35]	Bihar, India, 2017–2018	n 5664 Under 2 years (51% M, 49% F)	24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 1.14 (1.00, 1.33)	1863	High bias
Getaneh (2017) [33]	Gondar town, Ethiopia, February to May, 2017	n 523 6 to 14 years (51.4% M, 49·6% F)	FFQ + 24 h recall	DDS ≥ 7 food groups vs. DDS ≤ 3 food group	Anemia risk: 1·77 (0·69, 4.55)	219	High bias
Tiku (2018) [49]	Ethiopia, February to March 2016	n 399 Under 5 years (47.1% M, 52.9% F)	Not reported	DDS ≥ 4 food groups vs. DDS < 4 food group	Anemia risk: 3.24 (1.68, 6.23)	231	High bias
Nair (2016) [45]	Telangana, India, 2013–2015	n 445 Under 2 years (53.1% M, 46.9% F) n 347 2 to 5 years (48.3% M, 51.7% F)	FFQ FFQ	DDS ≥ 4 food groups vs. DDS < 4 food group DDS > 7 food groups vs. DDS ≤ 7 food group	Infants anemia risk: 1.51 (0.93, 2.46) Pre-schoolers anemia: 1.13 (0.56, 2.27)	198	High bias
Woldie (2015) [53]	Northeast Ethiopia, March to May, 2014	n 347 2 to 5 years (52·5% M, 47·7% F)	24 h recall	DDS ≥ 4 food groups vs. DDS < 4 food group	Odds of anemia: 3.20 (1.35, 7.38)	221	High bias

M male, *F* female, *DDS* dietary diversity, *FFQ* food frequency questionnaire, *IDA* iron deficiency anemia sizes within this range. Based on the estimated baseline anemia prevalence of 40% in this age group, the absolute effect suggests ~384 additional anemia cases per 1,000 children due to inadequate dietary diversity. Certainty of evidence was rated as low due to study limitations (high risk of bias), inconsistency ($I^2 > 80\%$), and imprecision (wide prediction intervals). No upgrade was applied (Table 2).

Potential sources of variation were evaluated by subgroup analysis; There was no heterogeneity in studies conducted in Asia. Moreover, Subgroup analysis suggested that there was a significant association between inadequate dietary diversity and an enhanced prevalence of anemia for 0 to 5 years old children with overall anemia prevalence (vs. iron deficiency anemia) (OR =2.19; 95% CI: 1.66, 2.86; $I^2 = 82.7\%$, $\tau^2 = 0.36$, $P = <0.001$; $n = 16$). Moreover, we found a significant heterogeneity among the studies with high or very high odds of bias (Table 3). Based on the visual inspection of funnel plot, we found an asymmetry; however, when we did Begg ($P = 0.135$) and Egger's regression tests ($P = 0.071$), no significant publication bias was seen (Fig. 3). Sensitivity analysis showed that the overall effect size regarding the association between inadequate dietary diversity and odds of anemia among 0 to 5 years old children did not depend on single study (CI range: 1.28, 2.95).

Dietary diversity and odds of anemia among 6 to 18 years old children and adolescents

Ten studies examined the relationship between insufficient dietary diversity and the prevalence anemia among children and adolescents aged 6 to 18 years. It has been demonstrated a significant association

