Interventions to Increase Knowledge, Attitude, and Iron Consumption Among Anemic Adolescents In Low-Middle Income Countries: A Systematic Review

ABSTRACT

Aims. This systematic review evaluated the effectiveness of educational interventions in increasing iron consumption and improving related health outcomes among anemic adolescents in LMICs.

Methods. Systematic searches were conducted across PubMed, EMBASE, Cochrane Library, and CINAHL, following PRISMA guidelines. Studies were included if they targeted adolescents aged 10–19 years with anemia in LMICs, implemented educational interventions, and reported outcomes such as dietary iron intake, adherence to supplementation, hemoglobin levels, anemia prevalence, or knowledge, attitudes, and practices (KAP). Data extraction focused on intervention characteristics and outcomes. Risk of bias was assessed using RoB 2 and CASP tools.

Fundings. Sixteen studies involving 2,078 participants were included. Educational interventions improved dietary iron intake, adherence to supplementation, and knowledge levels. Culturally tailored and interactive methods, including community-based sessions and digital tools, achieved notable improvements in knowledge and hemoglobin levels. Long-term reductions in anemia prevalence were observed in programs with sustained engagement, although variability in intervention design and limited long-term adherence posed challenges.

Conclusion. Educational interventions effectively address iron deficiency anemia among adolescents in LMICs by enhancing knowledge, dietary practices, and biological outcomes. Success depends on cultural relevance, innovative delivery methods, and ongoing support. These findings highlight the importance of integrating educational strategies into national nutrition programs and leveraging digital tools to scale interventions, while addressing contextual barriers to sustainability.

Keywords: Iron Deficiency Anemia, Adolescents, Health Education, Developing Countries, Food Habits, Medication Adherence

INTRODUCTION

Iron deficiency anemia (IDA) is a significant public health concern, particularly among adolescents in low- and middle-income countries (LMICs) [1–3]. Adolescents are highly vulnerable to IDA due to increased iron demands during growth and, in females, the onset of menstruation [4,5]. IDA during adolescence is associated with adverse cognitive, physical, and social outcomes, including poor academic performance, fatigue, and diminished quality of life [6–8]. Addressing IDA in this demographic is essential to break the cycle of poor health and socio-economic disadvantage [9].

In many LMICs, barriers to addressing IDA include inadequate awareness of iron-rich diets, limited knowledge about the importance of iron supplementation, and cultural practices that influence dietary habits [10–13]. Adolescents often lack autonomy in dietary decisions, which are typically influenced by family members [14–18]. Furthermore, gender dynamics

may limit access to iron-rich foods for adolescent girls. These challenges necessitate interventions that empower adolescents with knowledge and skills to improve their iron intake [19–21].

Educational interventions play a crucial role in addressing these barriers by improving knowledge, attitudes, and practices related to iron consumption [22,23]. These interventions include school-based programs, community health campaigns, peer education, and digital learning tools designed to raise awareness about iron-rich foods, the role of iron in health, and strategies to overcome barriers to iron intake. Educational approaches can also address misconceptions and stigma associated with iron supplementation, especially among adolescent girls [24,25].

Evidence suggests that educational interventions have the potential to significantly impact dietary behaviors and supplement adherence [26,27]. For example, school-based programs have demonstrated effectiveness in promoting healthy eating habits and increasing awareness about micronutrient deficiencies [28–31]. Similarly, community-based campaigns have been instrumental in mobilizing support for better nutritional practices at the household level. However, the success of these programs often depends on their cultural relevance, accessibility, and delivery methods [32,33].

Previous systematic reviews have explored the effectiveness of educational interventions in improving general health outcomes, but few have focused specifically on increasing iron consumption among adolescents in LMICs [34–37]. Reviews on adolescent nutrition interventions often highlight the role of education as a complementary strategy to supplementation and food fortification but lack a detailed analysis of education-focused initiatives [38,39]. This gap in evidence hinders the ability to design and implement targeted strategies to combat IDA in this vulnerable population.

Studies in LMICs have reported mixed results for educational interventions targeting iron consumption. Some programs have shown significant improvements in knowledge and dietary practices, while others have struggled with low engagement or minimal long-term impact. Factors such as intervention design, delivery mode, cultural sensitivity, and community involvement are often cited as determinants of success [40–42]. However, there is limited synthesis of these findings to inform future interventions.

