BKM
Berita Kedokteran Masyarakat

Volume 42 **Number** 06, 2026, **Pages** e29453
DOI: 10.22146/bkm.v42i06.29453

Educational interventions for diabetes prevention knowledge and behavior in children: a systematic review and meta-analysis

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Submitted:
March 25th, 2026
Accepted:
June 24th, 2026
Published:
June 30th, 2026

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Abstract

Purpose: This systematic review and meta-analysis evaluated educational interventions for improving type 2 diabetes prevention knowledge and preventive behaviors among children. **Methods:** A systematic search was conducted in PubMed, ScienceDirect, SAGE Journals, Scopus, ProQuest, MEDLINE, and the Cochrane Library for studies published between 2015 and 2025. Eligible studies were RCTs, cluster RCTs, and quasi-experimental studies evaluating diabetes prevention education among children aged approximately 6–18 years without diabetes and reporting knowledge or preventive behavior outcomes. Risk of bias was assessed using RoB 2 and ROBINS-I. Random-effects meta-analyses calculated standardized mean differences (SMDs) with 95% confidence intervals (CIs). **Results:** Thirteen studies were included; six were eligible for knowledge meta-analysis and four for preventive behavior meta-analysis, while the remaining studies were summarized narratively. Pooled analyses suggested that educational interventions were associated with improvements in diabetes prevention knowledge (SMD = 1.597; 95% CI: 0.796–2.398; $p < 0.001$) and preventive behaviors (SMD = 0.625; 95% CI: 0.162–1.089; $p = 0.008$). Interventions with more than four sessions and cluster RCTs appeared to show stronger effects. Substantial heterogeneity was observed, likely reflecting differences in study design, intervention duration, delivery methods, and outcome measures. **Conclusion:** Educational interventions appear to be associated with improved knowledge of type 2 diabetes prevention and may support preventive behaviors among children, but findings should be interpreted with caution given heterogeneity and methodological limitations. Multi- session school-based interventions, particularly those with more than four sessions, may be more promising. More rigorous studies with longer follow-up are needed.

Keywords: children; educational interventions; knowledge; preventive behaviors; type 2 diabetes prevention

INTRODUCTION

Diabetes mellitus has become a major global public health concern, with its prevalence increasing significantly in both adult and younger populations. In recent decades, the incidence of diabetes among children has risen worldwide, reflecting changes in lifestyle patterns and environmental factors. Increasing rates of childhood obesity, sedentary behavior, and unhealthy dietary patterns have been identified as major contributors to the growing burden of prediabetes and type 2 diabetes mellitus (T2DM) among younger populations [1,2]. Epidemiological evidence also indicates that youth-onset T2DM continues to increase globally, highlighting the emerging challenge of metabolic diseases during early life stages [3]. Early onset of diabetes is particularly concerning because it exposes individuals to prolonged hyperglycemia and increases the risk of long-term complications, including cardiovascular disease, nephropathy, neuropathy, and other metabolic disorders later in life [1,4]. As a result, diabetes prevention has become an important priority in public health strategies targeting children. In this review, “children” refers to children and adolescents under 18 years of age, with an included age range of approximately 6–18 years, encompassing both late childhood and adolescence. This broad age range includes children and adolescents at different developmental stages, which may influence how educational messages are understood, received, retained, and translated into preventive behaviors.

Lifestyle modification is widely recognized as a key strategy for preventing type 2 diabetes. In this review, “preventive behaviors” refer to behaviors related to diabetes prevention, including healthy dietary practices and physical activity. Interventions promoting healthy dietary habits, regular physical activity, and improved health literacy during childhood have been shown to reduce the risk of developing diabetes later in life [5]. Childhood and adolescence are important periods for developing health-related knowledge, attitudes, and lifestyle habits. Educational interventions may therefore help children understand diabetes risk factors, improve health literacy, and build motivation to adopt healthier dietary and physical activity behaviors. When implemented in school settings, these interventions may reinforce preventive messages through repeated exposure and interactive learning [6,7]. Educational interventions have therefore been increasingly implemented to improve children’s knowledge, risk awareness, and preventive behaviors related to chronic diseases.

Schools are considered a strategic setting for implementing such programs because they provide access to large populations of children and enable the integration of health promotion activities into existing educational systems. Previous studies have shown that school-based educational interventions can improve dietary behaviors, increase physical activity levels, and contribute to healthier lifestyle patterns among children [7,8]. Educational interventions delivered in school settings have also been shown to improve students’ knowledge and awareness regarding diabetes and other metabolic diseases, which may support the adoption of preventive behaviors early in life [9].

Despite the growing number of educational interventions aimed at preventing type 2 diabetes in children, their effectiveness remains inconsistent across studies. Educational interventions vary widely in their design, including differences in intervention duration, delivery methods, theoretical frameworks, and outcome measurements. Some interventions are delivered through classroom-based education, while others use teacher-led, peer-led, or community-based health promotion strategies [9–11]. In addition, behavioral theories such as the Health Belief Model, Social Cognitive Theory, and the Theory of Planned Behavior are often used to guide the development of educational interventions, which may influence how knowledge and preventive behaviors are shaped among children [10–12]. Furthermore, many intervention studies involve relatively small sample sizes, short follow-up periods, or quasi-experimental designs, which may limit the generalizability of their findings [13–15]. Differences in outcome measurements, such as knowledge scales, health belief constructs, and behavioral indicators, also make it difficult to compare results across studies and to determine the overall effectiveness of educational interventions for type 2 diabetes prevention among children [9,10,12,16].

Previous systematic reviews have examined related school-based, lifestyle, or diabetes education interventions in children and adolescents. Jacob et al. reported that school-based health education interventions may reduce BMI among adolescents [7], and Dabravolskaj et al. found that school-based health promotion interventions could improve obesity-related risk factors, such as physical activity, fruit and vegetable intake, and body weight [8]. More recently, Cockcroft et al. reviewed educational and psycho-educational self-management interventions for children and adolescents with diabetes and reported potential benefits for diabetes-related outcomes [17].

However, these reviews mainly focused on obesity-related outcomes, general health promotion, or diabetes management among young people already diagnosed with diabetes, rather than specifically synthesizing educational interventions for type 2 diabetes prevention among children without diabetes and integrating both knowledge and preventive behavior outcomes. In addition, existing studies often assess outcomes separately, such as knowledge, health beliefs, or behavioral changes, making it difficult to understand the combined impact of educational interventions on both knowledge and preventive behaviors [9,10,12]. Thus, the novelty of the present review lies in its specific focus on educational interventions for type 2 diabetes prevention among children without diabetes and in its integration of both knowledge and preventive behavior outcomes through systematic review and meta-analysis, where data were available.

Given these variations and gaps, a comprehensive synthesis that specifically focuses on children and integrates both knowledge and preventive behavior outcomes is needed to better understand the effectiveness of educational interventions for type 2 diabetes prevention. Systematic reviews and meta-analyses can provide stronger evidence by integrating findings from multiple studies and identifying patterns across different intervention approaches. Therefore, this systematic review and meta-analysis aimed to evaluate the effectiveness of educational interventions in improving knowledge of type 2 diabetes prevention and preventive behaviors among children. We hypothesized that educational interventions would be associated with improvements in knowledge of type 2 diabetes prevention and preventive behaviors among children.

METHODS

Study design, search strategy, and eligibility criteria

This study was conducted as a systematic review and meta-analysis to evaluate the effectiveness of educational interventions aimed at promoting type 2 diabetes among children. This systematic review and meta-analysis were conducted and reported in accordance with the PRISMA 2020 guidelines and registered with PROSPERO (CRD420251064044) [18]. Amendments to the registered protocol included updating the study design from a systematic review to a systematic review and meta-analysis.

A comprehensive literature search was conducted to identify studies evaluating educational interventions aimed at preventing type 2 diabetes in children. We searched PubMed, ScienceDirect, SAGE Journals, Scopus, ProQuest, MEDLINE, and the Cochrane Library. MEDLINE was searched separately from PubMed, and duplicate records were identified and removed using EndNote to avoid double-counting. In addition, reference lists of included studies and relevant reviews were manually screened to identify additional eligible studies.

The search strategy combined keywords and controlled vocabulary related to type 2 diabetes, children, educational interventions, and preventive behaviors. Boolean operators (AND, OR) were used to combine search terms, and Medical Subject Headings (MeSH) were applied when available to improve search sensitivity (Table 1).

