School-based healthy eating interventions for adolescents aged 10-19 years: An umbrella review

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Abstract

Background: The benefits of healthy eating are well known, yet adolescent diet is often poor. School based interventions offer a promising option to promote healthy eating, however, evidence is unclear.

Aim: This umbrella review synthesised the current evidence on school-based interventions for healthy eating in adolescents (10-19 years old).

Methods: Using Joanna Briggs Institute (JBI) umbrella review guidelines, a systematic search was conducted on 11 electronic databases (PubMed, CINHAL, EMBASE, Science Direct, PsycINFO, MEDLINE, Scopus, ERIC, Web of Science, Cochrane Register of Systemic Review and JBI Evidence Synthesis) to identify reviews published between January 2000 and December 2023. Methodological quality was assessed using JBI critical appraisal tool. A narrative synthesis was conducted informed by the World Health Organisation's Health Promoting School (HPS) framework that categorises school-based interventions into three components i.e., health education, school environment changes, and family and community involvement.

Results: Seventeen reviews were identified (including 347 unique primary studies) that were published between 2008 and 2023. 87% of the reviews were based on interventions in high- income countries, limiting applicability to low- and middle-income countries. Fourteen reviews were rated as high, two as moderate, and one was rated as low methodological quality. Evidence from 71% of the reviews (n=14 reviews, 13=high methodological quality) found that multi-component interventions (i.e., interventions incorporating more than two components of the HPS framework) improved adolescents' knowledge and behaviour concerning healthy eating. At the individual level, tech-driven healthy eating curricula effectively improved eating behaviours of adolescents. These individual-level interventions proved to be more effective and sustainable when supported by system-level changes, such as modifying school environments including increased availability of healthy foods and involving parents to promote healthy eating for adolescents. However, limited evidence from only three reviews suggests mixed feasibility for technology-based interventions and lower feasibility for multi-component interventions. The lack of information on stakeholder involvement in intervention design is another critical evidence gap.

Conclusion: School-based multi-component healthy eating interventions that combine individual-level interventions with system-level changes are effective in promoting healthy eating behaviours among adolescents. Future reviews should assess the effectiveness of participatory approaches in intervention design, feasibility and scale-up studies, and analysing evidence from low- and middle-income countries.

Keywords: review, healthy eating, school, adolescents

Introduction

Healthy eating is essential for adolescents' physical and mental development, providing the calories and nutrients needed to support their growth, development, and the maintenance of an active lifestyle throughout their lives (1,2). Unhealthy eating contributes to obesity and associated health issues among adolescents such as growth retardation, impaired organ development, micronutrient deficiencies, and later in life can lead to non-communicable diseases (NCDs) including cardiovascular diseases, diabetes mellitus, and hypertension (3–7). Adolescents (aged between 10 and 19 years old) (8) need to consume a daily intake of 2200 to 3000 calories, with a balanced distribution of macronutrients, including carbohydrates (45-65% of total energy intake), protein-rich foods, such as fish and meat (10-30%), and fats (25-35%) (9,10). Diets should also include at least five servings of fruits and vegetables (FV) rich in vitamins, minerals and fibre, 2.5-3 servings of dairy products and limit the intake of added sugar (less than 10% of total energy intake) and high fat foods (9,10).

Adolescents in both low- and middle-income countries (LMICs) and high-income countries (HICs) frequently have diets that are calorie-dense yet nutrient-deficient, marked by excessive consumption of sugar-sweetened beverage (SSB), ultra-processed foods, and insufficient intake of FV (11–13). Ultra-processed foods are laden with added sugars, salt and harmful fats, and are deficient in essential nutrients like dietary fibre, vitamins, and minerals (14). These should be avoided as they pose significant health risks including increased risk of cardio-metabolic events (14). A meta-analysis examining the Global School-based Student Health Surveys from 2008 to 2015 including Africa, Asia, Oceania, and Latin America revealed that 35% of adolescents do not meet the recommended intake of FV, 43% consume sugary sweetened beverages (SSBs) daily, and 46% eat processed foods at least weekly (12). Furthermore, a recent UNICEF report drew attention to the low FV intake among adolescents worldwide (13). The prevalence of meal skipping

among adolescents, especially breakfast, has also been linked to increased fast food consumption(15,16).

School can play a critical role in promoting healthy eating among adolescents. Broadly speaking, school-based healthy eating interventions use two approaches: individual-level interventions, which tailor curricula to influence adolescents' behaviours, and system-level interventions, which embed strategic actions into daily life to modify school policies (17). The World Health Organisation's (WHO) Health Promoting School (HPS) framework (18) provides a comprehensive approach to promoting healthy eating in schools, encompassing three key components: health education, school environment modifications, and engagement with families and communities. However, despite there being a plethora of school-based intervention, including many reviews, there is a lack of synthesised evidence on the diverse components and contents of these interventions and their impact on adolescents' eating behaviour. The existing literature has not adequately explored the effectiveness of specific intervention strategies within each component of HPS. One umbrella review assessed school-based healthy eating interventions focusing on behaviour changes in children aged 6 to 18 years, it did not present results separately for adolescents (19). This is important as adolescents have unique developmental needs and challenges that require tailored intervention approaches. The lack of adolescent-specific evidence limits the ability to design and implement interventions that effectively address the unique barriers and facilitators to healthy eating in this age group. Moreover, the umbrella review's omission of a synthesis of the interventions' specific components and their respective contents constitutes a notable evidence gap that merits further exploration (19). The comprehensive synthesis of intervention components and their respective contents is crucial for understanding the effectiveness, generalisability, and replicability of these interventions (20). This umbrella review addresses these evidence gaps by synthesising evidence from reviews evaluating school-based healthy eating interventions targeting adolescents. This review will provide insights to inform the development and implementation of evidence-based, tailored interventions that promote sustainable healthy eating among adolescents in school settings.

Materials and Methods

This umbrella review followed the Joanna Briggs Institute's (JBI) methodology for umbrella reviews (21) and is reported in accordance with the Preferred Reporting Items for Overviews of

Reviews (PRIOR) (22) (Supplementary file A). The umbrella review protocol is registered with the PROSPERO database for systematic reviews (CRD42022338762).

Eligibility criteria

Our population of interest were adolescents aged 10 to 19 years. Reviews on broader age range were included if they reported data for adolescents separately. School-based interventions promoting healthy eating were included, and interventions promoting other healthy behaviours such as physical activity were included only if outcomes related to healthy eating were reported separately. Comparison groups included no intervention, or comparison to one or more other interventions. Reviews using standardised measures, such as changes in healthy eating knowledge and behaviours among adolescents, were included and those that reported non-dietary or non-nutritional outcomes such as obesity, unhealthy weight, anthropometric measurements, BMI, metabolic outcomes, and physical activity, were excluded. Reviews were selected if they reported both dietary and non-dietary outcomes separately, based on specific primary studies included in their analysis. This criterion ensured that reviews providing distinct information on outcomes regarding healthy eating knowledge and behaviour were included in our study. All types of reviews were included- systematic reviews with or without meta-analyses, narrative reviews, scoping reviews, rapid reviews, critical reviews, and integrative reviews. Peer-reviewed published reviews were considered, while protocols, conference abstracts and proceedings, commentaries, editorials, unpublished reviews, or reviews published as grey literature were excluded. We included reviews published between 1st January 2000 and 31 December 2023 and written in English.

Search strategy

Database search

Eleven electronic databases were searched: PubMed, Cumulated Index to Nursing and Allied Health Literature (CINHAL), Excerpta Medica dataBASE (EMBASE), Science Direct, Psychological Information Database (PsycINFO), Medical Literature Analysis and Retrieval System Online (MEDLINE), Scopus, Education Resources Information Center (ERIC), and Web of Science, Cochrane Register of Systemic Review, and JBI Evidence Synthesis.

Search terms

Keywords for school-based interventions and healthy eating were discussed among the research team and further refined by consulting with a senior librarian at King's College London. The search

strategy was then piloted in PsycINFO, via Ovid, and Scopus before search terms were finalised (Supplementary file B).

Review screening

Records identified from database search were exported to Rayyan (23). After removing duplicates, titles and then abstracts were reviewed against the eligibility criteria by two independent reviewers (NS and FN). Full texts of eligible records were reviewed independently by NS and FN. The reasons for exclusion were recorded. Any discrepancies were resolved by consensus between the two reviewers and when required, a third reviewer (LB or DP or FA) was consulted. To assess the extent of overlap between reviews, we created a citation matrix following Cochrane guidelines (24) (Supplementary file C). We included all relevant reviews in our study, even if they shared some primary studies. However, we found no instances where one review completely overlapped with another in terms of primary studies.