Adolescents represent a critical window of opportunity for nutritional interventions due to their unique developmental stage and potential to influence future generations. Effective educational interventions targeting this group can have a multiplier effect by improving their health and equipping them to make informed dietary decisions as adults [43]. Despite the importance of education, most IDA intervention programs in LMICs continue to focus on supplementation and food fortification, with insufficient emphasis on educational strategies [44,45].

Moreover, addressing IDA through education requires a multidisciplinary approach that integrates health, education, and community sectors. Understanding the effectiveness of various educational strategies, their implementation challenges, and the factors influencing their impact can guide policymakers and program implementers in designing effective interventions [46,47].

The aim of this systematic review is to evaluate the effectiveness of educational interventions in increasing iron consumption among anemic adolescents in LMICs. By

synthesizing existing evidence, this review seeks to identify successful strategies, examine the contextual factors influencing their outcomes, and provide recommendations for designing and scaling educational programs to combat IDA in resource-constrained settings. This work fills a critical gap in the literature, offering insights into the role of education in addressing one of the most prevalent nutritional deficiencies among adolescents.

METHOD

This systematic review adhered to the PRISMA 2020 guidelines, providing a transparent and comprehensive methodology [48]. The process included developing eligibility criteria using the PICOS framework, conducting a systematic search, selecting studies, extracting data, assessing bias, and synthesizing results.

Eligibility Criteria

The inclusion and exclusion criteria were developed using the PICOS framework. Eligible studies targeted adolescents aged 10–19 years diagnosed with anemia and residing in low- and middle-income countries (Population). Interventions included educational approaches aimed at increasing iron consumption, such as school-based programs, community-based education, peer education, or digital tools (Intervention). Comparators were no intervention, standard care, or other types of interventions (Comparator). Primary outcomes included dietary iron intake and adherence to iron supplementation; secondary outcomes included hemoglobin levels, anemia prevalence, and knowledge, attitudes, and practices (Outcomes). Eligible study designs included randomized controlled trials and quasi-experimental studies (Study Design).

Search Strategy

A systematic search of electronic databases and grey literature was conducted. The search strategy combined Medical Subject Headings (MeSH) terms and free-text keywords, tailored for each database. Boolean operators and filters were used to refine the search.

Table 1. Search Strings for Major Databases

Database	Search String
Pubmed	((((("iron"[MeSH Terms]) OR ("dietary iron")) AND ("anemia"[MeSH Terms] OR "iron deficiency anemia")) AND ("education"[MeSH Terms] OR "educational intervention" OR "nutrition education" OR "health education")) AND ("adolescents"[MeSH Terms] OR "teenagers" OR "youth")) AND ("low- and middle-income countries" OR "developing countries").
Cochrane Library	("iron consumption" OR "iron deficiency anemia") AND ("educational intervention" OR "nutrition education") AND ("adolescents") AND ("low- and middle-income countries").
EMBASE	("iron consumption" OR "iron deficiency anemia") AND ("educational intervention" OR "nutrition education") AND ("adolescents") AND ("low- and middle-income countries").

CINAHL	("iron consumption" OR "iron deficiency anemia") AND ("educational intervention" OR "nutrition education") AND ("adolescents") AND ("low- and middle-income countries").

Selection Process

The selection of studies for this systematic review followed a rigorous, multi-step process to ensure that only relevant and high-quality studies were included. Initially, all records retrieved from the database searches were imported into Mendeley for de-duplication. Following this, two independent reviewers screened the titles and abstracts of the remaining records to assess their relevance based on the inclusion criteria. Studies that clearly did not meet the criteria, such as those focused on non-educational interventions or populations outside the age range of 10–19 years, were excluded at this stage. After the initial screening, full-text articles of potentially eligible studies were retrieved and assessed by both reviewers. The inclusion criteria were further applied, considering the study design (e.g., RCTs, quasi-experimental studies), the type of educational intervention, and the population of adolescents with anemia in low- and middle-income countries. Any disagreements between the reviewers were resolved through discussion or by consulting a third reviewer. The final set of included studies was compiled, and reasons for exclusion of studies at each stage were documented in a PRISMA flow diagram (Figure 1). This transparent selection process ensured that only studies with relevant and high-quality data were included for data extraction and analysis.