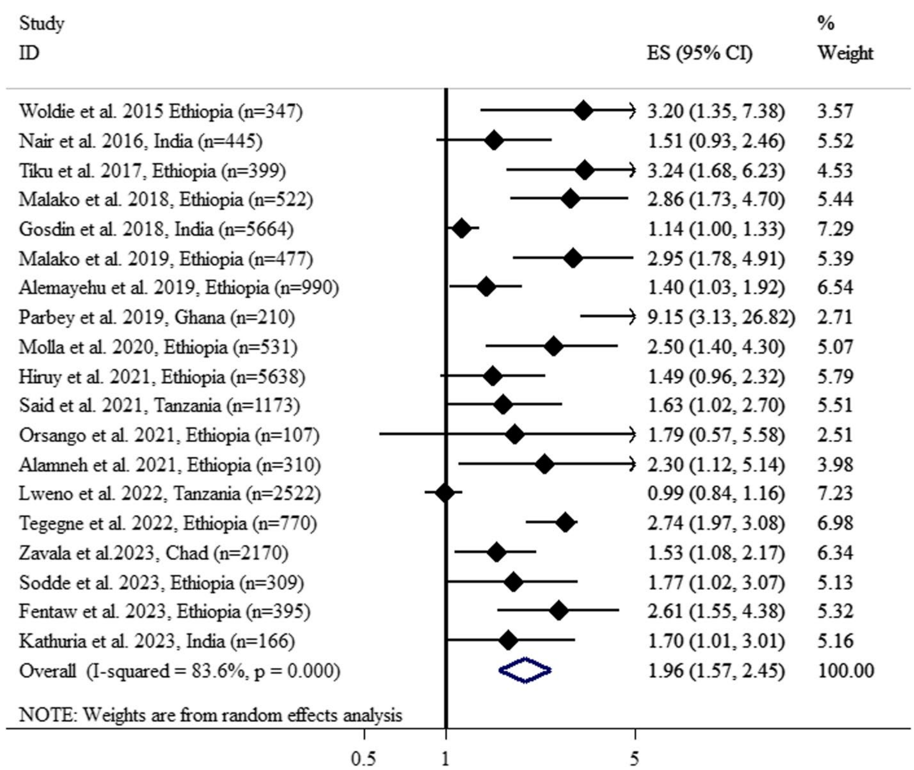

Fig. 2 Forest plot showing odds ratio with 95% confidence interval of the association between dietary diversity and odds of anemia among 0 to 5 years old children

Table 2 Summary of findings using the GRADE approach

Outcome	Relative Effect (OR)	Absolute Effect (per 1,000 people)	Certainty of Evidence (GRADE)
Anemia in children 0–5 years	OR = 1.96 (95% CI: 1.57, 2.45)	~ 384 additional cases per 1,000	Low
Anemia in children 6–18 years	OR = 1.73 (95% CI: 1.27, 2.36)	~ 183 additional cases per 1,000	Low

Table 3 Subgroup analyses for the association between dietary diversity and anemia among 0 to 5 years old children

	Number of effect sizes	WMD (95% CI)	*P* effect	*P* within	I^2 (%)	*P* between
Continent (Africa vs. Asia)						0.001
Africa	16	2.13 (1.63, 2.79)	< 0.001	< 0.001	83.6%	
Asia	3	1.28 (1.01, 1.62)	0.004	0.234	31.2%	
Type of anemia						< 0.001
Overall anemia	16	2.19 (1.66, 2.86)	< 0.001	< 0.001	82.7%	
Iron deficiency anemia	3	1.18 (0.89, 1.25)	0.65	0.42	21.3%	
Bias						< 0.001
Some concerns	2	1.15 (0.86, 1.28)	0.58	0.39	25.6%	
High or very high bias	17	2.26 (1.69, 2.89)	< 0.001	< 0.001	85.9%	

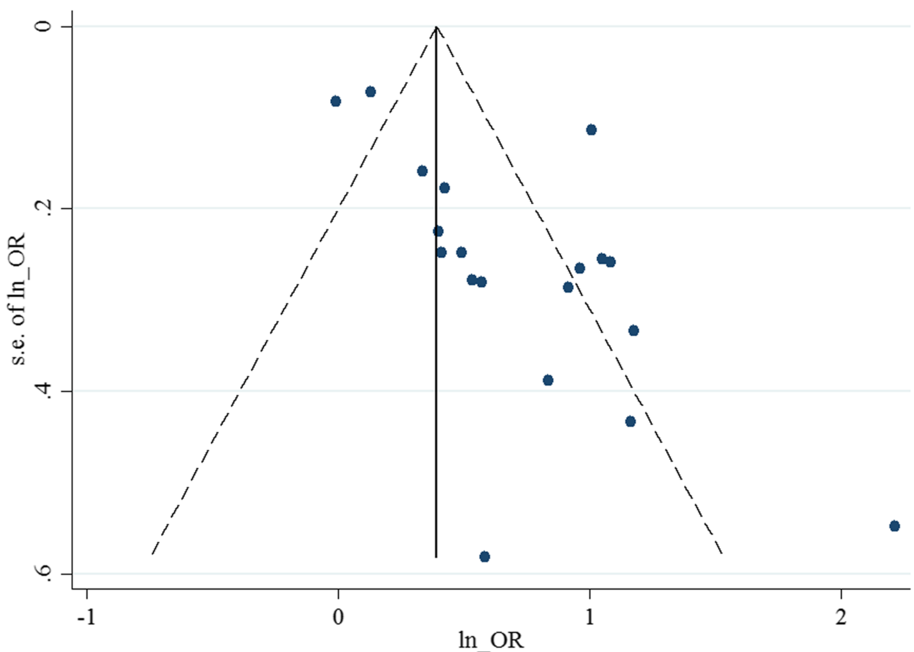

Fig. 3 Funnel plot representing publication bias in the studies reporting the association between dietary diversity and anemia among 0 to 5 years old children