Table 1. Presents the detailed search strategies used across all databases

Database	Search Strategy	Filters
PubMed	("Diabetes Mellitus"[Mesh] OR "Diabetes Mellitus, Type 2"[Mesh] OR diabetes[tiab]) AND ("Child"[Mesh] OR "Adolescent"[Mesh] OR child*[tiab] OR adolescen*[tiab] OR youth[tiab] OR teenager*[tiab] OR pediatric*[tiab]) AND ("Health Education"[Mesh] OR "Health Promotion"[Mesh] OR education[tiab] OR intervention[tiab] OR program[tiab] OR training[tiab] OR counseling[tiab] OR knowledge[tiab]) AND ("Primary Prevention"[Mesh] OR prevention[tiab] OR behavior*[tiab] OR lifestyle[tiab])	Free Full text, 2015-2025, Clinical Trial, Randomized Controlled Trial
Science-Direct	("diabetes prevention" OR "type 2 diabetes") AND (children OR adolescents) AND ("educational program" OR "health education") AND ("knowledge" OR "preventive behavior") AND intervention	Research article, Open Access and Open Archive, 2015-2025
Sage Journal	("diabetes prevention" OR "type 2 diabetes") AND (children OR adolescents) AND ("educational program" OR "health education") AND ("knowledge" OR "preventive behavior") AND intervention	2015-2025, Research article, Open Access
Scopus	(TITLE-ABS-KEY("diabetes prevention" OR "diabetes mellitus" OR "diabetes")) AND (TITLE-ABS-KEY(child* OR adolescen* OR youth)) AND (TITLE-ABS-KEY("educational intervention*" OR "health education" OR "educational program*")) AND (TITLE-ABS-KEY("knowledge" OR "preventive behavior*" OR "health behavior*"))	2015-2025, Article, English
ProQuest	("type 2 diabetes prevention") AND ("school based education" OR "educational intervention") AND ("children" OR "adolescents") AND ("knowledge" OR "preventive behavior")	Scholarly Journals, Article, Last ten years, English
MEDLINE	(diabetes OR "diabetes mellitus" OR "diabetes prevention") AND (child* OR adolescen* OR youth) AND ("educational intervention*" OR "health education" OR "educational program*") AND (knowledge OR "preventive behavior*" OR "health behavior*")	2015-2025, English
Cochrane	("children" OR "adolescents" OR "pediatric" OR "youth") AND ("educational intervention" OR "education program" OR "health education" OR "school based education") AND ("knowledge" OR "awareness" OR "preventive behavior") AND ("diabetes" OR "type 2 diabetes" OR "diabetes prevention")	Trial, English

Database-specific filters were applied, including publication year (2015–2025), English language, and article type (e.g., clinical trials and research articles). The full electronic search strategies for each database, including detailed search strings and applied filters, are presented in Table 1. The Boolean search syntax was reviewed for consistency across databases, while retaining database-specific adaptations in controlled vocabulary, field tags, and available filters. All databases were last searched on 24 August 2025. The search yielded 1,352 records across all databases.

Study eligibility was determined using the Population, Intervention, Comparison, Outcomes, and Study Design (PICOS) framework. **Population:** Studies involving children and adolescents under 18 years of age, with an included age range of approximately 6–18 years and without a diagnosis of diabetes, were included. This definition is broadly consistent with the Convention on the Rights of the Child definition of children as individuals below 18 years of age [19]. **Intervention:** Educational interventions aimed at promoting diabetes prevention, including school-based, peer-led, teacher-led, or community-based programs designed to improve knowledge and encourage healthy behaviors. **Comparison:** Control groups receiving no intervention or standard education, as well as pre–post comparisons in quasi-experimental studies without control groups. **Outcomes:** Outcomes related to diabetes prevention, including knowledge and preventive behaviors such as healthy dietary practices and physical activity, are measured using validated or structured questionnaires. Study design: Randomized controlled trials (RCTs), cluster randomized controlled trials (c-RCTs), and quasi-experimental studies were included. Studies were excluded if they involved adult populations, focused on individuals with diagnosed diabetes, were review articles, conference abstracts, editorials, study protocols, or did not report relevant outcomes.

Study selection and data extraction and risk of bias assessment

All retrieved records were imported into EndNote reference management software, and duplicate records were removed. Two reviewers independently screened the titles and abstracts according to the predefined inclusion and exclusion criteria. Articles considered potentially eligible were subsequently assessed through full-text screening, which was also conducted independently by two reviewers. Disagreements between reviewers were resolved through discussion until consensus was reached. No automation tools were used in the screening process.

Data extraction was conducted using a standardized form by two reviewers. Extracted data included study characteristics (author, publication year, country, study design, sample size, and participants' age), intervention characteristics (type of intervention, duration, delivery method, and use of behavioral theories), comparison conditions, follow-up periods, and outcome measures related to type 2 diabetes prevention knowledge and preventive behaviors. Study authors were not contacted for additional information.

When studies reported outcomes at multiple time points, data from the latest follow-up assessment were prioritized for meta-analysis to reflect the most sustained effects of the interventions. When multiple outcome measures were reported for similar constructs (e.g., different scales for knowledge or preventive behaviors), the most relevant and clearly reported measure was selected. If sufficient data were available, all compatible results were considered; however, only one effect size per study-outcome pair was included in the meta-analysis to avoid double-counting. When necessary, assumptions were made based on the information reported in the articles, and studies with unclear or insufficient data were excluded from quantitative synthesis.

The methodological quality of the included studies was assessed using tools appropriate to the study design. Cluster randomized controlled trials (c-RCTs) were evaluated using the Cochrane Risk of Bias tool version 2 (RoB 2) [20]. Quasi-experimental studies were assessed using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool [21]. The assessment considered potential bias related to the randomization process, confounding, participant selection, intervention classification, missing data, outcome measurement, and selective reporting. Risk of bias assessment was conducted independently by two reviewers, and disagreements were resolved through discussion. Reporting bias was not formally assessed because fewer than 10 studies were included in each meta-analysis, making funnel plot-based methods unreliable.

Data analysis

Meta-analysis was conducted using Comprehensive Meta-Analysis (CMA) software version 3 (Biostat, Englewood, NJ, USA). Pooled effect sizes for continuous outcomes were calculated as standardized mean differences (SMDs) with 95% confidence intervals (CIs). Studies were included in the meta-analysis if they reported sufficient quantitative data for both the intervention and comparison groups on outcomes related to knowledge of type 2 diabetes prevention or preventive behaviors. Studies with one-group pre–post designs or multi-arm comparative designs without a clearly defined control group were excluded from quantitative synthesis and were summarized narratively.

When studies reported outcomes using different measurement scales, standardized mean differences were calculated. Where necessary, summary statistics were converted into a common format to enable comparison across studies. Statistical heterogeneity among studies was assessed using Cochran's Q statistic and the I^2 index. An I^2 value greater than 50% or a Q statistic with $p < 0.10$ was considered indicative of substantial heterogeneity [22]. Given the expected variability in study design and intervention characteristics, a random-effects model was applied to estimate pooled effect sizes [23].

Separate meta-analyses were conducted on knowledge of type 2 diabetes prevention and preventive behaviors. Health beliefs, attitudes, perceptions, and related psychosocial constructs were not included in the meta-analysis because they were not the primary outcomes of this review, were measured using heterogeneous constructs and instruments, and were not consistently reported across studies in a format suitable for quantitative synthesis. Therefore, these outcomes were summarized narratively where relevant. Subgroup analyses were performed based on study design, use of behavior change theory, number of intervention sessions, and follow-up time points. For the subgroup analysis by intervention sessions, interventions were categorized as 1–4 sessions or more than 4 sessions to distinguish shorter educational interventions from more intensive multi-session programs. This categorization was based on the distribution of intervention characteristics across the included studies, in which programs with more than four sessions were considered to represent repeated educational exposure delivered over several weeks. Individual study characteristics and results were summarized in Tables 2 and 3, and pooled effects were presented using forest plots. Statistical significance was set at $p < 0.05$. Sensitivity analyses were not conducted due to the limited number of studies included in each meta-analysis.

RESULTS

Study selection

A total of 1,352 records were initially identified through database searching, with an additional two records identified through citation searching. After removing 184 duplicate records, 1,168 records remained for title and abstract screening. Of these, 1,142 records were excluded because they did not meet the inclusion criteria. A total of 26 reports from database searching were sought for retrieval. Of these, one report could not be retrieved because the full text was unavailable. Therefore, 25 full-text reports were assessed for eligibility. Following full-text assessment, 14 reports were excluded for several reasons, including studies conducted in adult populations (n = 3), studies that did not report relevant outcomes (n = 5), studies involving participants with type 1 diabetes (n = 1), protocol-only articles (n = 3), and qualitative research designs (n = 2). Thus, 11 studies from database searching met the inclusion criteria. In addition, two records identified through citation searching were assessed and included in the review.