Data Collection

Data collection for this systematic review was conducted using a standardized data extraction form, which was developed to ensure consistency and accuracy across studies. Two independent reviewers performed the data extraction process. In cases where discrepancies arose between the reviewers, these were resolved through discussion or consultation with a third reviewer. The data extraction form included information on study characteristics (e.g., author, year, country, setting, and study design), as well as details about the intervention (e.g., type, content, delivery method, duration, and frequency). For each study, the population characteristics were recorded, including the sample size, age range, and anemia status of the participants. The reviewers also extracted data related to the outcomes of interest, specifically the primary outcomes such as changes in dietary iron intake or adherence to iron supplementation, and secondary outcomes, including hemoglobin levels, anemia prevalence, and knowledge, attitudes, and practices (KAP). The time points at which these outcomes were measured were also noted. If studies reported multiple outcomes or time points, the reviewers focused on the most relevant or earliest available data. This systematic and consistent data extraction process ensured that all pertinent information was gathered for the subsequent synthesis and analysis of the results.

Study Quality

The reviewers assessed the literature individually to assess its suitability for inclusion in the review. While this step is not a requirement in systematic review protocols, they found it helpful for recognizing the strengths and weaknesses of the selected studies. Given the varied nature of the studies, the Critical Appraisal Skills Program (CASP) for randomized trials was selected, as it offers a structured framework for evaluating study quality. CASP provides specific

checklists with 11 questions for each study design, particularly randomized trials, with answers categorized as “yes,” “no,” or “can’t tell.” The quality of each study is then classified as Strong, Moderate, or Weak based on the responses: Strong if all answers are affirmative, Moderate if two responses are negative, and Weak if three responses are negative.

Risk of bias

Each study’s potential bias was evaluated using the Risk of Bias in Randomized Studies (RoB 2) tool. This tool was selected for its proven, organized framework designed to identify biases specifically in randomized controlled trials (RCTs). It covers key areas such as the process of randomization, deviations from intended interventions, missing outcome data, measurement of outcomes, and selective reporting. The RoB 2 tool offers a thorough and consistent approach to evaluating study quality, which enhances the reliability of the review’s findings. It assesses both internal and external validity through five domains, categorizing results into four levels: Low, Some Concerns, High, and Very High. All authors reviewed and approved the bias assessment outcomes, incorporating feedback from external reviewers.

Data Synthesis

The data synthesis for this systematic review followed a two-step process: a narrative synthesis and, where appropriate, a meta-analysis. a qualitative synthesis was performed to summarize the findings across all included studies. This narrative synthesis grouped the studies based on key themes such as the type of educational intervention, the delivery method (e.g., in-person, digital, peer education), and the outcomes reported (e.g., dietary iron intake, hemoglobin levels). This approach helped to provide an overview of the range of interventions and their effects on increasing iron consumption among anemic adolescents.

RESULTS

The initial database query yielded 305 articles. Following the removal of 151 duplicates and irrelevant articles unrelated to the review's focus, 149 articles were available for screening. In the eligibility evaluation, 27 studies underwent assessment, resulting in the exclusion of 11 articles for diverse reasons. Ultimately, only 16 studies fulfilled the criteria and will advance to the subsequent stage for data extraction and analysis.