Quality appraisal

The included reviews were appraised using the standard JBI critical appraisal tool by two independent reviewers (NS and FN). Seventy per cent of these were checked by another researcher (LB or DP). The tool consisted of 11 questions (responses: “Yes”, “No”, “Unclear” or “NA”). The overall score of a review was calculated by summing the affirmative answers (range 0-11 points). This tool does not mention cut-off points for categorising the quality of systematic reviews (21), hence, we applied these cut-off points: high quality (≥8 "Yes"), moderate quality (5-7 "Yes"), and low quality (≤4 "Yes") (Supplementary file D).

Data extraction

We extracted the following data from the included reviews: author and date, publication year, type of review, total number of included studies, age groups of the study participants, countries of the primary studies, study designs, studied interventions (components, contents, duration), outcome, and key findings. Data were extracted independently by two researchers (NS and FN), and 70% of the extracted data was checked by a third researcher (LB or DP). We adopted the Template for Intervention Description and Replication (TIDieR) framework to identify the intervention components, i.e., distinct element of the overall intervention strategy, and intervention ‘content’, i.e., specific materials, procedures, activities, and information that are provided or used within each component of the intervention (25).

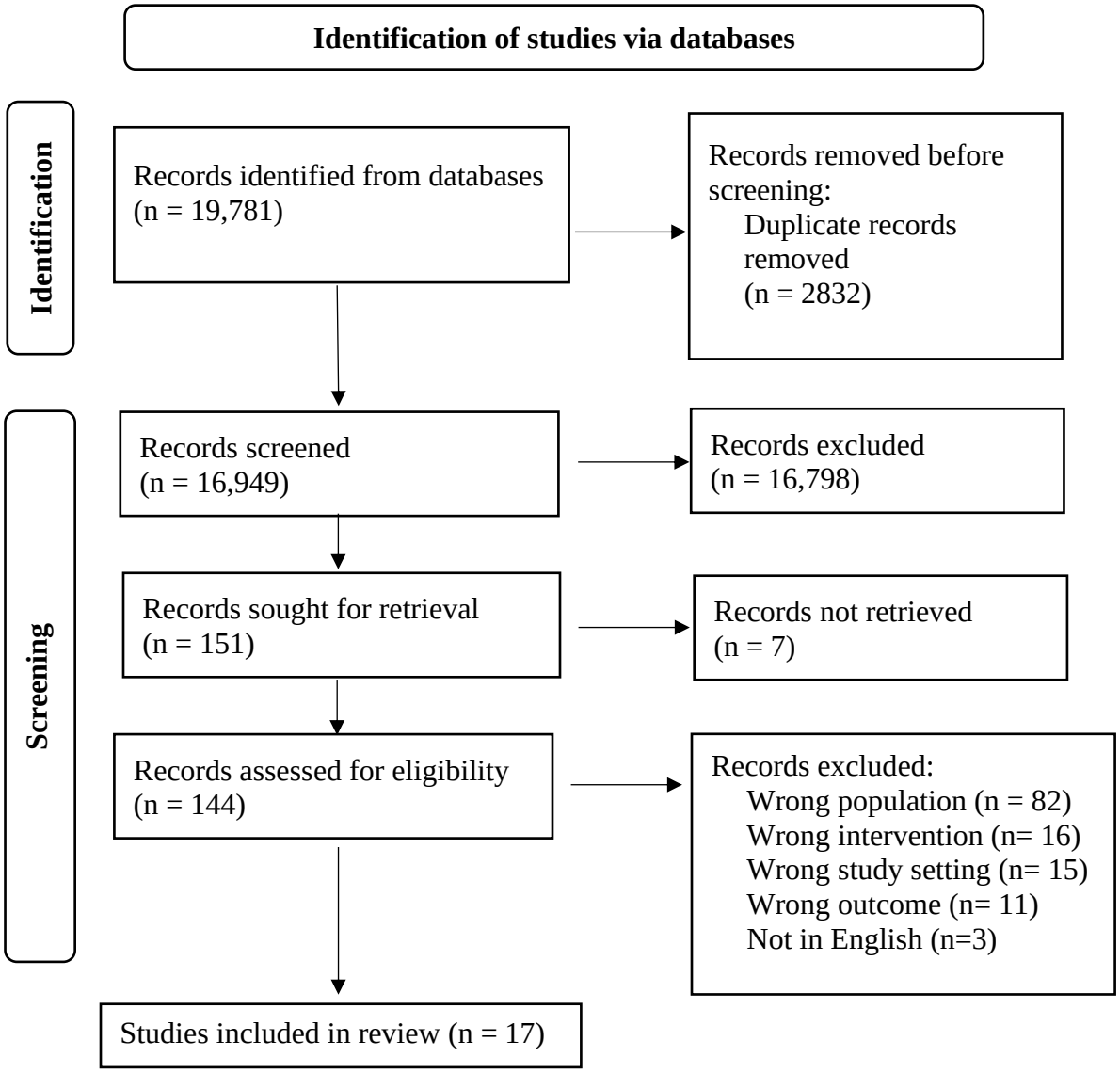
Data synthesis

We conducted a narrative synthesis of the finding (26). We categorised the intervention components according to the World Health Organisation's (WHO) Health Promoting School (HPS) framework and interventions with two or more components were categorised as multi-component interventions (18). We reported findings on the effectiveness of eating knowledge and behaviour outcomes according to a framework previously employed in a Cochrane overview of reviews framework (19,27). This framework evaluates the effectiveness of interventions as (19,27): "Likely effective" if evidence supporting intervention effectiveness is based on meta-analysis or narrative synthesis of all primary studies; "Promising" if evidence of effectiveness is based on over 50% of primary studies but requires further confirmation; "Probably ineffective" if majority of the primary studies results are ineffective; "Ineffective" if findings in all primary studies are found to be ineffective; and "Inconclusive" if there is inadequate evidence on effectiveness. Additionally, we applied the Behaviour Change Technique Taxonomy (BCTT) to identify effective combinations of intervention components for promoting healthy eating behaviours among adolescents (28).

Results

A total of 19,781 records were identified through database searching (Figure 1). After deduplication, 16,949 titles and abstracts were screened, and 151 reports were identified for full text screening. Out of 151 full text reports, four could not be retrieved because they were in conference proceedings. Remaining 144 full-text reports were assessed for eligibility, and 17 reviews were included in this umbrella review.

Figure 1: PRIOR Flow diagram



Characteristics of included reviews

The 17 included reviews were published between 2008 and 2023 and included studies published between 1987 and 2020 (Table 1). A total of 347 unique primary studies were captured in these 17 reviews. Fifteen of the reviews used narrative synthesis (29–43) and two included both meta-analysis and narrative synthesis (44,45). Two reviews included primary studies with a broader age range, but synthesised results for adolescents separately (32,34). We incorporated these adolescent-specific findings in our synthesis. Majority of the reviews (n=14) evaluated multi-component interventions (30–32,34–40,42–45) while three reviews evaluated only health education interventions (29,33,41). All the reviews included studies based in HICs, and only eight reviews included a few studies based in five LMICs (30,35–38,42,43,45). Several tools were used to measure the outcomes of the interventions. According to the JBI critical appraisal tool, 14 reviews scored high (30–32,34–41,43–45), two reviews scored moderate (33,42), and only one review scored low (29) in terms of methodological quality (Table 2).