between inadequate dietary diversity and odds of anemia, with a significant heterogeneity (OR = 1.73; 95% CI: 1.27, 2.36; $I^2 = 87\%$, $\tau^2 = 0.44$; $P < 0.001$) (Fig. 4). The 95% prediction interval was [0.45, 6.58], indicating that future studies might find effect sizes within this range. Using a baseline anemia prevalence of 25% in this age group, the absolute effect suggests ~183 additional anemia cases per 1,000 children due to inadequate dietary diversity (GRADE: Low certainty).

In the subgroup analysis based on sex, place of study and type of anemia, we couldn't find the source of heterogeneity. Moreover, subgroup analysis revealed that there was a significant association between inadequate dietary diversity and an increased prevalence of anemia for 6 to 18 years old children and adolescents in studies performed in Africa continent (vs. Asia) (Table 4).

Also, the leave-one-out sensitivity analysis showed that leaving each of studies had no significant effect on the pooled effect size. Although visually a small asymmetry was seen in the funnel plot, the results of Egger ($P = 0.376$) and Begg's test ($P = 0.156$) showed no evidence of publication bias (Fig. 5).

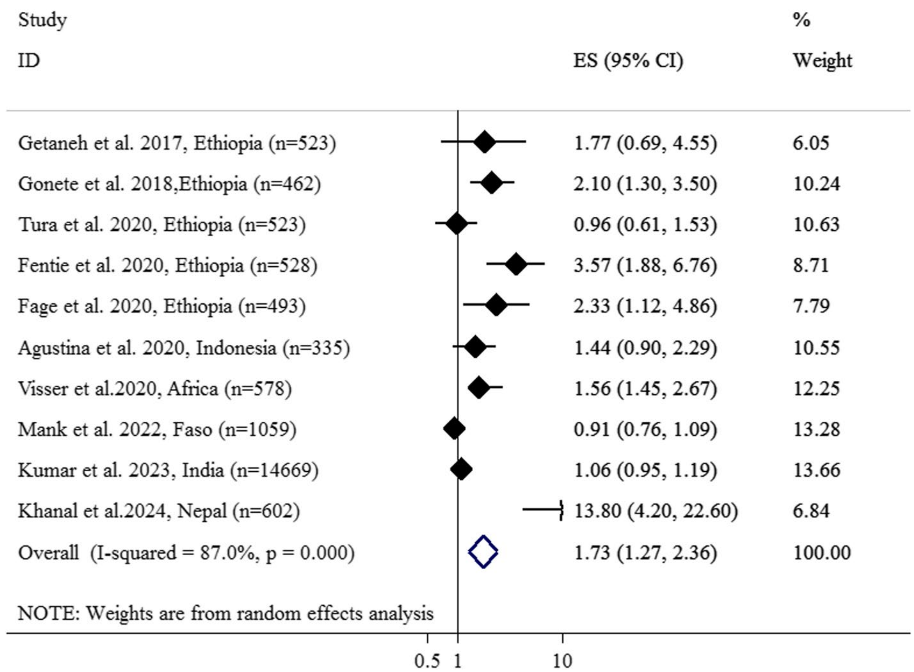

Fig. 4 Forest plot showing odds ratio with 95% confidence interval of the association between dietary diversity and anemia of among 6 to 18 years old children

Table 4 Subgroup analyses for the association between dietary diversity and anemia among 6 To 18 years old children and adolescents

	Number of effect sizes	WMD (95% CI)	*P* effect	*P* within	I^2 (%)	*P* between
Continent (Africa vs. Asia)						< 0.001
Africa	6	1.61 (1.10, 2.36)	0.015	< 0.001	81.6%	
Asia	4	2.51 (0.88, 7.20)	0.086	< 0.001	94.5%	
Type of anemia						< 0.001
Overall anemia	7	2.49 (1.12, 2.78)	< 0.001	< 0.001	83.2%	
Iron deficiency anemia	3	1.14 (1.05, 1.38)	0.043	< 0.001	93.3%	
Sex						0.001
Both (girls and boys)	6	1.39 (1.08, 1.95)	0.038	< 0.001	85.3%	
Girls	4	2.54 (1.15, 2.86)	0.001	< 0.001	88.37%	
Bias						0.001
Some concerns	2	1.53 (1.09, 2.12)	0.01	< 0.001	84%	
High or very high bias	8	2.65 (1.17, 3.12)	< 0.001	< 0.001	91.6%	