Ultimately, 13 studies met the inclusion criteria and were included in the systematic review. Among these, six studies that included both intervention and control groups were eligible for quantitative synthesis and were included in the meta-analysis. Specifically, six studies were included in the meta-analysis on knowledge of type 2 diabetes prevention [9,10,12,16,24,25]. Four studies were included in the meta-analysis of preventive behaviors [9,10,16,25]. The remaining seven studies were summarized narratively because they did not provide suitable data for quantitative synthesis. This was mainly due to one-group pre–post designs, comparative studies in which all groups received some form of intervention, or insufficient between-group data to estimate pooled effect sizes. Figure 1 shows the PRISMA flow diagram of the study selection process.

Characteristics of included studies

A total of 13 studies published between 2015 and 2024 were included in this systematic review. The studies were conducted in several countries, including Iran, the United States, Brazil, Canada, India, and Nigeria. The included studies used different research designs. Most studies employed quasi-experimental designs, including one-group pretest–posttest designs, quasi-experimental designs with control groups, and comparative designs, while two studies used cluster-randomized controlled trial (c-RCT) designs.

Sample sizes varied substantially across studies, ranging from fewer than 50 participants to more than 3,000 students. The participants were primarily school-aged children between approximately 9 and 16 years old. Educational interventions were mostly implemented in school settings and delivered through various approaches, such as teacher-led education, peer-led interventions, classroom-based health education interventions, and interactive learning strategies, including group discussions, role-playing, and educational games.

The duration of the interventions varied widely, ranging from a single educational session to multi-session programs delivered over several weeks. Some interventions incorporated behavior change theories to guide program design, most commonly the Health Belief Model. At the same time, other studies applied frameworks such as the Theory of Planned Behavior or the Social Ecological Model.

Outcome assessments were generally conducted at baseline and immediately after the intervention, with several studies also including follow-up evaluations up to two or three months after the intervention. The primary outcomes measured across studies were knowledge of type 2 diabetes prevention and preventive behaviors. In this review, preventive behaviors were operationalized as lifestyle behaviors related to diabetes prevention, including healthy dietary practices and physical activity.

These components were combined and analyzed as a single construct of preventive behaviors in the meta-analysis, as they represent key modifiable risk factors targeted by educational interventions. Table 2 shows the detailed characteristics of the included studies, including study design, sample size, intervention characteristics, and follow-up periods. Several studies also assessed additional outcomes such as health beliefs, attitudes, and preventive behaviors. Various instruments were used to measure these outcomes, including validated questionnaires and researcher-developed instruments designed for diabetes prevention programs. Overall, most studies reported improvements in diabetes- related knowledge and preventive behaviors following educational interventions. Table 3 shows the outcome measures and main findings of the included studies.

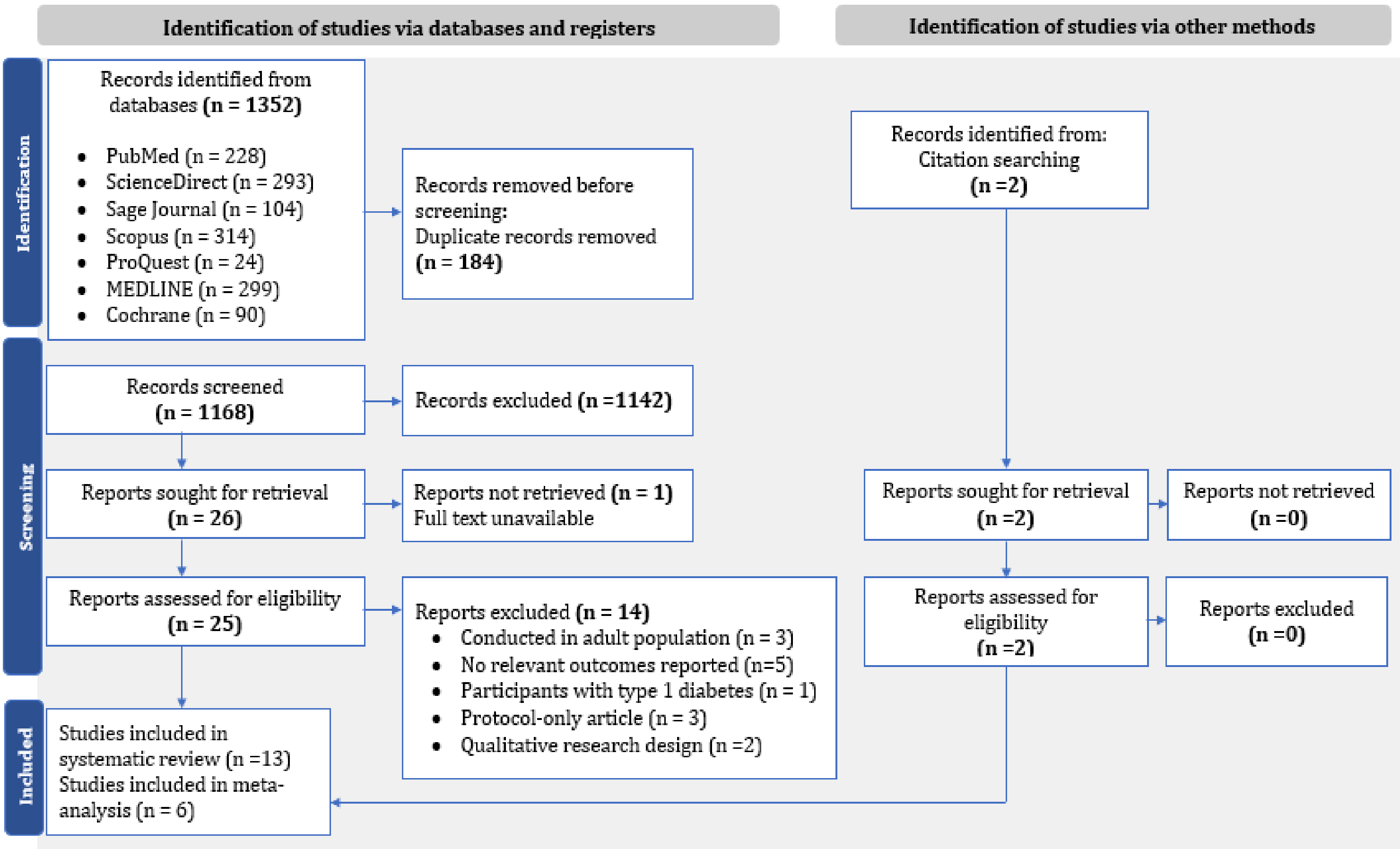

Figure 1. PRISMA flow diagram of the study selection process

Risk of bias assessment

The risk of bias in the included studies was assessed using tools appropriate to their study designs. Two cluster randomized controlled trials (c-RCTs) were evaluated using the Cochrane Risk of Bias 2 tool, while the remaining quasi-experimental studies were assessed using the ROBINS-I tool. Overall, both cluster randomized trials were judged to have a high risk of bias. The main concerns were related to the timing of participant identification relative to randomization and the measurement of outcomes, particularly due to reliance on self-reported measures. In contrast, the quasi-experimental studies demonstrated varying levels of bias across domains. The most prominent risks were related to confounding and participant selection, which were frequently judged to be moderate to serious. Additional concerns were observed in deviations from intended interventions, missing data, and outcome measurement, particularly due to reliance on self-reported questionnaires. Overall, the methodological quality of the included studies ranged from moderate to high risk of bias. Figures 2–4 present the detailed domain-level assessments and overall judgments for each study.

Meta-analysis results

Effect of educational interventions on knowledge

A meta-analysis was conducted to evaluate the effects of educational interventions on children's knowledge of diabetes prevention. Six studies that included both intervention and control groups were eligible for quantitative synthesis. Using a random-effects model, the pooled analysis showed that educational interventions had a significant positive effect on diabetes prevention knowledge compared with the control group (SMD = 1.597; 95% CI: 0.796–2.398; $p < 0.001$). This result indicates a large overall effect size, suggesting that educational interventions substantially improved children's knowledge of diabetes prevention.

Substantial heterogeneity was observed across the included studies ($I^2 = 97.93\%$), indicating considerable variability in the magnitude of intervention effects. Therefore, a random-effects model was used to estimate the pooled effect size. Overall, the findings suggest that educational interventions significantly improved children's knowledge of diabetes prevention. Figure 5 shows the forest plot illustrating the individual study effect sizes and the overall pooled estimate.