Table 1: Characteristics of the included reviews (n=17)

Author; Year;	Type of reviews	Total number of unique primary studies included; publication period	Population Age range	Included countries	Outcomes	Outcome measures
Alcântara et al., 2018 (29)	Integrative review	8; 2004-2016	10-19 years	HICs: France, Italy, US	Knowledge about health eating, and intake of FV, processed snacks, and SSB	Survey
Bailey CJ et al., 2019 (36)	Systematic review	44; 1996-2016	10-19 years	HICs: Australia, Canada, China, Denmark, France, Greece, Northern Ireland, Norway, Portugal, South Africa, Sweden, UK, US LMICs: India, Iran, Kenya	Eating knowledge, FV, processed snacks intake,	FFQ, 24 h dietary recalls, interviews, focus groups, audio/video-taping, observations, surveys
Calvert S et al., 2019 (37)	Systematic review	29; 1987-2017	11-16 years	HICs: Australia, Belgium, Canada, China, Denmark, England, Greece, Israel, Netherlands, Norway, Spain, Taiwan, US LMIC: Tunisia	FV, processed snacks, SSB, calorie, fat, protein, fibre, vitamins, frequency of regular meal consumption,	FFQ, 24-h recall
Champion KE et al., 2019 (44)	Systematic review and meta-analysis	13[a]; 2003-2017	Mean: 13.41 years	HICS: Belgium, Mexico, Netherland, Spain, US	Eating knowledge, FV intake, fat, fibre, processed snacks, SSB,	Self-administered survey, FFQ, 24-h recall, 3-day food record

Author; Year;	Type of reviews	Total number of unique primary studies included; publication period	Population Age range	Included countries	Outcomes	Outcome measures
Hackman et al., 2014 (38)	Systematic review	11; 2005-2013	10-19 years	HICs: Australia, Canada, England, Greece, US, Scotland, South Africa LMIC: Iran	FV intake, processed snack, frequency of breakfast consumption, stay in school for lunch	24-h recall, cognitive and attitudinal assessments, food diary, FV recall, number of days stayed, bought, ate school for lunch, snack scale, FFQ
McHugh C et al., 2020 (39)	Systematic review	4[b]; 1998-2016	11-18 years	HICs: Finland, US	FV, fat	24-h recall, self-administered KAP survey
Medeiros et al., 2022 (45)	Systematic review and meta-analysis	24; 1997-2019	10-19 years	HICs: Belgium, Brazil, China, Ecuador, Finland, Greece, Italy, Netherland, Norway, Trinidad Tobago, UK, US LMIC: Iran	FV, processed snacks, intake	FFQ, 24-h recall, 7-day food survey, KAP
Meiklejohn et al.; 2016 (40)	Systematic review	13; 2002-2013	10-18 years	HICS: Australia, Belgium, Finland, Greece, Netherland, Norway, Spain, Sweden, US	FV, processed snacks, water, protein intake,	FFQ, 24-h recall
Melo GRDA e al., 2017 (41)	Systematic review	11; 2007-2015	10-17 years	HICs: Austria, Australia, Belgium, Denmark, Germany, Greece, Netherlands, Spain, Sweden, Taiwan, UK, US	Eating knowledge, FV, SSB, processed snacks, fat intake,	FFQ
Nakabayashi J et al., 2020 (42)	Systematic review	14; 2003-2019	10-17 years	HICS: Belgium, Brazil, England, Malaysia, Mexico, Spain, Turkey, US	FV, fat, calorie intake,	FFQ, 5-day recall, food diary

Author; Year;	Type of reviews	Total number of unique primary studies included; publication period	Population Age range	Included countries	Outcomes	Outcome measures
				LMIC: Iran		
Pierre CS et al., 2021 (43)	Systematic review	53; 2005-2019	10-14 years	HICs: Aruba, Australia, Canada, China, New Zealand, US LMIC: Ethiopia	Eating knowledge, FV, SSB, frequency of breakfast consumption, willingness to try healthy foods	Surveys and focus groups
Rose K et al., 2021 (31)	Systematic review	27; 2009-2019	12-18 years	HICs: Denmark, France, Finland, Greece, Italy, Netherlands, Norway, Portugal, Spain, UK, Turkey	Eating knowledge, FV, processed snacks, SSB, calorie, water intake, frequency of meal consumption, food choice competency	survey, cashless system- transactions from point of sale/till, freestanding interactive computer terminals
Sa JD & Lock K, 2008 (32)	Systematic review	7[c]; 1999-2007	11-18 years	HICs: Belgium, Norway, US	FV intake	FFQ, 24 h recall, KAP
Shinde et al., 2023 (30)	Systematic review	27[d]; 2006-2020	10-19 years	HICs: Brazil, China, Malaysia, Palestine, Turkey LMICs: Ethiopia, India, Iran	Eating knowledge, FV, processed snacks, SSB, breakfast frequency	Not reported
Tallon JM et al., 2019 (33)	Systematic review	13; 2004-2018	12-18 years	HICs: Belgium, Denmark, UK, US	Eating knowledge, FV, fat, meal frequency	Not reported

Author; Year;	Type of reviews	Total number of unique primary studies included; publication period	Population Age range	Included countries	Outcomes	Outcome measures
Van Cauwenberghe et al., 2010 (34)	Systematic review	13[e]; 1991-2008	13-18 years	HICs: Belgium, Denmark, France, Italy, Netherlands, Norway, Sweden, UK	FV, fat, water, SSB, fish	Food diary, 24-h recall, FFQ, self-reported questionnaire, observation, sales data
Vézina-Im LA et al., 2017 (35)	Systematic review	36; 1989-2016	12-17 years	HICs: Australia, Belgium, Brazil, Canada, China, Korea, Netherlands, US LMICs: India	SSB consumption	FFQ, 24-h recall, web-based self-administered survey

HICs: High Income Countries; LMICs: Low- and middle-income countries; FV: Fruits and Vegetables; SSB: Sugar-sweetened Beverage; FFQ: Food Frequency Questionnaire; a: out of 22 unique primary studies assessing different health outcomes, 13 specifically reported on healthy eating outcomes; b: out of 12 unique primary studies assessing different health outcomes, four specifically reported on healthy eating outcomes; c: out of 30 unique primary studies assessing healthy eating outcomes for children and adolescents, seven reported on adolescents aged 11 to 18 years; d: out of 68 unique primary studies, 27 specifically reported on healthy eating outcomes; e: out of 42 unique primary studies assessing healthy eating outcomes for children and adolescents, 13 specifically reported on adolescents

Single-component interventions

Out of 17 reviews, three reviews (29,33,41), comprising a total of 32 unique primary studies, focused on single-component individual-level interventions (Table 2). The methodological quality of these reviews was mixed: one study was rated as high (41), one as moderate (33), and one was rated as poor methodological quality (29). These reviews exclusively synthesised data from HICs. All the three reviews focused on promoting health eating and included some tech-driven curriculum, i.e., the integration of technological tools into educational practices. The contents included lessons on nutrition, personal diet recommendations, gamified learning experiences (such as levelling up based on healthy eating knowledge and behaviour), cooking recipes, and an app to record daily food intake. Only one review (38) reported on the theoretical frameworks that underpinned interventions - the social cognitive theory (SCT), social learning theory (SLT), and theory of reasoned action (TRA). The intervention duration, ranged from two to 10 weeks (30,38) and the timing of follow up assessments ranged from immediately after intervention to three years after the intervention (30,38). Primary outcomes for these reviews were healthy eating knowledge and behaviour such as consumption of FV, dairy, meat and fibre, tendency to skip meals and intake of processed snacks and SSBs (26,30,38). Two reviews (26,38) used the food frequency questionnaire (FFQ) to measure outcomes and the third review did not report such tools (30). Applying the effectiveness categorisation framework (25), these interventions were considered "likely effective" in improving both knowledge about healthy eating and actual eating behaviours. Two reviews (26,38) reported on acceptability of the tech-driven curriculum and reported there was higher participation and engagement by adolescents. These reviews also found that these interventions improved accessibility overall and were equitable as they were able to engage adolescents with low resources. Flexible participation, time-saving and the ability to customise content by language were key features that improved the feasibility of these interventions (26,38). The combination of three BCTT hierarchical clusters was "likely effective", as reported by only one review with high methodological quality: feedback and monitoring (SMS-based diaries); shaping knowledge (computer-tailored workshops); and associations (SMS) (Supplementary file E).