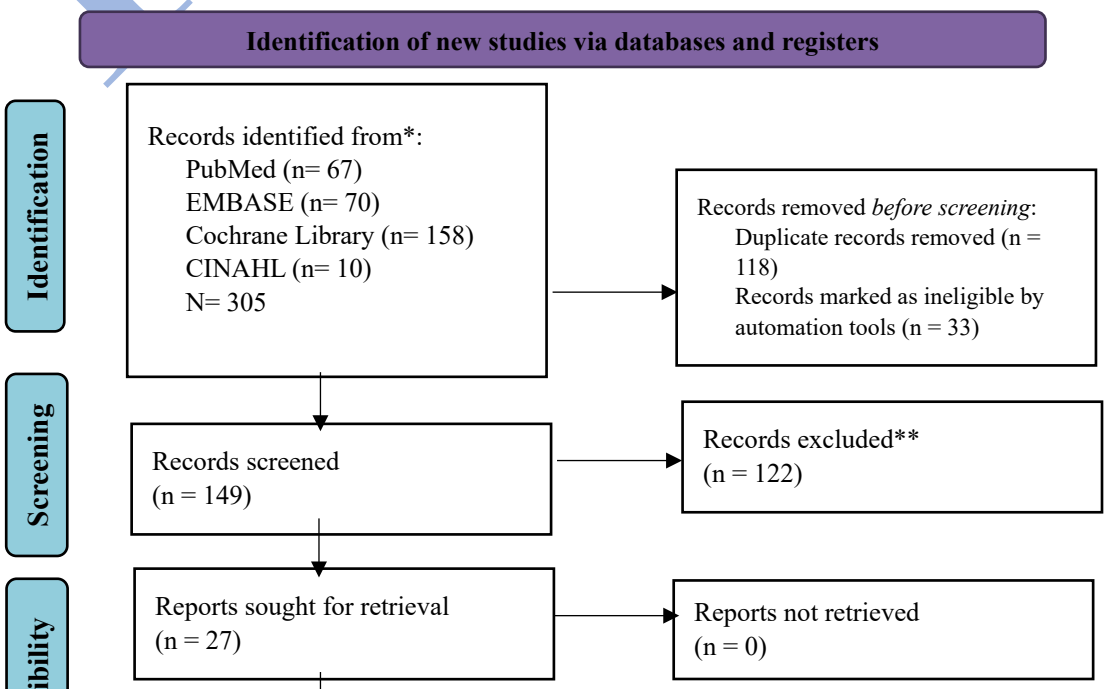

Figure 1. PRISMA flowchart for study selection

Table 2. Extraction data

Author, Year, Country	Study Design	Sample Size		Mean Age		Hb		BMI		Educational Method		Duration	Main Results
		I	C	I	C	I	C	I	C	I	C		
Abu-Baker et al., 2021, Jordan [49]	quasi-experimental	194	169	14.15	14.15	11.68	11.68	NA	NA	Nutrition Education Program: lectures, videos, and brochures	None	4 sessions; 45 min each	- Improved knowledge, attitudes, practices
Alaofe et al., 2009, Benin [50]	quasi-experimental	34	34	13	14.5	11.2	11.2	21.1	21.5	Nutrition intervention: lesson, motivation, quiz	None	26 weeks; 4 sessions; 1 hour	- Increased hemoglobin, reduced anemia
Bhanushali et al., 2011, India [51]	quasi-experimental	104	104	13.5	13.5	9.34	9.35	18.63	17.82	Lectures on nutrition and good eating Habits; counseling	None	3 months	Improved hemoglobin levels
Gambir et al., 2020, Indonesia [52]	quasi-experimental	25	25	12	12	NA	NA	NA	NA	Diary-book of nutrition; Counseling: program information, anemia in adolescence and the recommendation to consume iron tablets regularly	Iron tablet	2 months	- Increased knowledge and iron intake

Ghadam et al., 2022, Iran [53]	RCT	80	80	14.5	14.5	11.84	11.96	21.03	20.59	Digital games	Education: PowerPoint presentation and pamphlets	14 weeks	Improved dietary nutrient intake
Jalambo et al., 2018, Palestine [54]	RCT	45	42	16.37	16.51	11.45	11.73	22.63	22.49	Group A: iron supplementation; Group B (iron supplementation with nutrition education)	None	3 months; 9 sessions; 1.5 hours/session	- Increased hemoglobin and ferritin levels
Jeihooni et al., 2021, Iran [55]	quasi-experimental	80	80	13.85	13.60	12.34	12.58	NA	NA	Nutrition education: SGD, Q&A, practical demonstration, videos, PowerPoint, and booklet	None	6 sessions; 45-50 min	- Improved hemoglobin and ferritin
Madestria et al., 2021, Indonesia [56]	quasi-experimental	62	62	14	13	NA	NA	NA	NA	education media: video; packaging modifications of iron tablets	Video	Not explained	- Improved knowledge, attitudes, intentions
Magfirah et al., 2023, Indonesia [57]	quasi-experimental	25	24	16.5	16.5	12.34	12.41	NA	NA	LADIES App	e-posters: whatsapp	3 months; 2 sessions a week; 30 min	- Increased knowledge and nutritional intake
McCormack et al.,	Pre-post study	32	NA	13.8	NA	12	NA	NA	NA	POCT program; educational	NA	8 weeks	- Improved hemoglobin