Exploratory analysis for small-study effects

To further explore small-study effects, we compared the results from the fixed-effects model with the random-effects model. For children aged 0–5 years, the random-effects model yielded an OR = 1.96 (95% CI: 1.57, 2.45), while the fixed-effects model resulted in an OR = 1.77 (95% CI: 1.49, 2.33). Similarly, for children aged 6–18 years, the random-effects model showed an OR = 1.73 (95% CI: 1.27, 2.36), whereas the fixed-effects model yielded an OR = 1.50 (95% CI: 1.21, 2.24).

The observed differences between the models suggest that smaller studies may have contributed to the

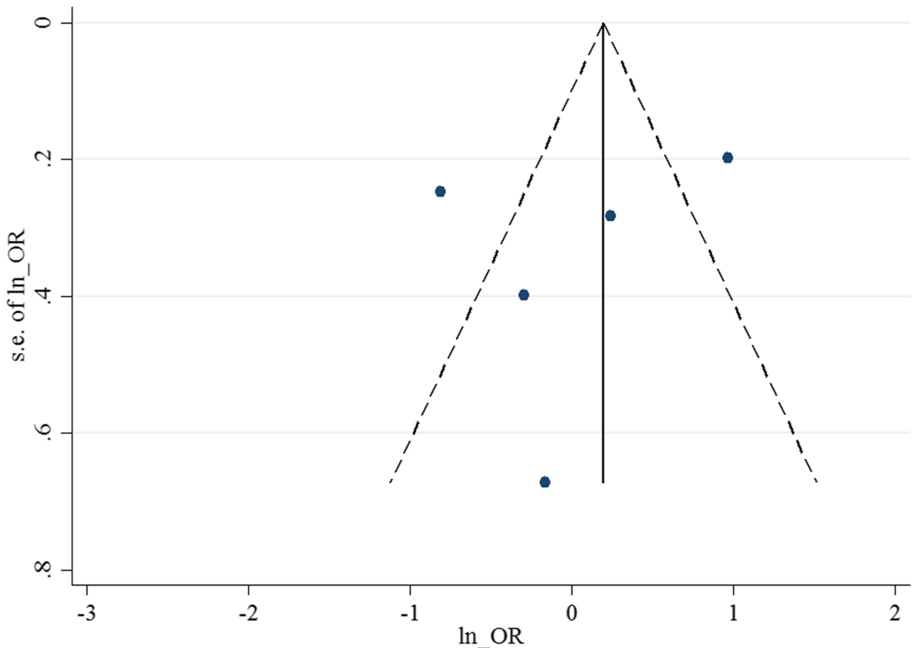

Fig. 5 Funnel plot representing publication bias in the studies reporting the association between dietary diversity and anemia among 6 to 18 years old children

heterogeneity in effect sizes. This finding, combined with visual asymmetry in the funnel plot, underscores the need for cautious interpretation of potential small-study effects.

Discussion

The present systematic review and meta-analysis investigated the association between dietary diversity and the prevalence of anemia among children and adolescents. The results indicate a significant positive correlation between inadequate dietary diversity and increased odds of anemia in both age groups examined (0–5 years and 6–18 years). These findings underscore the importance of dietary diversity and its association with anemia, a prevalent nutritional deficiency with significant health implications for young populations.

Anemia is still a significant public health issue in most low-income and less developed countries, especially some African countries [55]. Anemia remains a major public health concern in sub-Saharan Africa, as demonstrated by the high prevalence rate of 72.0% [95% CI: 70.9%, 72.9%] among children aged 6–23 months [56]. One potential reason could be the persistent issue of malnutrition among children in these countries, stemming from inadequate dietary intake of essential nutrients. Several previous studies have shown an association between insufficient dietary diversity and nutrition-related diseases. Some of these studies have reported an inverse association between dietary diversity and child stunting in among the children in children in Cambodia [57] and Bangladesh [58]. However, contrary to these findings, Ali and colleagues discovered that dietary diversity did not influence the relationship between household food security and child stunting or wasting in any of the four countries they examined [59]. The comparability of these findings is hindered by various methodological challenges associated with assessing dietary diversity.