Table 2: Evidence on single component (healthy eating education) interventions

Author; Year	Intervention design of studies included in the review	Interventions description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
Alcântara et al., 2018 (29)	**Study design:** RCT (n=5), quasi-experimental (n=2), mixed-methods (n=1) **Theories:** Not reported	**Components:** computer-tailored workshops, virtual canteen, blogs, games **Contents:** lessons on nutrition, personal healthy eating dietary recommendations, and gamified learning experiences, such as level up based on healthy eating knowledge, eating behaviour, intake measures **Duration of intervention:** Not reported **Follow-up range:** Not reported	All included reviews reported improved healthy eating knowledge, increased FV intake, decreased intake of processed snacks and SSBs	Likely effective; 4 (low quality)
Melo GRDA e al., 2017 (41)	**Study design:** RCT (n=7), quasi-experimental (n=4) **Theories:** SCT, SLT, TTM, TPB, TRA	**Components:** computer-tailored workshops, , SMS, SMS-based diaries **Contents:** nutritional lessons and dietary guidance, healthy cooking recipes via handbooks, guidance leaflets, and sending timed SMS for users to report food intake, real-time tracking and feedback on eating behaviour, as contents of SMS-based diaries **Duration of intervention:** 2-10 weeks **Follow-up range:** 2 weeks to 2 years	All the included studies reported improved healthy eating knowledge, increased intake of FV, dairy, meat, and fibre, decreased intake of processed snacks and SSB	Likely effective; 9 (high quality)

Author; Year	Intervention design of studies included in the review	Interventions description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
Tallon JM et al., 2019 (33)	**Study designs:** Not reported **Theories:** Not reported	**Components:** workshops, games, SMS-based diary apps**Contents:** healthy eating knowledge and advice, app to to measure and monitor daily food intake **Duration range:** not reported **Follow-up range:** 1 month to 3 years	All included studies reported improved healthy eating knowledge and behaviour with increased FV, decreased fat intake, decreased meal skipping	Likely effective; 6 (moderate quality)

RCT: Randomised Control Trial; SCT: Social Cognitive Theory; SLT: Social Learning Theory; TTM: Transtheoretical Model; TPB: Theory of Planned Behaviour; TRA: Theory of Reasoned Action; SMS: short message service

Multi-component interventions

Fourteen reviews, including 313 unique primary studies, assessed interventions with at least two components: healthy eating education, changes to the school environment, and family involvement (Table 3). Thirteen reviews were rated as high, and only one was rated as moderate methodological quality. These reviews mostly included studies based in HICs. Eight reviews among these 14 included primary studies based in five LMICs (30,35–38,42,43,45).

Two high-quality reviews (including 80 unique primary studies) found that interventions incorporating all three components of the HPS framework, were "likely effective" in improving healthy eating knowledge and behaviour, particularly increased consumption of FV and water, reduced consumption of SSB, total daily calories, regularly eating breakfast and other meals, willingness to try healthy foods, and improved food choice competency in HICs (31,43). One of these reviews included a single study from an LMIC, Ethiopia (43).

The **healthy eating education** components at the individual level, included lectures, tailored leaflets, handbooks, text messages, board games, drama, mobile health counselling, healthy eating club, and motivational visits from athletes and other role models. The contents involved healthy eating information, nutrition, healthy cooking lessons, club activities, such as healthy eating photography.

The **school environment change** components at the system level, included school-wide marketing and canteen modification with contents involving healthy food promotion and increased availability of healthy foods in schools. In the context of healthy eating interventions in our included reviews, both terms "canteen" and "cafeteria" refer to the main food service area in a school. We have used "canteen" consistently throughout.

The **family involvement** components at the system level, included parents' meetings and homework with contents on healthy eating information and feeding healthy foods at home.

Only one of the reviews (43) commented on the theoretical models on which the interventions were based - trans-theoretical model (TTM), SCT, theory of planned behaviour (TPB), and

attitudes social influence self-efficacy (ASE) model. Interventions in studies in these reviews ranged from one to 18 months. The outcomes were measured by surveys, focus groups, or sales transactions (31,43). Components related to the school environment, such as increased availability of healthy foods and parental involvement requires resources for implementation and so were found to be less feasible (31).

There were promising effects of multi-component interventions on healthy eating behaviour reported in seven high-quality (30,32,35–38,45) and one moderate-quality reviews (42) (including 192 unique studies) (30,32,35–38,42,45). The primary outcomes for these reviews were intake of FV (30,32,36–38,42,45), processed snacks (30,36–38,45), SSB (30,35,37), fat (37,42), protein, fibre and vitamins (37), frequency of regular meals (30,37,38), recommended calorie intake (37,42), healthy eating knowledge (30,36), and staying in school for having healthy lunch (38). These reviews mainly focused on interventions in HICs - only 11 primary studies were from LMICs (Ethiopia, India, Iran, Kenya, and Tunisia) (30,35–38,42,45). One review (including 14 unique studies) included healthy eating education and family involvement (42), one review (including 44 unique studies) included healthy eating education and environmental changes (36), and rest six reviews (including 134 unique studies) included all the three components of the HPS framework (30,32,35,37,38,45).

The **healthy eating education** components at the individual level, included lectures (30,32,36,38,42,45), quizzes and games (30,36,38), media shows (37), plays, electronic messages, rewards, peer-leading activities and training for teachers (38). The contents involved lessons on healthy eating (32,37,38,42,45), food labelling, healthy cooking (30,36), consequences of SSB intake (35), nutrition, food safety farmers' visits on healthy food cultivation (36), menu planning, healthy eating goal setting and self-monitoring, healthy food as rewards, and food tasting (38).

The **school environment change** components at the system level, involved FV gardening (32,36), school food marketing (38,45), canteen modifications (30,36), vending machine modifications (35), postering (45), workshops with kitchen staff (36), and loyalty programs (32). The contents involved increased availability of milk and protein (32,35–38,45) and fresh fruits (30), free or

subsidised FV (35), replacing SSB with healthier alternatives (milk, water, juice) in vending machines (35), chef, staff consultations on healthy culinary lessons (36), and healthy eating posters around school (45).

The **family involvement** components at the system level included communicating with families via newsletters (30,32,35,37,38), leaflets (30,45), emails (35,37), booklets (30), brochures (30) and texts (37), organising parents' meetings (35,45), in-school learning sessions, food coupons (37) and social support groups (35), and providing parents recipe guides (30). The contents involved information on healthy eating knowledge (30,32,35,38,42,45), healthy cooking, feeding healthy foods to children at home (37), nutritional guidelines (38), coupons to purchase healthy foods (37), offering FV and free healthy foods (45).

The interventions within the studies were informed by several theoretical models - SCT (30,35,36,45), TPB (30,35,38,45), TTM (36,42,45), health belief model (30,36), TRA (30,38), pedagogy of the oppressed by Paulo Freire (30,45), socio-ecological model (SEM) (30,45), self-regulation theory (SRT) (35,45), ASE Model, the action planning literature, Bloom's mastery of learning model, Bronfenbrenner's ecological theory (45), cognitive behavioural theory (30), health action process approach (30), HPS (30), diffusion of innovation theory (DIT) (40), expectancy theory (40), self-determination theory (40), elaboration likelihood model (35), and theory of interpersonal behaviour (35). The outcomes were measured by FFQ (32,35–38,42,45), 24 h dietary recalls (32,35–38,45), food diary (38,42), knowledge attitude practice (KAP) survey (32,45), cognitive and attitudinal assessments (38), FV recall, number of days stayed, bought, ate healthy lunch at schools, snack scale (38), and 7-day recall (45), or 5-day food recall (42). The intervention duration ranged from 15 minutes to 10 years (30,36–38,42,45) and time of the follow up assessments ranged from immediately to four years after the intervention (30,32,36,37,42).

Four high-quality reviews (including unique 43 studies) reported "inconclusive" impacts on eating knowledge and behaviour, particularly in terms of healthy eating knowledge (44), intake of FV (34,39,40,44), recommended fat (34,39,44), water (34,40), processed snacks (40,44), protein (40), fibre (44), and SSB (34). These reviews exclusively focussed on interventions in HICs.

The **healthy eating education** components included lectures (34,39,40), group discussions (40,44), games (39,44), distribution of materials via compact discs (CDs), videos, emails, and text messages, blogs by a health coach (44), workshops for staff and students (39), and drama (40). The contents involved healthy eating lessons (34,39,40,44), food preparation, and taste testing (40).

The **school environment** components, working at the school system level, included canteen modifications (34,39), food distributions (34), reduced price of fruits (44), social food marketing, staff trainings (39), loyalty programmes (34,39), gardening, postering, and vending machine modifications (40). The contents involved FV subscriptions (34,40), increased availability of healthy food in canteen (34,39), FV plantation (40), incentives to purchase healthy foods (34), staff training on healthy cooking healthy eating poster (39), healthy eating posters around schools (40), enhanced lunch sessions with healthy meals, and replacing SSBs with healthy foods (40).

The **family involvement** components included parents' meetings and workshops (34,39,40), distribution of newsletters, CDs, magazines, calendars (39,40,44), engaging parents in school nutrition council groups (39), and loyalty programmes (39,40). The contents involved healthy eating lessons (34,39,40,44), incentives to purchase healthy foods (34,39), money rewards for purchasing healthy foods (40), cooking recipes (39), and healthy feeding to children (40).