Effect of educational interventions on preventive behaviors

A meta-analysis was conducted to examine the effects of educational interventions on diabetes-related preventive behaviors among children. Four studies that included both intervention and control groups were eligible for quantitative synthesis. Using a random-effects model, the pooled analysis indicated that educational interventions had a significant positive effect on preventive behaviors compared with the control group (SMD = 0.625; 95% CI: 0.162–1.089; $p = 0.008$). This pooled effect size represents a moderate improvement in preventive behaviors among children following educational interventions. Substantial heterogeneity was observed across the included studies ($I^2 = 87.40\%$). Therefore, a random-effects model was used to account for between-study variability when estimating the pooled effect size. Overall, the findings suggest that educational interventions significantly improved diabetes-related preventive behaviors among children. Figure 6 shows the forest plot illustrating the individual study effect sizes and the overall pooled estimate.

Subgroup analysis

Subgroup analyses were conducted to explore potential sources of heterogeneity based on study design, use of behavior change theory, number of intervention sessions, and follow-up assessment time points. Table 4 shows the results of the subgroup analyses. Given the substantial heterogeneity observed in the pooled analyses and the small number of studies included in each subgroup, these findings should be interpreted as exploratory rather than confirmatory.

For the knowledge outcome, improvements were observed across both study designs, with larger effect sizes in cluster-randomized controlled trials (c-RCTs) than in quasi-experimental studies. Interventions consisting of more than four sessions appeared to be associated with greater improvements in knowledge, whereas shorter interventions did not consistently demonstrate statistically significant effects. Interventions not explicitly reporting the use of behavior change theory appeared to have larger effect sizes than theory-based interventions; however, this finding should be interpreted with caution, given the limited number of studies in each subgroup and potential differences in intervention intensity, delivery strategies, and outcome measurement tools. Improvements in knowledge were observed at both 1–2 months and more than two months after the intervention.

For preventive behaviors, cluster-randomized trials appeared to show greater improvements than quasi-experimental studies, although these findings should be interpreted with caution. Similarly, interventions with more than four sessions appeared to be associated with improvements in preventive behaviors, whereas shorter interventions did not consistently demonstrate significant effects. Improvements in preventive behaviors were also more evident at follow-up periods longer than two months.

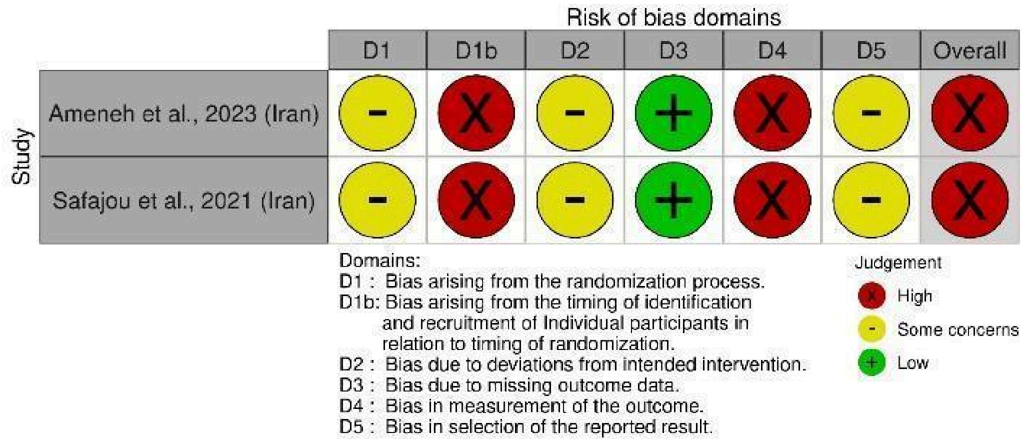

Figure 2. Risk of bias assessment of the included cluster randomized controlled trials

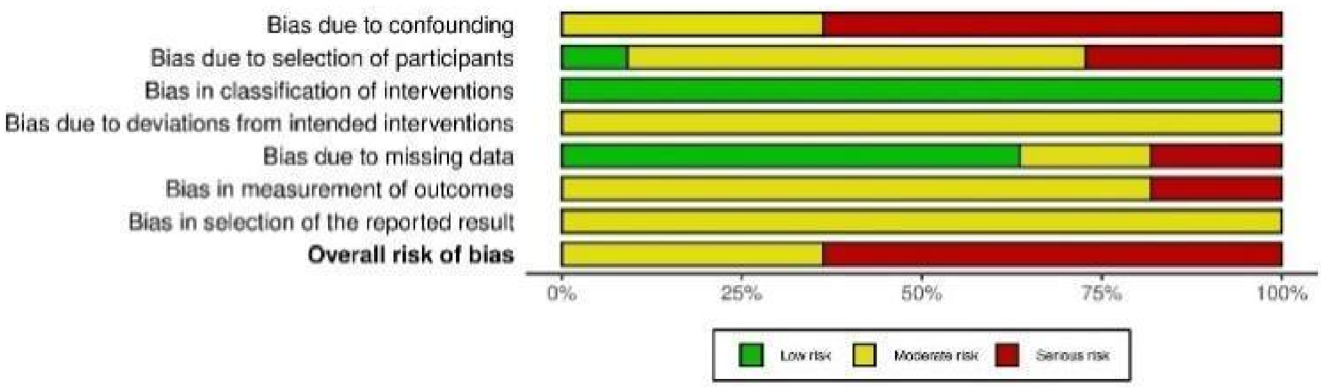

Figure 3. Risk of bias summary of the included quasi-experimental studies using ROBINS-I

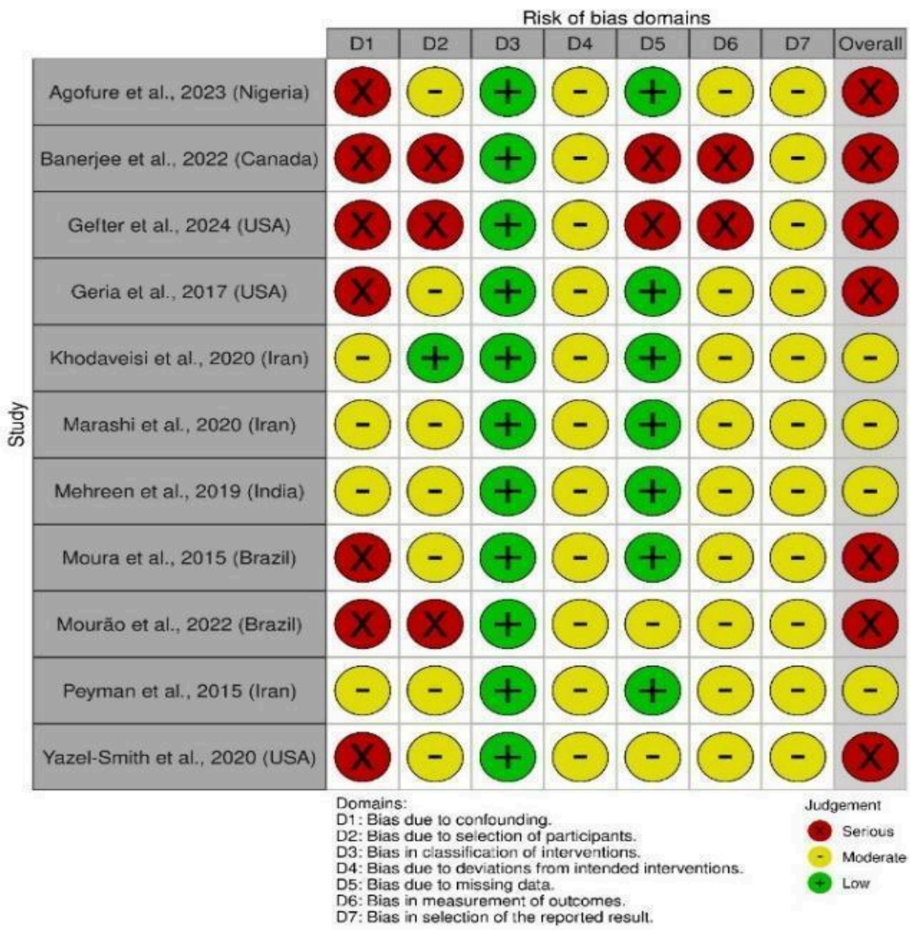

Figure 4. Risk of bias domains of the included quasi-experimental studies using ROBINS-I