2017, Pakistan [58]										campaign, counseling			, reduced anemia
Rahmiwati et al., 2023, Indonesia [59]	quasi-experimental	58	68	15.95	16.15	NA	NA	20.49	21.04	IFAS and local culture-based nutrition education (Video, Comedy)	Leaflet and IFAS	12 weeks;	- Improved knowledge, compliance with IFAS
Salam et al., 2023, India [60]	Pre-post study	455	NA	11.5	NA	NA	NA	NA	NA	lectures, role play and practical demonstrations	NA	7 weeks	- Increased knowledge
Raihani et al., 2024, Indonesia [61]	quasi-experimental	15	15	18.5	18.5	10	10	NA	NA	flipcharts and leaflets	Leaflet	3 months	- Improved knowledge and compliance
Rusdin et al., 2021, Indonesia [62]	quasi-experimental	35	35	16.5	16.5	NA	NA	NA	NA	PAKEM: lectures, group discussions, problem-solving, and game simulations	Leaflet; audio-visual media	1 month	- Enhanced knowledge, attitudes, motivation
Zakiah et al., 2023, Indonesia [63]	quasi-experimental	16	11	14.5	14.5	NA	NA	21.5	20	Nutrition education: speech method and Teams Games Tournament (TGT)	speech method	1 month	- Improved knowledge, attitudes, nutrition

Zuraida et al., 2020, Indonesia [64]	quasi-experimental	55	47	15.1	15.3	NA	NA	19.8	20.05	Nutrition education based anemia free club sessions	None	12 weeks	- Increased iron intake

Study Selection

The systematic review initially identified 305 studies through systematic database searches across PubMed, EMBASE, Cochrane Library, and CINAHL. Following a rigorous selection process, 151 duplicate records were removed. The remaining 149 articles underwent title and abstract screening, where 122 studies were excluded for not meeting the inclusion criteria. The exclusion reasons included irrelevance to educational interventions, focus on populations outside the specified age range of 10–19 years, or targeting conditions other than iron deficiency anemia. After this step, 27 studies were evaluated in full text. Eleven of these were excluded for specific reasons: five involved adult populations, four focused on interventions that were not educational, and two targeted pregnant women rather than adolescents. Ultimately, 16 studies met all inclusion criteria and were included in the review for data extraction and analysis. These selected studies represented diverse geographical locations, methodologies, and intervention designs, offering a robust dataset to evaluate the impact of educational strategies on anemia among adolescents in low- and middle-income countries (LMICs).

Characteristics of Included Studies

The characteristics of the included studies demonstrated a wide variation in design, sample size, and intervention strategies. The studies spanned across multiple LMICs, with a notable concentration in Asia, including Indonesia, India, and Pakistan, as well as regions in Africa and the Middle East. Sample sizes ranged from as small as 15 participants in Raihani et al. [61] to as large as 455 participants in Salam et al. [60]. Most studies focused on adolescents aged 10–19 years, with mean ages varying slightly but consistently representing the target population. Educational interventions were delivered through diverse formats, including traditional classroom lectures, multimedia tools like videos and apps, and interactive methods such as role-playing and group discussions. These varied methodologies provided a comprehensive overview of approaches to addressing iron deficiency anemia in adolescents.

The intervention duration also varied significantly, ranging from short-term programs lasting one month to longer-term efforts spanning up to six months. The content of the educational programs commonly included information on the importance of dietary iron, sources of iron-rich foods, proper supplementation practices, and strategies to overcome barriers to iron consumption. Many interventions incorporated culturally tailored content to enhance relevance and engagement, especially in community-based programs. A detailed summary of the characteristics and outcomes of each study is presented in Table 3.

Study Quality Assessment

The following is a summary of the study quality assessment using the CASP tool (Table 4). Based on the assessment results, in general the eligible studies are in the Strong category, while seven studies are in the Medium category, and Three studies are Weak.