The studies assessed in these four reviews employed RCTs (n=39) (34,39,40,44), non-RCTs (n=16), cohort (n=7), pre-post (n=7) (34), and quasi-experimental (n=2) designs (44). The interventions were informed by TPB (34,39,40,44), SCT (39,40,44), TTM (39,44), ASE model, principles of interactive technology, SLT, health promotion model (Pender's) (44), SEM, DIT, control theory, information-motivation-behavioural skills model (39), and community-based capacity building approach (40). These outcomes were measured by 24-h recall (34,39,40,44), FFQ (34,40,44), KAP (39), and 3-day food record (44). The intervention duration ranged from 12 hours to three years (34,39,40,44) and only one review reported follow up assessments occurred ranged from immediately to three years after the intervention (34,39,40,44).

Although none of the reviews mentioned that key stakeholders were involved in the intervention design process, only four reviews mentioned that engaging adolescents and key stakeholders in designing and implementing interventions is crucial to ensure their effectiveness (31,33,43,44).

Overall, the combination of three BCTT hierarchical clusters was “likely effective”, as reported by two reviews with high methodological quality: shaping knowledge (workshops, games for students, homework for parents); associations (nutri-advice kiosks, entertainments such as drama, visits by inspiring personalities, SMS, emails, counselling via mHealth i.e., nutritional behavioural counselling); and antecedents (healthy eating club, school food marketing, canteen modification, such as increased availability of healthy foods, reduced fruit prices, parents’ meeting) (Supplementary file E).

Table 3: Evidence on multi-component interventions

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
Bailey CJ et al., 2019 (36)	**Study design:** cross-sectional (n= 16), quasi-experimental (n=13), qualitative (n=7), mixed methods (n=4), pre–post intervention (1), RCT (n=1), longitudinal cohort (n=1), observational (n=1) **Theories:** SCT, TTM, TPB, HBM	**Healthy eating education components:** workshops, nutri-advice kiosk, cooking classes, quiz, games, field visits <u>*Contents:*</u> nutrition education, food safety, reading nutritional labels, healthy food purchase knowledge, farmers to visit schools to interact on healthy food cultivations **School environment change component:** school gardening, workshops with kitchen staff, canteen modification **Contents:** FV gardening, culinary lessons for kitchen staff and on-site chef consultations on healthy cooking, FV, milk, meat provision in canteen **Duration of interventions:** 1 week to 10 years **Follow-up range:** immediate to 2 years	97% of the included studies reported improved healthy eating knowledge, increased FV, decreased processed snacks intake	Promising; 8 (high quality)
Calvert S et al., 2019; (37)	**Study design:** RCT (n=19), quasi-experimental (n=7), cohort (n=3) **Theories:** Not reported	**Healthy eating education components:** workshops, quiz, self-evaluation diary, self-assessment homework, entertainments, media shows (radio/TV), practical culinary lessons <u>*Contents:*</u> healthy eating education, handbooks, worksheets, (e.g. problem solving, goal setting on healthy eating), computerised feedback, healthy cooking, media shows **School environment change components:** canteen modification <u>*Contents:*</u> increased availability of healthy foods	83% of the included studies reported increased FV, decreased SSB, fat, and processed snack intake, improved intake of recommended calories and protein	Promising; 8 (high quality)

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
		Family involvement components: workshops, SMS, emails, homework, coupons *Contents:* information on healthy eating, heathy cooking via newsletters, feeding healthy foods to children, coupons for healthy food purchase **Duration of interventions:** 2 weeks to 3 years **Follow-up range:** 1 week to 4 years		
Champion KE et al., 2019 (44)	**Study design:** RCT (n=14), quasi-experimental (n=2) **Theories:** ASE model, Principles of interactive technology, SCT, SLT, TTM, TPB, HPM (pender's),	**Healthy eating education components:** online discussion boards, online games, SMS, emails, blog by health coach *Contents:* healthy eating lessons, knowledge and information via compact disc (CD), videos **School environment change component:** reduced price of fruit **Family involvement component:** healthy eating information handouts *Contents:* healthy eating information via newsletters, CD **Duration of interventions:** 1 month to 3 years **Follow-up range:** Immediately after intervention to 2 years	Inadequate evidence in improving healthy eating behaviour across all studies	No conclusion; 9 (high quality)

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
Hackman et al., 2014 (38)	**Study design:** RCT (n=8), quasi-experimental (n=2), pre-post (n=1) **Theories:** TRA, TPB	**Healthy eating education components:** workshops, conference, campaign, games, quiz, SMS, entertainment, rewards *Contents:* healthy eating lessons, healthy cooking lesson, healthy menu planning, healthy foods as rewards, role play, creative writing on healthy eating, poster, comic workbooks, theatre play **School environment components:** school food marketing, food provision *Contents:* provision of FV, taste testing, healthy food promotion in school **Family involvement components:** healthy eating information handouts *Contents:* nutritional needs for adolescents via newsletters **Duration of interventions:** 15 minutes to 1 year **Follow-up range:** not reported	88% of included studies reported improved healthy eating knowledge and behaviour with increased FV, decreased snacks, high fat, SSB intake, increased intention for eating lunch in school	Promising; 8 (high quality)
McHugh C et al., 2020 (39)	**Study design:** RCT (n=9) **Theories:** SCT, TTM, TPB, SEM, Diffusion of innovation theory, ASE model, control theory, IMBSM	**Healthy eating education components:** workshops for staff and students *Contents:* food and nutrition lessons, drama workshops on healthy eating **School environment change components:** canteen modification, social food marketing, staff training *Contents:* restriction of unhealthy foods, increased FV and healthy snacks, healthy food promotion, staff training on healthy cooking **Family involvement components:** events with parents (meetings, workshops, invite to school meals, including them in school nutrition council group), healthy eating information handouts, loyalty programs	Inadequate evidence in improving healthy eating behaviour across all studies	No conclusion; 8 (high quality)

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
		Contents: adolescents' healthy eating, healthy cooking recipes, healthy eating information via calendars, newsletters, magazines, incentives to purchase healthy foods **Duration range:** 8 months to 3 years **Follow-up range:** 1-3 years		
Medeiros et al., 2022 (45)	**Study design:** RCT (n=24) **Theory:** Self-Regulation Theory, ASE Model, The action planning literature, Pedagogy of the Oppressed, by Paulo Freire, SCT, SEM, Bloom's mastery of learning model, Bronfenbrenner's ecological theory, TPB, TTM	**Healthy eating education components:** workshops *Contents:* healthy eating lessons **School environment change components:** canteen modification, postering, media marketing of healthy foods *Contents:* provision of healthy foods including FV, healthy eating posters around school premises, campaign on healthy eating **Family involvement components:** parents meeting, workshops, free healthy foods provision, *Contents:* healthy eating information discussion, leaflets, offering FV **Duration range:** 2 months to 3 years **Follow-up range:** Not reported	70% of the included reviews reported increased intake of FV, protein, healthy snacks	Promising; 11 (high quality)
Meiklejohn et al.; 2016 (40)	**Study design:** RCT (n=13) **Theories:** SCT, TPB, Community-based capacity building approach	**Healthy eating education components:** workshops, games, entertainment *Contents:* healthy eating knowledge based lessons, food preparation, taste testing, drama **School environment change components:** gardening, postering, canteen modification, loyalty program	Inadequate evidence in improving healthy eating behaviour across all studies	No conclusion; 9 (high quality)

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
		Contents: FV gardening, posters display in lunch room on healthy eating, enhanced lunch session with healthy meals, replacing processed foods and SSBs with healthy foods and juice in vending machines, subscriptions (paying for regular access) to FV **Family involvement components:** parents' meeting, loyalty program, healthy eating information handouts *Contents:* discussion on FV intake, meal preparation, money rewards for healthy feeding to their children, healthy eating information via newsletter, fact sheets, brochure, CD, magazine **Duration range:** 12 hours to 12 weeks **Follow up range:** immediately after intervention to 2 years		
Nakabayashi J et al., 2020 (42)	**Study design:** RCT (n=8), quasi-experimental (n=6) **Theory:** TTM	**Healthy eating education components:** workshops *Contents:* healthy eating knowledge, behaviour, and goal setting worksheets **Family involvement components:** healthy eating information handouts SMS *Contents:* healthy eating behaviour, nutritional guidelines for adolescents via magazines, letters **Duration range:** 1 hour to 3 years **Follow up range:** 1 week to 2 years	86% of the included studies reported increased FV, decreased fat intake, balanced calorie intake	Promising; 7 (moderate quality)
Pierre CS et al., 2021 (43)	**Study design:** Not reported	**Healthy eating education components:** workshops, visits by inspiring personalities, games, SMS, healthy eating club	All included studies reported improved healthy eating knowledge and	Likely effective; 9 (high quality)