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Ameneh et al., 2023 (Iran)	2.628	0.211	0.044	2.216	3.041	12.478	0.000
Khodaveisi et al., 2020 (Iran)	0.696	0.143	0.020	0.416	0.976	4.874	0.000
Marashi et al., 2020 (Iran)	1.861	0.208	0.043	1.453	2.269	8.931	0.000
Mehreen et al., 2019 (India)	0.376	0.038	0.001	0.301	0.452	9.803	0.000
Peyman et al., 2015 (Iran)	2.752	0.276	0.076	2.210	3.293	9.960	0.000
Safajou et al., 2021 (Iran)	1.383	0.186	0.035	1.018	1.748	7.428	0.000
	1.597	0.409	0.167	0.796	2.398	3.907	0.000

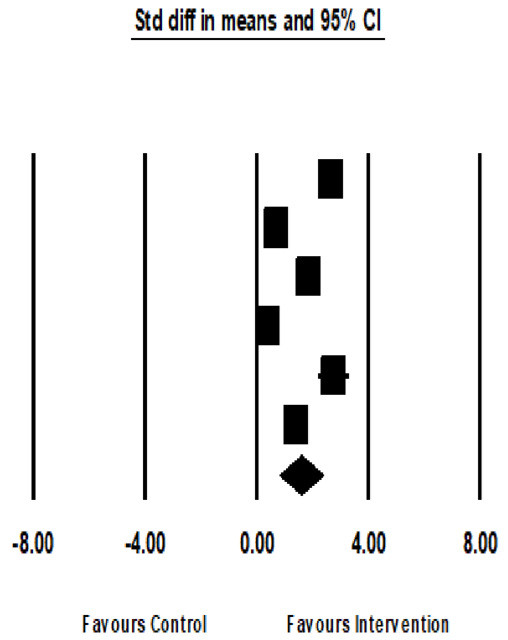

Figure 5. Forest plot of the effect of educational interventions on knowledge of diabetes prevention

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Ameneh et al., 2023 (Iran)	0.976	0.163	0.027	0.656	1.296	5.982	0.000
Khodaveisi et al., 2020 (Iran)	0.034	0.139	0.019	-0.238	0.306	0.247	0.805
Peyman et al., 2015 (Iran)	0.910	0.208	0.043	0.502	1.318	4.374	0.000
Safajou et al., 2021 (Iran)	0.621	0.171	0.029	0.285	0.957	3.625	0.000
	0.625	0.236	0.056	0.162	1.089	2.645	0.008

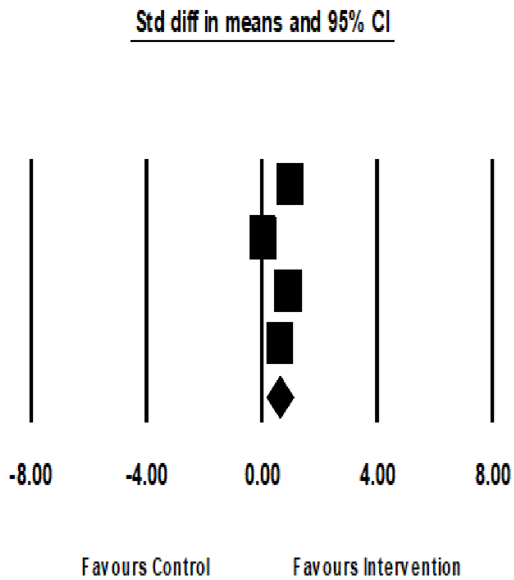

Figure 6. Forest plot of the effect of educational interventions on preventive behaviors for diabetes prevention

Table 2. Characteristics of included studies

Author, Year (Country)	Study design	Participants (n)	Age [M (SD)]	Intervention characteristics (Type, duration, mode of delivery, behavior change theory)	Comparison	Assessment time points / Follow-up
Agofure et al., 2023 (Nigeria) [14]	Quasi-experimental one-group, pretest/posttest design	I: 100 C: -	I: 13.95 (1.92) C: -	• Type: Teacher-led diabetes mellitus educational intervention • Duration: 3 weeks (3 sessions; 3 hours/session) • Mode of delivery: Group-based education including lectures, discussions, and flip-chart teaching materials delivered by trained teachers • Behavior change theory: Health Belief Model	No control group (one-group pre-test–post-test comparison)	• Baseline (pre-intervention) • 1 month after intervention
Ameneh et al., 2023 (Iran) [9]	Cluster Randomized Trial (c-RCT)	I: 84 C: 84	I: 14 (-) C: 14 (-)	• Type: School-based peer-led diabetes prevention education • Duration: 8 sessions, 90 minutes each (45-day period program) • Mode of delivery: Peer education using lectures, Q&A, group discussion, pamphlets, educational video clips, and text messages • Behavior change theory: Not specified	The control group received no educational intervention	• Baseline (Pre-intervention) • 2 months after the intervention
Banerjee et al., 2022 (Canada) [15]	One-group pre-test, post-test design	I: 49 C: -	I: 14.5 (-) C: -	• Type: South Asian Adolescent Diabetes Awareness Program (SAADAP), culturally tailored diabetes education • Duration: 10-week programme • Mode of delivery: In-person group sessions (8 sessions, 1.5 hours each) • Behavior change theory: Critical Consciousness Raising (CCR) and community-based participatory research approach.	No control group (one-group pre-test–post-test comparison)	• Baseline (pre-intervention) • 1 week after intervention
Gefter et al., 2024 (USA) [11]	Quasi-experimental comparative study (three intervention groups)	Remote: 115 Hybrid: 25 In-Person: 39	Remote: 16.2 (-) Hybrid: 16.4 (-) In-Person: 14.9 (-)	• Type: School-based health promotion and peer health coaching program (Stanford Youth Diabetes Coaches Program) • Duration: 8 weeks (1 session/week, 1 hour/session) • Mode of delivery: Remote, hybrid, and in-person • Behavior change theory: Social Cognitive Theory, Chronic Disease Self-Management Model, peer health coaching	Remote vs Hybrid vs In-person	• Baseline (Pre-intervention) • Immediately post-intervention
Geria et al., 2017 (USA) [26]	Quasi-experimental one-group, pretest/posttest design	I: 101 C: -	I: 15.36 (1.13) C: -	• Type: Modified CDC Diabetes Prevention Program (DPP) • Duration: 11 weeks (10 sessions) • Mode of delivery: School-based classroom sessions during health education class (60–80 minutes/session) • Behavior change theory: Not specified	No control group (one-group pre-test–post-test comparison)	• Baseline (pre-intervention) • Immediately post-intervention (≤1 week after intervention)
Khodaveisi et al., 2020 (Iran) [10]	Quasi-experimental with control group	I: 104 C: 104	I: 13.22 ± 1.40 C: 13.35 ± 0.63	• Type: Health Belief Model (HBM)-based diabetes prevention education • Duration: 4 sessions (45–60 min/session) • Mode of delivery: Classroom-based education using lectures, PowerPoint, and group discussion • Behavior change theory: Health Belief Model (HBM)	The control group received no educational intervention	• Baseline (pre-intervention) • 1 month after intervention

Author, Year (Country)	Study design	Participants (n)	Age [M (SD)]	Intervention characteristics (Type, duration, mode of delivery, behavior change theory)	Comparison	Assessment time points / Follow-up
Marashi et al., 2020 (Iran) [12]	Quasi-experimental with control group	I: 66 I: 66	I: 11–13 (-) C: 11–13 (-)	• Type: Education program based on the Theory of Planned Behavior (TPB) for diabetes prevention and physical activity promotion • Duration: 5 sessions (4 theoretical + 1 practical), 45–60 minutes/session • Mode of delivery: School-based education using lectures, brainstorming, group discussions, role play, pamphlets, posters, and exercise demonstrations • Behavior change theory: Theory of Planned Behavior (TPB)	The control group received no educational intervention	• Baseline (pre-intervention) • Immediately after the intervention • 3 months after the intervention
Mehreen et al., 2019 (India) [24]	Quasi-experimental with control group	I: 2276 C: 987	I: 11.1 (0.9) C: 11.2 (0.9)	• Type: School-based diabesity (diabetes + obesity) awareness program. • Duration: 5 classroom activities delivered monthly. • Mode of delivery: Teacher-led and peer-leader-facilitated classroom activities (discussion, worksheets, games, case studies, and nutrition activities). • Behavior change theory: Health Belief Model and Social Ecological Model	The control group received a one-time standard training session on diabetes and obesity	• Baseline (pre-intervention) • Follow-up after intervention
Moura et al., 2015 (Brazil) [13]	Quasi-experimental comparative study (two intervention groups)	I: 30 C: 30	I: 14.4 (-) C: -	• Type: Educational intervention for T2DM prevention comparing two strategies. • Duration: Group intervention: 5 meetings (2 hours each; total 10 hours) • Mode of delivery: GA – Individual education using an informational folder. GB – Group educational meetings with interactive activities and discussion • Behavior change theory: Not specified	GA (individual education) vs GB (group education)	• Pre-intervention • 1 day after intervention • 60 days after intervention
Mourão et al., 2022 (Brazil) [27]	Quasi-experimental one-group, pretest/posttest design	I : Students: 73 School staff: 16 Total: 89 C: -	I: Students: 9 (1) School staff: 45 (6) C: -	• Type: School-based diabetes educational intervention • Duration: Single educational session with follow-up evaluation after 2 months • Mode of delivery: Theater play, true–false interactive game, and educational training workshop for school staff. • Behavior change theory: Not specified	No control group (one-group pre-test–post-test comparison)	• Baseline (pre-intervention) • 2 months after the intervention
Peyman et al., 2015 (Iran) [25]	Quasi-experimental with control group	I: 51 I: 51	I: 11.48 (0.72) C: -	• Type: Diabetes prevention educational program • Duration: 4 weeks (4 sessions × 2 hours) • Mode of delivery: Lectures, question–answer sessions, brainstorming, group discussion, and slide presentations. • Behavior change theory: Not specified	The control group received no educational intervention	• Baseline (pre-intervention) • Immediately after the intervention • 2 months after the intervention
Safajou et al., 2021 (Iran) [16]	Cluster Randomized Trial (c-RCT)	I: 70 C: 73	I: 16.43 (0.67) C: 16.17 (0.65)	• Type: Educational intervention for diabetes prevention based on the Health Belief Model (HBM) • Duration: 7 sessions (60 minutes/session)	The control group received no educational intervention	• Baseline (before intervention) • Immediately after the intervention