A growing body of research indicates a concerning trend in children's diets: they are often high in calorie-dense foods but lacking in essential micronutrients [60–62]. Among all age groups, children under five exhibit the greatest vulnerability to chronic malnutrition and its associated micronutrient deficiencies [63]. Several studies have established a link between limited dietary diversity and micronutrient deficiencies, particularly iron deficiency, a major contributor to anemia [64, 65]. Meng et al. reported that higher dietary diversity scores, particularly for fruits, vegetables, and animal products, were positively correlated with adequate micronutrient intake especially iron and Net Absorption Rate (NAR) for a range of micronutrients in their study population [66]. The rationale behind a diet with higher dietary diversity score is clear. Plant-based sources like fruits and vegetables offer a rich tapestry of vitamins and minerals, including carotene, potassium, vitamin C, the B vitamin family, and even some vitamin D. Animal foods complement this profile by providing essential minerals like magnesium, zinc, and iron, alongside calcium and vitamins E and B complex vitamins [66–68]. Also, Faber et al. [67] observed that while over 85% of children in South Africa consistently consumed cereals and root vegetables, a staple food group, less than a quarter achieved the Minimum Dietary Diversity (MDD) standard [69]. This implies that frequent cereal and root vegetable intake might not guarantee adequate micronutrients. The low MDD scores likely indicate an infrequent intake of fruits, vegetables, and animal-based foods, which are crucial sources of micronutrients [69]. A diverse diet rich in iron-rich foods like red meat, poultry, fish, legumes, and leafy green vegetables is crucial for maintaining adequate iron stores and associated with anemia development [70, 71]. Children and adolescents with limited dietary diversity are more likely to have lower intakes of these essential iron sources, increasing their vulnerability to anemia [30, 72].

Iron, an essential micronutrient, plays a crucial role in oxygen transport, energy metabolism, and immune function. Dietary iron exists in two primary forms: heme iron and non-heme iron, which differ in bioavailability and dietary sources. Heme iron, found predominantly in animal-based foods such as red meat, poultry, and fish, has a higher absorption rate (15–35%) due to its direct uptake by enterocytes via specific transport mechanisms [73]. In contrast, non-heme iron, primarily sourced from plant-based foods such as legumes, whole grains, nuts, and leafy green vegetables, has a lower absorption rate (2–20%) and is influenced by dietary enhancers (e.g., vitamin C) and inhibitors (e.g., phytates, polyphenols, and calcium) [74].

Dietary diversity plays a critical role in ensuring adequate iron intake and optimizing iron bioavailability. A diverse diet that includes both heme and non-heme iron sources enhances total iron absorption and reduces the odds of iron deficiency anemia. Populations with limited dietary diversity, particularly those relying heavily on plant-based diets without sufficient enhancers of non-heme iron absorption, may face an increased odds of anemia. For instance, individuals consuming predominantly cereal-based diets with minimal access to vitamin C-rich fruits or animal products are more susceptible to iron deficiency anemia due to the inhibitory effects of phytates and polyphenols [75]. Conversely, those with higher dietary diversity, incorporating both animal and plant-based sources, tend to have improved iron status due to better iron bioavailability [76].

The findings from our meta-analysis highlight the association between dietary diversity and anemia odds in children and adolescents. Given the distinct absorption characteristics of heme and non-heme iron, future research should explore strategies to improve dietary diversity by incorporating iron-rich food sources alongside dietary enhancers. Public health initiatives should emphasize the consumption of a balanced diet that includes heme iron sources where feasible and non-heme iron sources with enhancers such as vitamin C to maximize iron absorption and mitigate odds of anemia [77].

Our findings also add to the growing body of evidence suggesting the importance of promoting dietary diversity across different age groups. Previous studies have primarily focused on children under 5 years old, a critical period for growth and development. However, our analysis for adolescents (aged 6–18 years) also revealed a significant association between low dietary diversity and anemia. This highlights the need for continued emphasis on maintaining a healthy and diverse diet throughout childhood and adolescence to ensure optimal iron intake and reduce the likelihood of anemia.

Prespecified subgroups included age categories (0–5 years, 6–18 years) and study design (cross-sectional, case–control), as these factors were identified as potential effect modifiers based on prior literature. Post-hoc analyses were conducted based on geographic location and dietary diversity assessment methods to further investigate sources of heterogeneity. Despite these efforts, significant heterogeneity remained, suggesting that unmeasured confounding factors such as socioeconomic status, dietary patterns, and healthcare access may contribute to variability in the results. Future research should consider more granular subgroup analyses and standardized dietary diversity assessment tools to reduce heterogeneity.