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
	Theories: TTM, SCT, TPB, ASE model	*Contents:* healthy eating and nutrition lessons, cartoon-style nutrition handbook, visits by athletes, dancers, club activities (healthy cooking, drama, role-playing, poster making, photography exhibition on unhealthy eating) **School environment changes components:** school-wide food marketing *Contents:* SNaX messages- promotional displays via digital media, posters on healthy snacks **Family involvement components:** Parents meeting, homework *Contents:* healthy eating education for adolescents, feeding healthy foods to adolescents at home **Duration range:** 1 month-1 year **Follow-up range:** Not reported	behaviour including increased FV, decreased SSB intake, willingness to try new healthy foods, increased frequency of breakfast consumption	
Rose K et al., 2021 (31)	**Study desing:** Quasi-experimental (n=11), RCT (n=9), Qualitative (n=4) mixed-method (n=2), cross-sectional (n=1) **Theories:** Not reported	**Healthy eating education component:** lectures, board game, instrumental SMS, nutri-active kiosks, drama, counselling via mHealth *Contents:* healthy eating, nutrition information via computer-generated tailored leaflet, nutritional behavioural counselling **School environment changes components: S**ocial food marketing, canteen modification *Contents:* daily free healthy meal, food choice towards plant based foods, chef demonstration, promotion of healthy snack purchases **Family involvement components:** Parents meeting *Contents:* healthy eating for adolescents	All included studies reported improved nutritional knowledge, increased FV, protein, decreased SSB, red meat, fat, processed snacks intake, improved frequency of breakfast consumption	Likely effective; 10 (high quality)

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
		Duration of interventions: Not reported **Follow-up range:** 4 weeks to 18 months		
Sa JD & Lock K, 2008 (32)	**Study design:** RCT (n=6), non-RCT (n=1) **Theories:** Not reported	**Healthy eating education contents:** workshops, peer-leading activities *Contents:* lectures on healthy eating and its promotion, peer-leaders to promote healthy eating knowledge **School environment change components:** canteen modification, loyalty programmes, gardening *Contents:* increased provision of FV- free and/or subsidised, FV gardening **Family involvement components:** healthy eating information handouts *Contents:* healthy eating behaviour for adolescents via newsletters **Duration of interventions:** Not reported **Follow-up range:** 12 months to 3 years	70% of the included studies reported increased intake of FV	Promising; 9 (high quality)
Shinde et al., 2023 (30)	**Study design:** RCT (n=19), CBA (n=8) **Theories:** SCT, CBT, TPB, HBM, Pedagogy of the Oppressed, Health action process	**Healthy eating education components:** workshop, quiz, games, healthy eating information handouts, , culinary activities, entertainments *Contents:* healthy eating knowledge, role-plays, blackboard writing on healthy and unhealthy foods, food classifications, food label reading information via booklets, brochures, posters, magazines, webpage, puppet shows, movies, food tasting, healthy cooking recipe **School environment change components:** canteen modification, training for school staff *Contents:* daily sell of fresh fruits, nutrition training session	78% of the included studies reported improved healthy eating knowledge, increased FV, decreased SSB and processed food intake	Promising; 9 (high quality)

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
	approach, HPS, TRA	**Family involvement components:** workshops, healthy eating information handouts information provision- *Contents:* healthy eating behaviour for adolescents via booklets, brochures, blackboard writings, posters, slogans, news leaflets, healthy recipe guides **Duration of interventions:** 7 days to 3 years **Follow-up range:** 8 weeks to 28 months		
Van Cauwenberghe Evet al., 2010 (34)	**Study design:** RCT (n=5), non-RCT (n=5), prospective cohort (n=2), pre-post (n=1) **Theories:** TPB	**Healthy eating education components**: workshops *Contents:* healthy eating lessons **School environment change components:** canteen modification, , loyalty programs *Contents:* healthy foods in canteen, FV distributions, subscription (paying for regular access) to healthy foods, and incentives for purchasing healthy foods **Family involvement components:** Parents meeting *Content:* discussion on promoting healthy eating behaviour among their children **Duration of interventions:** 1 week to 2 years **Follow-up range:** 2 weeks to 2 years	Inadequate evidence in improving healthy eating behaviour across all studies	No conclusion; 8 (high quality)
Vézina-Im LA et al.,	**Study design:**	**Curriculum components:** workshops *Contents:* consequences of SSB intake, healthy eating goal setting, self-monitoring of eating behaviour	72% of the included studies reported decreased intake of SSB	Promising; 9 (high quality)

Author; year	Intervention design	Intervention description	Findings	Cochrane categorisation of effectiveness; JBI critical appraisal score
2017 (35)	RCT (n=13), quasi-experimental (n=11), pre–post (n=12) Theories: SCT, TPB, DIT, ET, SDT, ELM, SRT, TIT	**School environment change components:** canteen modification *Contents:* replacing SSB with healthier alternatives (milk, juice, water) in vending machine **Family and community involvement component:** parents' meetings, social support groups, healthy eating information handouts *Contents:* healthy eating knowledge, parents and family involvement to share experience, challenges and encourage healthy eating behaviour, information distribution via newsletter, emails, postcards **Duration range:** not reported **Follow-up range:** not reported		

RCT: Randomised Controlled Trial; CBA: Controlled before-after; FV: Fruit and Vegetable; ASE: Attitude, social influence and self-efficacy Model; SCT: Social Cognitive Theory; TTM: Trans-theoretical Model; TPB: Theory of Planned Behaviour; HBM: Health Belief Model ; HPM: Health Promotion Model ; SLT: Social Learning Theory; SSB: Sugar-sweetened Beverage; SEM: Socio-ecological Model; IMBSM: Information-Motivation Behavioural Skills Model ; CBT: Cognitive Behavioural Theory; HPS: Health Promoting School; DIT: Diffusion of Innovations Theory ; ET: Expectancy Theory; SDT: Self-determination Theory; ELM: Elaboration Likelihood Model; SRT: Self-regulation Theory ; TIT: Theory of Interpersonal Behaviour; SMS: short message service

Discussion

To our knowledge, this umbrella review represents the first comprehensive synthesis of evidence on the effectiveness of school-based healthy eating interventions targeting adolescents aged 10 to 19 years. Most (83%) of the reviews were of high methodological quality, providing confidence in the findings. The majority (71%) of high-quality reviews assessing multi-component interventions reported "promising" to "likely effectiveness", suggesting that a combination of individual- and system-level interventions is most effective in promoting healthy eating among adolescents. This finding is consistent with recent empirical evidence (46–49), highlighting the potential of such interventions to address the complex factors influencing adolescents' eating behaviour. Our review found that curricula driven by technology effectively encouraged healthy eating behaviours at the individual level, a finding further reinforced by recent studies (50–52). However, our review also found that the broader impact and sustainability of individual-level interventions are contingent upon their integration into the system-level interventions that include changing the school environment to improve availability of healthy foods and involving families. Combining system and individual-level interventions can create supportive environments that underpin and perpetuate changes in individual behaviour (17,19,53,54). Reviews examining school-based healthy eating interventions for a wider age range, including both children and adolescents, reveal different emphases. Effective intervention components focusing on children emphasise antecedents, particularly parental involvement in shaping eating behaviour and the importance of healthy food accessibility (32,34,49). However, our review found that the combination of effective components within the collaborative individual- and system-level approach for adolescents aged 10 to 19 years involved shaping knowledge through educational instructions and experiments, creating associations with stimuli that cue healthy behaviours, and establishing antecedents to facilitate healthy food choices (17,19,53,54).