Table 3. Summary of Quality Appraisal of Eligible studies

Studies	Questions											Overall
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	
Abu-Baker et al. [49]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Strong
Alaofe et al. [50]	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Medium
Bhanushali et al. [51]	Y	Y	Y	N	N	Y	Y	Y	CT	Y	Y	Medium
Gambir et al. [52]	N	N	N	Y	Y	Ct	Y	Y	Y	Y	Y	Weak
Ghadam et al. [53]	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Strong
Jalambo et al. [54]	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Strong
Jeihooni et al. [55]	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Strong
Madestria et al. [56]	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Medium
Magfirah et al. [57]	Y	N	CT	Y	N	N	Y	Y	Y	Y	Y	Weak
McCormack et al. [58]	Y	Y	CT	Y	Y	CT	Y	Y	Y	Y	Y	Medium
Rahmiwati et al. [59]	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Medium
Salam et al. [60]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Strong
Raihani et al.[61]	Y	N	Y	N	Y	CT	Y	Y	Y	Y	Y	Medium
Rusdin et al.[62]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Strong
Zakiah et al. [63]	N	N	Y	N	Y	Y	Y	CT	Y	Y	Y	Weak
Zuraida et al. [64]	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Medium

Results of RoB assessment

Based on the results of the risk of bias assessment, it was found that there were three studies in the High RoB category and five studies in the Some Concerns category. But overall, most of the studies were in the Low RoB category.

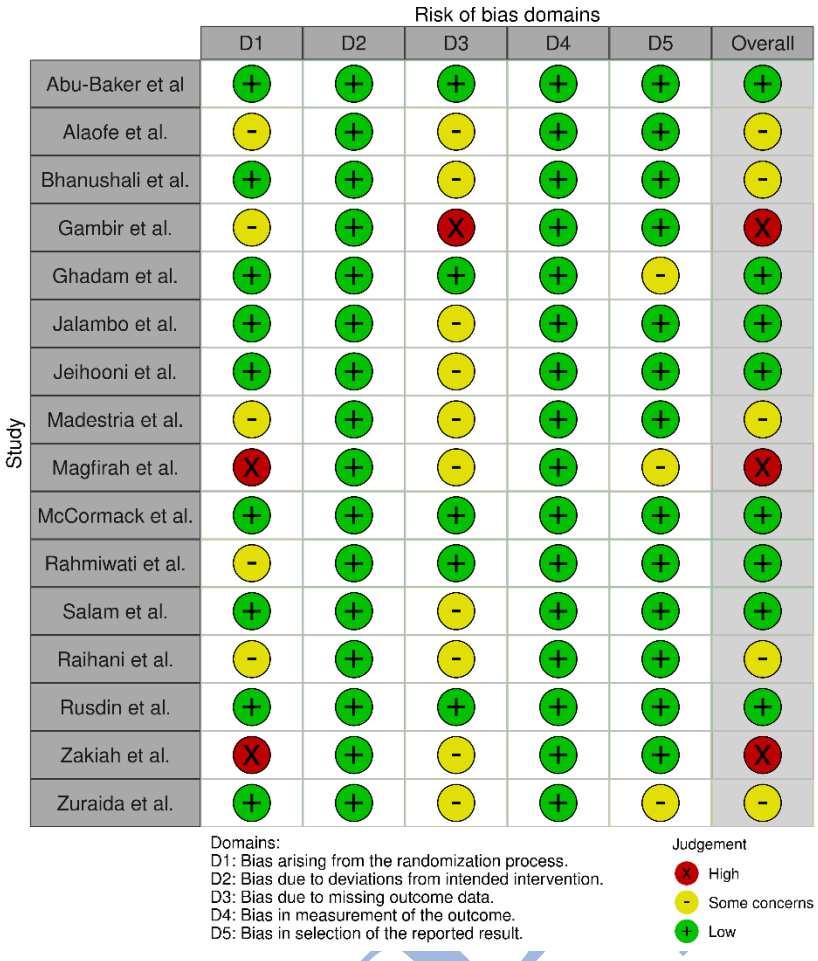

Fig. 2. Visualization of RoB assessment

Effectiveness of Educational Interventions

The primary outcomes assessed across the studies included dietary iron intake and adherence to iron supplementation. Secondary outcomes included changes in hemoglobin (Hb) levels, anemia prevalence, and knowledge, attitudes, and practices (KAP) related to iron intake. The interventions demonstrated varied levels of effectiveness depending on their design, delivery methods, and cultural appropriateness.