Author, Year (Country)	Study design	Participants (n)	Age [M (SD)]	Intervention characteristics (Type, duration, mode of delivery, behavior change theory)	Comparison	Assessment time points / Follow-up
				• Mode of delivery: Lecture, question–answer, and group discussion using slides, pamphlets, and CDs • Behavior change theory: Health Belief Model (HBM)		• 3 months after the intervention
Yazel-Smith et al., 2020 (USA) [28]	Quasi-experimental one-group, pretest/posttest design	I: 144 C: -	I: 15.8 (0.7) C: -	• Type: Diabetes and obesity prevention education integrated into summer employment program (ENHANCE) • Duration: 6-week program with weekly sessions (30 minutes/session) • Mode of delivery: Health education sessions integrated into workplace activities (farm worksite), including discussions and practical health messages • Behavior change theory: Social Ecological Model (SEM)	No control group (one-group pre-test–post-test comparison)	• Baseline (week 1) • Post-intervention (week 6)

Table 3. Outcome measures and main findings of the included studies

Author, Year (Country)	Outcomes	Outcome measurements	Main findings
Agofure et al., 2023 (Nigeria) [14]	1. Knowledge of diabetes mellitus 2. Perception of diabetes prevention 3. Attitude toward diabetes prevention	Validated self-administered questionnaire including: 1. Knowledge questionnaire 2. Perception scale based on Health Belief Model constructs 3. Attitude questionnaire	• Knowledge increased significantly (5.42±2.79 → 9.27±3.43, p < 0.001). • Perception improved (10.68±5.18 → 14.77±5.53, p < 0.001). • Attitude toward DM prevention improved (3.32±2.63 → 6.09±2.41, p < 0.001).
Ameneh et al., 2023 (Iran) [9]	1. Knowledge: symptoms, risk factors, complications. 2. Health beliefs: self-efficacy, behavioral beliefs, perceived susceptibility, perceived severity 3. Behavior: stress prevention, healthy diet, unhealthy diet, high-risk behaviors, self-care	Researcher-developed and internally validated questionnaires : 1. Knowledge questionnaire 2. Health Beliefs questionnaire 3. Behavior questionnaire	• Knowledge: 67.63 → 91.48 (p < 0.001) • Health beliefs: 68.09 → 79.28 (p < 0.001) • Preventive behaviors: 59.24 → 81.31 (p < 0.001)
Banerjee et al., 2022 (Canada) [15]	1. Diabetes knowledge 2. Risk perception 3. Preventive behaviors (physical activity and diet)	1. Adapted Brief Diabetes Knowledge Test (BDKT) 2. Risk perception questionnaire 3. Self-reported health behavior questionnaire (diet and physical activity)	• Diabetes knowledge increased: MD = 3.32 / 21 (p < 0.001) • Risk factor knowledge increased significantly (total score +1.40, p < 0.001) • 59% showed no change in risk perception • 73.2% increased physical activity • 80.5% reduced sweets and junk food intake
Gefter et al., 2024 (USA) [11]	1. Health knowledge 2. Psychosocial assets: Self-esteem, Self-efficacy, Problem-solving 3. Health behaviors: Physical activity, Nutrition (fruit and vegetable intake), Stress reduction, Sleep	1. Diabetes Knowledge Test, Spoken Knowledge in Low Literacy in Diabetes (SKILLD) 2. Rosenberg Self-Esteem Scale, California Healthy Kids Survey (CHKS) 3. PROMIS Pediatric Physical Activity Short Form, Youth Risk Behavior Survey (YRBS), Stanford Mind and Body Lab measures	• Health knowledge: MD = 3.64 ± 2.15 (p < 0.01) • Self-esteem: MD = 0.849 ± 3.88 (p < 0.01) • Self-efficacy: MD = 0.654 ± 2.34 (p < 0.01) • Problem-solving: MD = 0.531 ± 2.08 (p < 0.01) • Physical activity: MD = 0.486 ± 1.99 (p < 0.01) • Fruit & vegetable intake: MD = 0.369 ± 1.02 (p < 0.01)

Author, Year (Country)	Outcomes	Outcome measurements	Main findings
			• Stress reduction: MD = 0.413 ± 1.10 ($p < 0.01$) No significant differences in effectiveness across delivery modes (remote, hybrid, in-person).
Geria et al., 2017 (USA) [26]	1. Self-efficacy for healthy eating 2. Self-efficacy for physical activity 3. Physical activity behavior 4. Food knowledge 5. Healthy food choices 6. BMI 7. Waist circumference	1. Self-Efficacy for Healthy Eating Survey 2. Self-Efficacy for Physical Activity Survey 3. Stanford Exercise Behaviors Survey 4. Food Knowledge Questionnaire 5. Adolescent Food Habits Checklist 6. BMI and waist circumference measurements	• Food knowledge: 37.95 → 55.15 ($p < 0.001$) • Self-efficacy healthy eating: 25.35 → 30.63 ($p < 0.001$) • Self-efficacy physical activity: 24.68 → 27.22 ($p < 0.001$) • Aerobic exercise: 145.21 → 209.55 min/week ($p < 0.001$) • Healthy food choices: 8.44 → 11.57 ($p < 0.001$) • BMI decreased: 25.02 → 24.82 ($p = 0.016$) • Waist circumference decreased: 29.21 → 28.43 ($p < 0.001$)
Khodaveisi et al., 2020 (Iran) [10]	1. Awareness (knowledge) 2. Health Belief Model constructs 3. Preventive Behavior	Researcher-developed and internally validated questionnaires : 1. Awareness questionnaire 2. Health Belief Model constructs questionnaire 3. Preventive Behavior questionnaire	• Awareness: 3.77 ± 1.99 → 6.64 ± 1.42 ($p < 0.001$) • Preventive behaviors: 16.10 ± 1.94 → 16.53 ± 1.88 ($p < 0.001$) • HBM constructs improved significantly (perceived susceptibility, severity, benefits, barriers, self-efficacy) ($p < 0.05$)
Marashi et al., 2020 (Iran) [12]	1. Diabetes Knowledge 2. Theory of Planned Behavior constructs 3. Physical Activity	1. Diabetes Awareness Questionnaire 2. IPAQ (Physical Activity) 3. TPB questionnaires (Attitude, Subjective Norms, Perceived Behavioral Control, Behavioral Intention)	• Knowledge increased in the intervention group. (5.24±1.65 → 7.73±1.95 immediately after → 7.94±1.82 at 3 months). • Subjective norms increased (23.09±3.40 → 23.88±3.18). • Perceived behavioral control increased (14.74±2.27 → 16.05±2.51). • Physical activity increased significantly immediately after the intervention ($p < 0.001$).
Mehreen et al., 2019 (India) [24]	Knowledge on Diabesity	Self-administered 17-item Diabesity questionnaire	• The total knowledge score increased in the intervention group (11.51 → 12.25, $p < 0.001$). • Students in the intervention group were more likely to have good knowledge. (OR = 1.31, 95% CI: 1.12–1.52, $p < 0.001$).
Moura et al., 2015 (Brazil) [13]	1. Knowledge about type 2 diabetes 2. Behavioral intention to change habits (diet and physical activity)	1. Knowledge questionnaire (T2DM knowledge level scale) 2. Behavior intention questionnaire (diet and physical activity habits)	• Knowledge increased significantly in both groups after the intervention ($p = 0.0001$). • Behavior observed: - Diet change: GA $p = 0.001$; GB $p = 0.004$ - Physical activity increased only in GB ($p < 0.0001$).
Mourão et al., 2022 (Brazil) [27]	1. Diabetes knowledge 2. Diabetes signs and symptoms recognition 3. Diabetes management in school 4. Perception about diabetes	Structured interview questionnaire developed by the research team (20 questions for students, 24 questions for school staff)	Knowledge and perception about diabetes improved significantly after the intervention, especially regarding hypoglycemia management and sugar intake by people with diabetes ($p < 0.05$).