Confounding factors such as child's age, sex, maternal education, and household socioeconomic status were frequently controlled for across studies. These factors are known to influence outcomes like anemia, and accounting for them likely strengthened the reliability of the findings in many studies. Studies that adjusted for a broader range of confounders (e.g., maternal nutrition, child's feeding practices, household food insecurity) generally reported more consistent and stronger associations between dietary patterns and anemia. For instance, studies that included variables such as iron intake and maternal health indicators (e.g., mother's smoking, number of under-five children, stunting, and wasting) provided a more nuanced understanding of the relationship between dietary factors and anemia in children. However, several studies did not adjust for key confounders, such as socioeconomic status, maternal education, or dietary intake. In particular, three studies [33, 34, 39] did not make adjustments for any potential confounders, which limits the ability to draw definitive conclusions from these studies. The lack of adjustment for these factors could have introduced bias, potentially overstating or understating the true relationship between dietary patterns and anemia. This highlights the importance of controlling for confounders in future research, particularly those related to socioeconomic status and nutrition, which are known to significantly influence anemia prevalence.

Recognizing the potential for nutritional deficiencies during early life stages to persist into later stages, the WHO advocates for improved micronutrient intake. Their recommendations include consuming nutrient-dense foods, such as animal products or fortified options, to address potential shortfalls [63, 78]. While our study does not directly elucidate the underlying mechanisms, several plausible pathways warrant consideration. First, dietary diversity ensures a broader array of micronutrients, which collectively contribute to hemoglobin synthesis. Iron, in particular, plays a central role in erythropoiesis, and its deficiency remains a primary driver of anemia. Second, dietary variety may serve as a proxy for overall nutritional status and food security. Individuals with diverse diets are more likely to meet their nutritional needs, enhancing iron absorption and utilization. Future investigations should explore these mechanistic links to deepen our understanding of the observed association.

Based on our knowledge, the present study was the first systematic review and meta-analysis study which evaluated the association between dietary diversity and odds of anemia among children and adolescents. Despite the comprehensive approach and robust findings, this systematic review and meta-analysis have several limitations that warrant discussion. First, the observational nature of the included studies limits the ability to infer causality. While the associations observed between dietary diversity and anemia are significant, we cannot definitively establish that low dietary diversity causes anemia. Second, given the high odds of bias in many included studies, particularly in confounding and dietary exposure measurement, the findings should be interpreted with caution. Future research should employ longitudinal or experimental designs to strengthen causal inference. Third, there was considerable heterogeneity among the studies included in our analysis. This heterogeneity could stem from variations in study populations, settings, dietary diversity assessment methods, and criteria for defining anemia. Although we performed subgroup analyses based on continent, type of anemia, sex, and odds of bias, these factors did not fully explain the observed heterogeneity. This suggests that other unmeasured variables may contribute to the variability in results. Standardizing the measurement tools and criteria across studies could enhance comparability and reduce heterogeneity in future research. Finally, the assessment of dietary diversity was based on various tools and indices across the included studies, which may impact the consistency of the findings. Different studies used different criteria and cut-off points to evaluate dietary diversity, which might affect the comparability and generalizability of the results. Additionally, dietary diversity scores do not capture the quality or nutrient content of the diet, which are crucial factors influencing anemia. Future research should aim to standardize dietary diversity assessment methods and incorporate more detailed dietary quality measurements.

Conclusion

In this systematic review and meta-analysis, we examined the association between dietary diversity and the odds of anemia in children and adolescents. Based on current evidence, there is low certainty that inadequate dietary diversity is associated with increased odds of anemia in children and adolescents. While the findings suggest a potential link, limitations in the underlying studies including high odds of bias, inconsistency, and imprecision, warrant cautious interpretation. Public health interventions to improve dietary diversity may be beneficial, but further high-quality research is needed to confirm these associations. Future research should aim to standardize dietary diversity assessment methods and incorporate detailed dietary quality measurements to enhance comparability and reduce heterogeneity.

Supplementary Information

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Supplementary Material 1.

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Clinical trial number

Not applicable.

Authors' contributions

H.L and S.P.M. designed this study. H.L and S.P.M. conducted the literature search. N.G and S.H.M contributed in data extraction. M.R performed the statistical analysis and interpretation of the data. SPM, MR, and H.L wrote the manuscript. All authors approved the final version of the manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

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Consent for publication
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Competing interests
The authors declare no competing interests.

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