Educational interventions consistently improved dietary iron intake among participants. Ten studies reported statistically significant increases in iron consumption following the intervention. For instance, Gambir et al. [52] in Indonesia implemented a diary-book system combined with counseling, which effectively increased participants' awareness and consumption of iron-rich foods ($p < 0.05$). Similarly, Zuraida et al. [64] employed anemia-free club sessions that emphasized practical dietary modifications, resulting in a measurable improvement in dietary habits. These findings highlight the potential of interactive and participatory education methods in influencing adolescents' dietary behaviors.

Adherence to iron supplementation also improved in many studies, particularly when interventions included counseling or culturally relevant materials. Jalambo et al. [54] in Palestine demonstrated that combining nutrition education with supplementation significantly

enhanced both hemoglobin levels and ferritin concentration ($p < 0.001$). Similarly, Rahmiwati et al. [59] integrated local cultural elements into nutrition education, which fostered better adherence to iron-folic acid supplementation, though compliance levels remained variable due to external factors like pill availability and participant motivation.

The secondary outcomes provided further evidence of the interventions' impact. Eight studies reported significant improvements in hemoglobin levels among participants. For example, Abu-Baker et al. [49] in Jordan used a combination of lectures, videos, and brochures to improve hemoglobin levels and overall anemia knowledge ($p < 0.001$). Salam et al. [60] in India employed a blend of role-playing and practical demonstrations, which resulted in similar gains. Reductions in anemia prevalence were noted in studies like McCormack et al. [58] and Alaofe et al. [50], further underscoring the potential of educational approaches to complement traditional supplementation programs.

Knowledge, attitudes, and practices (KAP) related to anemia and iron consumption showed substantial improvements across all 16 studies. Interventions involving interactive or participatory components appeared particularly effective. For instance, Rusdin et al. [62] in Indonesia utilized a combination of lectures, group discussions, and problem-solving activities, which significantly improved participants' motivation and behavior toward iron consumption ($p < 0.001$). However, while knowledge gains were universal, the translation of this knowledge into long-term dietary behavior and supplementation adherence varied, often depending on factors such as program duration and follow-up support.

Factors Influencing Effectiveness

Several key factors influenced the effectiveness of the educational interventions. Cultural relevance emerged as a critical determinant, as interventions tailored to local dietary habits and cultural norms tended to achieve better outcomes. For example, Rahmiwati et al. [59] successfully integrated cultural practices into the program design, fostering higher engagement and adherence rates among participants.

The method of delivery also played a significant role. Digital tools, including mobile applications and gamified learning approaches, were particularly effective in engaging adolescents. For instance, Magfirah et al. [57] utilized the LADIES App and e-posters delivered via WhatsApp, which not only increased knowledge ($p < 0.001$) but also improved dietary nutrient intake. Similarly, Ghadam et al. [53] employed a digital gaming approach alongside traditional presentations, achieving significant improvements in nutrient consumption ($p < 0.001$). These findings suggest that leveraging technology can enhance the accessibility and appeal of educational interventions for younger populations.

Another important factor was the duration and intensity of the interventions. Programs with longer durations and more frequent sessions tended to yield more sustained improvements in outcomes. For example, Madestria et al. [56] implemented a program spanning 12 weeks with multiple sessions, leading to significant gains in knowledge, attitudes, and behavioral intentions toward iron consumption.

DISCUSSION

The findings of this systematic review highlight the effectiveness of educational interventions in addressing iron deficiency anemia (IDA) among adolescents in low- and middle-income

countries (LMICs). The analysis of the included studies underscores several critical themes related to the design, delivery, and outcomes of these interventions, offering valuable insights into their potential to combat a significant public health issue. The review found consistent evidence that educational interventions improved dietary iron intake and adherence to iron supplementation among adolescents. This aligns with previous studies indicating that education is a powerful tool for fostering health-related behavior changes. By providing adolescents with the knowledge and skills to make informed dietary choices, these interventions addressed both the lack of awareness and the barriers associated with iron consumption. For example, studies such as those by Gambir et al. [52] and Zuraida et al. [64] demonstrated significant improvements in iron-rich food consumption following culturally tailored and interactive educational sessions. This supports the notion that interventions grounded in the local context are more likely to resonate with participants and effect meaningful behavioral change. The observed improvements in hemoglobin levels and reductions in anemia prevalence, as seen in studies by Alaofe et al. [50] and McCormack et al. [58], further emphasize the role of education as a complementary strategy to supplementation and food fortification.