The evidence synthesised in this review was primarily from studies in HICs (87%) that did not differentiate between geographical contexts. As interventions are likely to be context specific, this limits its applicability to LMICs. For example, the socioeconomic and infrastructural differences between HICs and LMICs may influence the effectiveness and feasibility of interventions (54–56) or limited access to technology, financial resources, and trained personnel in LMICs may hinder the successful implementation of tech-driven as well as multi-component interventions that have been promising in HICs (29,43,54–56). However, the evidence from HICs in this umbrella review still provides valuable insights and a foundation for future research and intervention development in resource-limited settings. The components and contents of effective interventions identified in HICs, such as the importance of multi-component approaches with the potential of technology-based strategies, are a starting point for designing and testing school-based healthy eating interventions in LMICs. However, these interventions will require adaptation and contextualisation to the constraints and opportunities in LMICs.

The limited number of reviews reporting on stakeholder involvement in intervention development underscores a critical gap in the current literature. Empirical evidence suggests that engaging key stakeholders, including adolescents, parents,

teachers, and policy experts, in intervention design ensures tailoring to adolescents' needs, feasibility, and successful implementation (57–59). Adolescents offer insights into their eating habits and preferences (57–59), parents shape their children's eating behaviours (59,60), teachers ensure compatibility with school resources (59), and policymakers promote policies for long-term support (59,61).

The scarcity of reviews reporting on the feasibility of these intervention exposes a significant gap in the current literature. Although a few reviews suggest that technology-driven interventions may be feasible (29,41), recent studies have identified several challenges that undermine their feasibility. These challenges include teachers' lack of understanding of the operating systems of the technology, limited internet access, and poor technology infrastructure (51,52). Furthermore, the feasibility of multi-component interventions that require additional resources has been questioned (52,62), which is consistent with the reporting from one review (39). This highlights the need for more comprehensive feasibility assessments to identify and address the logistical, contextual, and stakeholder factors that influence intervention effectiveness (62,63).

Inconsistent reporting across reviews made it difficult to determine if effectiveness varied based on theoretical underpinnings. While psychosocial theories, such as SCT, SLT, and TPB were most commonly used to inform the interventions, these interventions did not incorporate behaviour change taxonomy technique (BCTT) (64,65). Literature suggests using BCTT with behaviour change theories and frameworks, such as goal setting theory, TTM, TRA, and Capability, Opportunity, Motivation-Behaviour (COM-B) framework, for more effective and sustainable behaviour change (64–67). BCTT can improve intervention designs, enable cross-study analysis, and inform implementation feasibility (64,68,69).

The interventions assessed in the reviews relied on survey methods, mostly FFQs and food recalls. These outcome measures are prone to biases and inaccuracies, due to recall bias, social desirability bias (i.e., providing answers they perceive as more socially acceptable rather than accurate), short-term dietary variability, challenges in estimating portion sizes, limited food options, and seasonal variation (70). Triangulating this data with data from wearable tech, mobile apps, and school canteen sales data, ecological momentary assessment (EMA) for real-time data collection, direct observation of adolescents' eating behaviours, and proxy reports from family members can provide insights into behaviour changes (70–76). However, the acceptability and feasibility of some of methods should be explored within the context of resource availability prior to implementation.

This umbrella review stands out for two key strengths. First, it provides a comprehensive narrative synthesis of the evidence while critically examining methodological gaps in intervention designs. Second, it goes beyond a simple narrative compilation of findings by employing the HPS framework, TIDieR framework, and an intervention effectiveness categorisation system to synthesise intervention components, contents, and their effectiveness. However, our review had some limitations. The included reviews had mixed methodological quality, and many included low-quality primary studies. Our findings may also be influenced by the heterogeneity of the intervention designs of selected reviews and

inconsistent reporting of intervention characteristics. Our umbrella review included English-language peer-reviewed reviews, excluding literature in other languages and grey literature. Therefore, we might have missed reviews published in other languages or as grey literature. This may have also led to an overestimation of the interventions' effectiveness due to publication bias (77,78).

Conclusion

Multi-component school-based healthy eating interventions have shown promising results in improving healthy eating knowledge and behaviour among adolescents aged 10 to 19 years, particularly when combining individual- and systemic-level approaches. However, this umbrella review highlighted a significant gap in evidence from LMICs and a lack of participatory approach in designing and implementing the interventions. The limited and inconsistent reporting on intervention characteristics and strategies emphasises the need for comprehensive and high-quality systematic reviews of primary studies. Such reviews would allow for the consolidation of evidence from all types of school-based healthy eating interventions and the investigation of specific intervention components' effectiveness. Addressing these gaps is crucial for developing effective and sustainable interventions to promote healthy eating among adolescents worldwide.

Declarations

Ethical approval and consent to participate

Not applicable

Authors' contributions

NS was the primary reviewer and FN was the second reviewer during the review screening process. LB, FA, and DP contributed to resolving discrepancies in reviews if they occurred. NS prepared the draft with substantial input from LB, FN, FA, and DP. All authors approved the submitted version.

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests.

Consent for publication

All authors consented for the publication.

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Supplementary files

Supplementary file A

PRIOR Checklist

(Gates M, Gates A, Pieper D, et al. Reporting guideline for overviews of reviews of healthcare interventions: development of the PRIOR statement. *BMJ* 2022;378:e070849. doi:10.1136/bmj-2022-070849.)

Section Topic	**#**	**Item**	**Location reported**
TITLE			Page no., supplementary files
Title	1	Identify the report as an overview of reviews.	1
ABSTRACT			
Abstract	2	Provide a comprehensive and accurate summary of the purpose, methods, and results of the overview of reviews.	2,3
INTRODUCTION			
Rationale	3	Describe the rationale for conducting the overview of reviews in the context of existing knowledge.	3,4
Objectives	4	Provide an explicit statement of the objective(s) or question(s) addressed by the overview of reviews.	4
METHODS			
Eligibility criteria	5a	Specify the inclusion and exclusion criteria for the overview of reviews. If supplemental primary studies were included, this should be stated, with a rationale.	5
	5b	Specify the definition of 'systematic review' as used in the inclusion criteria for the overview of reviews.	5
Information sources	6	Specify all databases, registers, websites, organizations, reference lists, and other sources searched or consulted to identify systematic reviews and supplemental primary studies (if included). Specify the date when each source was last searched or consulted.	5
Search strategy	7	Present the full search strategies for all databases, registers and websites, such that they could be reproduced. Describe any search filters and limits applied.	5, Supplementary file B
Selection process	8a	Describe the methods used to decide whether a systematic review or supplemental primary study (if included) met the inclusion criteria of the overview of reviews.	5

	8b	Describe how overlap in the populations, interventions, comparators, and/or outcomes of systematic reviews was identified and managed during study selection.	N/A
Data collection process	9a	Describe the methods used to collect data from reports.	6
	9b	If applicable, describe the methods used to identify and manage primary study overlap at the level of the comparison and outcome during data collection. For each outcome, specify the method used to illustrate and/or quantify the degree of primary study overlap across systematic reviews.	N/A
	9c	If applicable, specify the methods used to manage discrepant data across systematic reviews during data collection.	N/A
Data items	10	List and define all variables and outcomes for which data were sought. Describe any assumptions made and/or measures taken to identify and clarify missing or unclear information.	6
Risk of bias assessment	11a	Describe the methods used to *assess* risk of bias or methodological quality of the included systematic reviews.	6
	11b	Describe the methods used to *collect* data on (from the systematic reviews) and/or *assess* the risk of bias of the primary studies included in the systematic reviews. Provide a justification for instances where flawed, incomplete, or missing assessments are identified but not re-assessed.	6
	11c	Describe the methods used to *assess* the risk of bias of supplemental primary studies (if included).	N/A
Synthesis methods	12a	Describe the methods used to summarize or synthesize results and provide a rationale for the choice(s).	6
	12b	Describe any methods used to explore possible causes of heterogeneity among results.	N/A
	12c	Describe any sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting bias assessment	13	Describe the methods used to *collect* data on (from the systematic reviews) and/or *assess* the risk of bias due to missing results in a summary or synthesis (arising from reporting biases at the levels of the systematic reviews, primary studies, and supplemental primary studies, if included).	6
Certainty assessment	14	Describe the methods used to *collect* data on (from the systematic reviews) and/or *assess* certainty (or confidence) in the body of evidence for an outcome.	6
RESULTS			
Systematic review and supplemental	15a	Describe the results of the search and selection process, including the number of records screened, assessed for eligibility, and included in the overview of reviews, ideally with a flow diagram.	7,8

primary study selection	15b	Provide a list of studies that might appear to meet the inclusion criteria, but were excluded, with the main reason for exclusion.	N/A