Author, Year (Country)	Outcomes	Outcome measurements	Main findings
Peyman et al., 2015 (Iran) [25]	1. Knowledge 2. Attitude 3. Practice (Preventive Behavior)	Researcher-developed and internally validated questionnaires. 1. Knowledge questionnaire 2. Attitude questionnaire 3. Practice questionnaire	• Knowledge increased in the intervention group (5.14±1.7 → 9.24±1.06 immediately → 8.82±1.12 at 2 months). • Attitude improved (14.67±2.33 → 19.58±1.75 at 2 months). • Practice improved (24.98±8.60 → 43.74±10.04 immediately → 30.62±8.85 at 2 months). All changes were significant (p < 0.001).
Safajou et al., 2021 (Iran) [16]	1. Awareness (knowledge) 2. Health Belief Model constructs (susceptibility, severity, benefits, barriers, self-efficacy, cues to action) 3. Preventive behaviors	Researcher-developed and internally validated questionnaires : 1. Knowledge questionnaire 2. Health Beliefs questionnaire 3. Behavior questionnaire	• Awareness increased in the intervention group (37.66±5.92 → 49.41±4.32 → 52.91±3.33, p = 0.0001). • Preventive behavior improved (17.26±4.95 → 22.96±4.95 → 18.57±3.45, p = 0.0001). • HBM constructs (susceptibility, severity, benefits, self-efficacy, cues to action) improved significantly after the intervention (p < 0.05).
Yazel-Smith et al., 2020 (USA) [28]	1. Physical activity 2. Knowledge about healthy behaviors 3. Dietary intake 4. Self-efficacy 5. Food insecurity 6. Depression screening	31-item self-administered questionnaire including: 1. Youth Risk Behavior Surveillance System physical activity questions 2. Nutrition knowledge and dietary intake questions 3. Self-efficacy items 4. Food insecurity screening 5. PHQ-2 depression screening	• Physical activity increased (51.1±16.4 → 57.37±16.0, p=0.000). • Knowledge improved (79.66±17.4 → 88.5±15.01, p=0.000). • Dietary intake (p=0.204) and self-efficacy (p=0.584) showed no significant change.

Table 4. Subgroup analysis of the effects of educational interventions on knowledge and preventive behaviors

Variables	Knowledge (n=6)			Preventive behaviors (n=4)		
	n	SMD (95% CI)	p	n	SMD (95% CI)	p
Study design			< **0.001**			< **0.001**
Cluster RCT	2	2.002 (0.782 – 3.222)	0.001	2	0.802 (0.454–1.151)	< 0.001
Quasi-experimental	4	1.389 (0.519 – 2.258)	0.002	2	0.458 (-0.399–1.316)	0.295
Behavior change theory			< **0.001**			< **0.001**
Yes	4	1.058 (0.418–1.698)	0.001	2	0.319 (-0.256–0.894)	0.277
No	2	2.674 (2.345–3.002)	<0.001	2	0.951 (0.699–1.203)	<0.001
Intervention sessions			**0.001**			< **0.001**
1-4	2	1.710 (-0.304–3.724)	0.096	2	0.458 (-0.399–1.316)	0.295
>4	4	1.552 (0.442–2.662)	0.006	2	0.802 (0.454–1.151)	<0.001
Assessment time points			**0.001**			< **0.001**
1-2 months after intervention	3	2.014 (0.547–3.481)	0.007	3	0.631 (-0.021–1.283)	0.058
>2 months after intervention	3	1.192 (0.203–2.182)	0.018	1	0.621 (0.285–0.957)	<0.001

DISCUSSION

This systematic review and meta-analysis examined the effectiveness of educational interventions in improving knowledge and preventive behaviors related to diabetes prevention among children. Overall, the findings suggest that educational interventions may improve children's awareness of diabetes risk factors and encourage the adoption of preventive behaviors, although the strength of evidence varies across studies.

Several studies included in this review reported improvements in diabetes-related knowledge following educational interventions delivered in school or community settings [9,10,24,25]. Educational interventions typically provide structured information about diabetes risk factors, healthy dietary habits, and the importance of physical activity, which may enhance children's understanding of disease prevention [10,12,24]. Interactive strategies such as peer education, discussions, and participatory learning may increase students' engagement and facilitate knowledge retention [9,10,24]. These findings are consistent with previous research demonstrating that school-based educational interventions can improve health-related knowledge and awareness among children [7,8], as well as systematic reviews showing improvements in preventive behaviors and overall well-being [29].

Previous school-based health education and health promotion meta-analyses mainly examined anthropometric or obesity-related outcomes. Jacob et al. reported a small pooled reduction in BMI z-score among adolescents following school-based health education interventions (−0.06; 95% CI: −0.10 to −0.03), while Dabravolskaj et al. reported modest BMI reductions for Comprehensive School Health interventions (−0.26; 95% CI: −0.40 to −0.12), physical education curriculum modifications (−0.16; 95% CI: −0.30 to −0.02), and multicomponent interventions (−0.18; 95% CI: −0.29 to −0.07) [7,8]. In comparison, the present meta-analysis found pooled effects for diabetes prevention knowledge (SMD = 1.597) and preventive behaviors (SMD = 0.625). These findings suggest that educational interventions may produce more immediate changes in cognitive and self-reported behavioral outcomes than in anthropometric outcomes. However, this comparison is indirect and should be interpreted cautiously because the outcomes, measurement scales, intervention targets, and follow-up periods differed across reviews.

This interpretation is also reflected in the present findings, in which improvements in preventive behaviors appeared less consistent compared with knowledge outcomes. This difference may reflect the complexity of behavior change, which is influenced by multiple interacting factors, including individual motivation, social support, and environmental context. Behavioral science frameworks emphasize that preventive behaviors are shaped by interactions between personal capability, motivation, and environmental opportunities [30]. While improved knowledge can increase awareness of health risks, sustained lifestyle changes often require additional support, including family involvement, supportive school environments, and access to healthy food and opportunities for physical activity [31].

The discrepancy between the larger effect on knowledge and the smaller effect on preventive behaviors suggests that educational interventions may more readily improve cognitive outcomes than sustained lifestyle behaviors. In children and adolescents, knowledge improvement may be necessary but insufficient for behavior change because dietary choices, physical activity, screen time, and daily routines are often shaped by parents, household practices, peer norms, and school environments [31,32]. Children may understand the importance of healthy eating and regular physical activity. However, their ability to apply this knowledge can be limited when healthy food options are unavailable at home or at school, when opportunities for physical activity are restricted, or when family routines do not support lifestyle change [32–34]. Therefore, educational interventions should not be considered fully effective when delivered solely as child-focused knowledge interventions; rather, their behavioral impact may depend on whether they are supported by parents, schools, and broader environmental changes [32,34,35]. In this context, peer-led interventions may be particularly relevant for children and adolescents because peers can influence social norms, motivation, and engagement in health-related behaviors [35]. Several included studies used peer-led education, peer health coaching, or peer-leader-facilitated classroom activities, suggesting that peer-based strategies may make educational programs more relatable and acceptable to students [9,11,24]. These approaches may potentially help bridge the gap between knowledge acquisition and behavioral practice, although further studies are needed to determine their specific contribution to sustained behavior change.

Although several studies conducted in different settings, including Nigeria, Brazil, India, and the United States, reported improvements in diabetes-related knowledge, attitudes, or preventive behaviors [13,14,24,26], the magnitude and consistency of behavioral outcomes varied. Some studies showed increases in physical activity and healthier dietary choices following educational interventions [15,26], suggesting that behavior change may occur but is influenced by contextual and implementation factors.