One of the key findings of this review was the critical importance of cultural relevance in intervention design. Programs that incorporated culturally appropriate content, such as those by Rahmiwati et al. [59], demonstrated higher levels of participant engagement and adherence. This is consistent with literature suggesting that culturally tailored health interventions are more effective in addressing the unique needs and barriers faced by specific populations [65–67]. Moreover, involving community stakeholders in the design and implementation of interventions appeared to enhance their acceptability and sustainability [68,69]. The role of community-based approaches cannot be overstated, particularly in contexts where adolescents rely on family members or community norms for dietary decisions. Programs that engaged caregivers and community leaders in addition to adolescents, such as those involving group discussions and shared learning activities, created an enabling environment for change. These findings are in line with previous studies emphasizing the role of social support in promoting health-related behaviors [70–73].

The review also highlighted the growing importance of digital tools in delivering educational interventions. Studies utilizing mobile applications, gamification, and social media platforms reported significant improvements in knowledge and dietary practices. For instance, Magfirah et al. [57] and Ghadam et al. [53] demonstrated the effectiveness of digital tools in enhancing engagement and making learning more accessible. This aligns with global trends in leveraging technology for health education, particularly in LMICs where digital penetration is increasing. However, it is worth noting that digital interventions require careful consideration of access and equity. In settings where digital literacy or infrastructure is limited, traditional methods may still play a critical role. Future programs should consider integrating digital tools with in-person sessions to maximize reach and effectiveness while addressing disparities in access [74,75].

Despite the overall success of the interventions, several challenges were noted. First, the sustainability of behavior changes post-intervention remains a concern. While many studies reported immediate improvements in dietary intake and supplementation adherence, long-term

follow-up data were often lacking. This highlights the need for sustained engagement and periodic reinforcement to ensure that the gains are maintained over time. Another limitation was the variability in program duration and intensity. While longer and more frequent sessions tended to produce better outcomes, resource constraints in LMICs often limit the scalability of such interventions. Balancing the need for comprehensive education with the realities of limited funding and infrastructure remains a key challenge. Additionally, the heterogeneity in study designs, intervention types, and outcome measures made it difficult to directly compare results across studies. Standardizing the methodologies and metrics used in future research could help build a more cohesive body of evidence to guide intervention development.

The findings of this review have important implications for policymakers and practitioners aiming to reduce IDA among adolescents in LMICs. Integrating educational components into national nutrition programs can complement existing strategies like supplementation and food fortification. Policymakers should prioritize culturally relevant and context-specific interventions that engage both adolescents and their communities. Leveraging digital tools can enhance the scalability and accessibility of educational programs. Investments in digital health infrastructure, combined with efforts to improve digital literacy, could amplify the impact of such interventions. However, ensuring equitable access to these technologies is crucial to avoid exacerbating existing health disparities. Multi-sectoral collaboration is essential for the success of educational interventions. Partnerships between health, education, and community sectors can help address the diverse factors contributing to IDA, from dietary habits to social norms and systemic barriers.

Future research should focus on addressing the gaps identified in this review, particularly the need for long-term follow-up data to assess the sustainability of intervention outcomes. Studies should also explore the cost-effectiveness of different educational strategies to inform resource allocation in LMICs. Moreover, integrating qualitative methods to capture participants' experiences and perspectives could provide deeper insights into the factors influencing intervention success.

CONCLUSION

Educational interventions offer a promising approach to addressing iron deficiency anemia among adolescents in LMICs. By improving knowledge, attitudes, and behaviors related to iron consumption, these programs have the potential to significantly impact public health outcomes. However, their success depends on cultural relevance, innovative delivery methods, and sustained engagement. Moving forward, a collaborative and adaptive approach that integrates education with other nutrition strategies will be essential to combat this pervasive health issue effectively.