The substantial heterogeneity observed across studies is an important consideration when interpreting these findings. This heterogeneity is likely attributable to variations in study design (cluster randomized controlled trials versus quasi-experimental studies), participant characteristics (age range and sociocultural context), intervention intensity (number and duration of sessions), delivery methods (teacher-led, peer-led, or interactive approaches), use of behavior change theories, and differences in outcome measurement instruments.

The broad age range of participants may also have contributed to the substantial heterogeneity observed in this review. Children and adolescents aged 6–18 years differ markedly in cognitive development, autonomy, social influence, and ability to translate health knowledge into daily behaviors. Younger children may understand basic diabetes prevention messages but have limited control over food availability, meal preparation, screen time, and opportunities for physical activity, as parents and the home or school environment largely determine these. In contrast, adolescents may have greater autonomy in purchasing food and making lifestyle choices. However, their behaviors may be more strongly influenced by peer norms, academic demands, body image concerns, and access to unhealthy foods around school. Therefore, the same educational intervention may produce different levels of knowledge retention and behavior change across developmental stages, contributing to variability in intervention effects and the high statistical heterogeneity observed in the meta-analysis.

The interpretation of these findings should also consider the methodological limitations of the included studies. Many studies used quasi-experimental designs, and several relied on self-reported measures of knowledge, attitudes, and preventive behaviors, which may introduce confounding, selection, recall, or social desirability bias. As a result, the observed large effect sizes, particularly for knowledge outcomes, may have been overestimated. Therefore, the findings should be interpreted as suggesting an association between educational interventions and improved outcomes rather than providing strong causal evidence of intervention effectiveness. This cautious interpretation is particularly important when considering the clinical and public health relevance of the findings.

Several interventions included in this review were informed by behavior change theories, particularly the Health Belief Model and the Theory of Planned Behavior [10,12,16]. These frameworks aim to influence individuals' perceptions of health risks and strengthen motivation to adopt preventive actions [31]. Interventions that address perceived susceptibility, perceived severity, and self-efficacy may support children's motivation to engage in healthier behaviors related to diabetes prevention [10,16,31]. However, differences in how theoretical frameworks are reported and implemented across studies make it difficult to determine their specific contribution to intervention effectiveness.

Interestingly, subgroup findings suggested that studies not explicitly reporting the use of behavioral theories appeared to demonstrate larger effects. However, this finding should be interpreted with considerable caution and should not be taken as evidence that non-theory-based interventions are superior to theory-based interventions. The apparent larger effects may reflect statistical artifacts due to the small number of studies within each subgroup, differences in sample size, intervention intensity, delivery strategies, or outcome measurement tools. In addition, some interventions may have incorporated theory-informed components, such as peer support, interactive learning, self-efficacy enhancement, or environmental reinforcement, without explicitly reporting an underlying behavioral theory [31]. Another possible explanation is that some interventions not described as theory-based may have been more practical, action-oriented, or contextually adapted. In contrast, explicitly theory-based programs may have varied in the extent to which they implemented theoretical constructs. Therefore, this subgroup finding should be considered exploratory and requires confirmation in future studies with clearer reporting of intervention components and theoretical foundations.

Another important observation is the variation in intervention characteristics across studies. Differences in duration, number of sessions, delivery strategies, and educational approaches may contribute to differences in effectiveness. Interventions that include multiple sessions and interactive learning strategies may provide greater opportunities for reinforcement and engagement, thereby supporting more meaningful behavioral change among children. At the same time, variability in intervention design and outcome measurement across studies likely contributes to the observed heterogeneity.

The findings of this review highlight the importance of strengthening early diabetes prevention efforts through school-based programs that are feasible and scalable within existing public health and education systems. Schools provide a strategic platform for delivering structured and continuous health education to children, making them an important setting for preventive interventions. At the program level, ministries of health and education may consider integrating diabetes prevention education into existing school health programs, such as school health units or national school health initiatives. This integration could include structured modules on healthy eating, physical activity, and diabetes risk awareness, adapted to age-appropriate learning levels.

School nurses and public health practitioners can play a key role in implementing these interventions by delivering interactive educational sessions, facilitating peer-led activities, and monitoring students' health behaviors. In addition, involving teachers and parents may help reinforce behavior change by creating supportive environments at both school and home. The findings also suggest that interventions delivered through multiple sessions and interactive approaches may be more effective, indicating that short, one-time education sessions may be insufficient. Therefore, program planners should consider designing sustained, engaging interventions integrated into routine school activities. From a broader public health perspective, these findings support the need for multi-sectoral collaboration between health and education sectors to address lifestyle-related risk factors from an early age. While educational interventions alone may not be sufficient to produce long-term behavior change, they represent an important component of comprehensive strategies that include environmental and policy-level support for healthy lifestyles among children.

Several limitations should be considered when interpreting the findings of this review. First, many of the included studies used quasi-experimental designs, which may introduce potential bias and limit causal inference. Second, the number of studies included in the quantitative synthesis was relatively small, which may reduce the strength and stability of the pooled estimates and limit the ability to conduct additional analyses, such as sensitivity analyses or assessments of publication bias. Third, variability in intervention characteristics, study designs, and outcome measurement tools across studies may influence the comparability of findings. Finally, most studies included relatively short follow-up periods, making it difficult to evaluate the long-term sustainability of behavioral changes following educational interventions.

In addition, this review has several methodological limitations. The search was restricted to English-language studies, which may have introduced language bias. Although multiple databases were searched, relevant studies may have been missed. Publication bias could not be formally assessed due to the limited number of studies included in each meta-analysis. Furthermore, incomplete reporting in some primary studies may have affected the accuracy of data extraction and synthesis.

Future research should focus on strengthening the evidence base for diabetes prevention interventions among children. Additional well-designed randomized controlled trials are needed to evaluate the effectiveness of educational interventions in different settings and populations. Future studies should also consider longer follow-up periods to assess whether improvements in knowledge and behaviors can be sustained over time. Furthermore, the use of standardized measurement instruments to assess knowledge, health beliefs, and preventive behaviors may improve the comparability of findings across studies and facilitate more robust evidence synthesis in future systematic reviews.

CONCLUSION

This systematic review and meta-analysis suggest that educational interventions are associated with improved knowledge of type 2 diabetes prevention among children and may support improvements in preventive behaviors. However, the findings should be interpreted with caution due to substantial heterogeneity, the predominance of quasi-experimental designs, moderate-to-high risk of bias, and reliance on self-reported outcomes in several included studies. The larger effect observed for knowledge compared with preventive behaviors indicates that educational interventions may improve cognitive outcomes more readily than sustained lifestyle behaviors. Therefore, educational interventions should be viewed as one component of broader diabetes prevention strategies rather than as stand-alone interventions for behavior change.

From a practical perspective, school-based educational programs may be more promising when delivered through repeated, age-appropriate sessions, particularly for interventions with more than four sessions, and when combined with interactive or peer-led strategies. To strengthen behavioral impact, future programs should also involve parents, teachers, and supportive school environments that facilitate healthy food choices and opportunities for physical activity. Future research should prioritize well-designed randomized or cluster-randomized trials, longer follow-up periods, standardized measures of knowledge and preventive behaviors, and clearer reporting of intervention components, theoretical foundations, and implementation context to better determine the long-term effectiveness of educational interventions for diabetes prevention among children.

Acknowledgments
The authors would like to thank all researchers whose studies were included in this systematic review for their valuable contributions to the scientific literature.

Authors' contribution
M.U.: Conceptualization, Data curation, Formal analysis, Literature search, Writing—original draft. O.D.L.: Conceptualization, Writing—review & editing. N.A.: Writing—review & editing, Supervision. H.H.: Writing—review & editing, Supervision. I.I.C.: Data curation, Investigation. M.H.H.: Conceptualization, Methodology, Supervision, Writing—review & editing. All authors reviewed and approved the final manuscript.

Funding
This research received no external funding and was conducted as part of academic activities at the Faculty of Nursing, Universitas Indonesia.

Data availability
All data analyzed in this study were obtained from previously published articles and are publicly available in the databases described in the Methods section. The extracted dataset, data extraction form, and meta-analysis outputs generated during this review are available from the corresponding author upon reasonable request.

Conflicts of interest
The authors declare no conflict of interest.

Use of artificial intelligence (AI)
ChatGPT (OpenAI) was used to assist with language editing, including improving grammar, clarity, and overall readability in selected sections of the manuscript, particularly the Introduction, Discussion, and Conclusion. The AI tool was not used for data analysis, data interpretation, or generation of scientific content. All AI-assisted text was carefully reviewed, revised, and validated by the authors, who take full responsibility for the accuracy, integrity, and originality of the final manuscript.

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