Section Topic	**#**	**Item**	**Location reported**
Characteristics of systematic reviews and supplemental primary studies	16	Cite each included systematic review and supplemental primary study (if included) and present its characteristics.	9-12
Primary study overlap	17	Describe the extent of primary study overlap across the included systematic reviews.	Supplementary file C
Risk of bias in systematic reviews, primary studies, and supplemental primary studies	18a	Present assessments of risk of bias or methodological quality for each included systematic review.	Table 1, Table 2, Supplementary file D
	18b	Present assessments (*collected* from systematic reviews or *assessed* anew) of the risk of bias of the primary studies included in the systematic reviews.	N/A
	18c	Present assessments of the risk of bias of supplemental primary studies (if included).	N/A
Summary or synthesis of results	19a	For all outcomes, summarize the evidence from the systematic reviews and supplemental primary studies (if included). If meta-analyses were done, present for each the summary estimate and its precision and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	13-25
	19b	If meta-analyses were done, present results of all investigations of possible causes of heterogeneity.	N/A
	19c	If meta-analyses were done, present results of all sensitivity analyses conducted to assess the	N/A

		robustness of synthesized results.	
Reporting biases	20	Present assessments (*collected* from systematic reviews and/or *assessed* anew) of the risk of bias due to missing primary studies, analyses, or results in a summary or synthesis (arising from reporting biases at the levels of the systematic reviews, primary studies, and supplemental primary studies, if included) for each summary or synthesis assessed.	N/A
Certainty of evidence	21	Present assessments (*collected* or *assessed* anew) of certainty (or confidence) in the body of evidence for each outcome.	N/A
DISCUSSION			
Discussion	22a	Summarize the main findings, including any discrepancies in findings across the included systematic reviews and supplemental primary studies (if included).	26
	22b	Provide a general interpretation of the results in the context of other evidence.	26,27
	22c	Discuss any limitations of the evidence from systematic reviews, their primary studies, and supplemental primary studies (if included) included in the overview of reviews. Discuss any limitations of the overview of reviews methods used.	28
	22d	Discuss implications for practice, policy, and future research (both systematic reviews and primary research). Consider the relevance of the findings to the end users of the overview of reviews, e.g., healthcare providers, policymakers, patients, among others.	26,27,28
OTHER INFORMATION			
Registration and protocol	23a	Provide registration information for the overview of reviews, including register name and registration number, or state that the overview of reviews was not registered.	5
	23b	Indicate where the overview of reviews protocol can be accessed, or state that a protocol was not prepared.	N/A
	23c	Describe and explain any amendments to information provided at registration or in the protocol. Indicate the stage of the overview of reviews at which amendments were made.	N/A
Support	24	Describe sources of financial or non-financial support for the overview of reviews, and the role of the funders or sponsors in the overview of reviews.	29
Competing	25	Declare any competing interests of the overview of reviews' authors.	29

interests			
Author information	26a	Provide contact information for the corresponding author.	1
	26b	Describe the contributions of individual authors and identify the guarantor of the overview of reviews.	29
Availability of data and other materials	27	Report which of the following are available, where they can be found, and under which conditions they may be accessed: template data collection forms; data collected from included systematic reviews and supplemental primary studies; analytic code; any other materials used in the overview of reviews.	29

Supplementary file B

Search details

All databases searched on 30th December 2023

PubMed search strategy: 4324

1# (((((School health service[MeSH terms]) OR School [MeSH Terms]) OR Teacher-led OR Peer-led)

2# (((((((Adolescents[MeSH Terms]) OR Children[MeSH Terms]) OR Student[MeSH Terms]) OR teenage [MeSH Terms]) OR Young adult[MeSH Terms]) OR young people OR Youth [MeSH Terms]))

3# ((((((((((((((healthy diet[MeSH Terms]) OR nutrition[MeSH Terms]) OR fruit[MeSH Terms]) OR vegetable[MeSH Terms]) OR sugar[MeSH Terms]) OR calorie) OR protein[MeSH Terms]) OR milk[MeSH Terms]) OR dairy) OR dietary behaviour) OR diet pattern) OR healthy eating[MeSH Terms]) OR diet[MeSH Terms]) OR food[MeSH Terms]) OR snacks[MeSH Terms]) OR processed) OR beverage[MeSH Terms]

4# (((((Review) OR Research synthesis) OR Meta-analysis) OR Meta synthesis))

5# (1# AND 2# AND 3# AND 4#)

Science direct search strategy: 406

("School health service") AND ("Adolescents" OR "children" OR "students" OR) AND ("healthy diet" OR "nutrition" OR "dietary behavior") AND ("review" OR "Meta-analysis")

CINAHL search strategy: 14

S1 TI School

S2 TI school health service

S3 TI Teacher-led

S4 TI Peer-led

S5 MW Adolescent

S6 MW children

S7 MW Student

S8 MH Young adult

S9 MH adult

S10 TI Young people

S11 TI youth

S12 MH Nutrition

S13 TI calorie

S14 MW protein

S15 MH milk

S16 MW dairy

S17 MW snacks

S18 TI processed

S19 TI beverage

S20 TI Healthy diet

S21 MH Fruit

S22 MW vegetable

S23 MW Sugar

S24 TI Dietary behavior

S25 TI Diet pattern

S26 TI Healthy eating

S27 MH Diet

S28 MH Food

S29 TI Review

S30 TI Research synthesis

S31 MW Meta-analysis

S32 TI Meta synthesis

S33 (S1 OR S2 OR S3 OR S4)

S34 (S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11)

S35 (S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25 OR S26 OR S27 OR S28)

S36 (S29 OR S30 OR S31 OR S32)

S37 (S33 AND S34 AND S35 AND S36)

Cochrane systematic review search strategy: 5

#1 MeSH descriptor: [School Health Services] this term only

#2 MeSH descriptor: [School] this term only

#3 (Teacher-led):ti,ab,kw

#4 (peer-led):ti,ab,kw

#5 MeSH descriptor: [Adolescent] this term only

#6 MeSH descriptor: [Children] this term only

#7 MeSH descriptor: [Students] this term only

#8 (teenage) :ti,ab,kw

#9 (Young Adult) :ti,ab,kw

#10 (Young people) :ti,ab,kw

#11 (Youth) :ti,ab,kw

#12 MeSH descriptor: [Adult] this term only

#13 MeSH descriptor: [Diet, Healthy] this term only

#14 MeSH descriptor: [Fruit] this term only

#15 MeSH descriptor: [Vegetable] this term only

#16 MeSH descriptor: [Sugars] this term only

17 (calorie):ti,ab,kw

18 MeSH descriptor: [Proteins] this term only

19 MeSH descriptor: [Milk] this term only

20 MeSH descriptor: [Dairy product] this term only

21 (dietary behaviour):ti,ab,kw

22 (diet pattern):ti,ab,kw

23 MeSH descriptor: [Snacks] this term only

24 (processed):ti,ab,kw

25 MeSH descriptor: [Beverages] this term only

#26 MeSH descriptor: [Diet] this term only

#27 MeSH descriptor: [Food] this term only

#28 (Review):ti,ab,kw

#29 (Research synthesis):ti,ab,kw

#30 (Meta-analysis):ti,ab,kw

#31 (Meta synthesis):ti,ab,kw

#32 (#1 OR #2 OR #3 OR #4)

#33 (#5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12)

#34 (#13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR #21 OR #22 OR #23 OR #24 OR #25 OR #26 OR #27)

#35 (#28 OR #29 OR #30 OR #31)

#36 (#32 AND #33 AND #34 AND #35)

Scopus search strategy: 6928

TITLE-ABS-KEY(("School health service" OR "school" OR "Peer-led" OR "Teacher-led") AND ("Adolescent" OR "Children" OR "Student" OR "young-adult" OR "teenage" OR "youth" OR "Young people") AND ("Healthy diet" OR "nutrition" OR "Fruit" OR "Vegetable" OR "sugar" OR "calorie" OR "protein" OR "milk" OR "dairy" OR "dietary behaviour" OR "diet pattern" OR "healthy eating" OR "diet" OR "Food" OR "snacks" OR "processed" OR "beverage") AND ("Review" OR "Meta-analysis" OR "research synthesis" OR "Meta synthesis"))

Eric search strategy: 269

(“School health service” OR “school” OR “Peer-led” OR “Teacher-led”) AND (“Adolescent” OR “Children” OR “Student” OR “young-adult” OR “teenage” OR “youth” OR “Young people”) AND (“Healthy diet” OR “nutrition” OR “Fruit” OR “Vegetable” OR “sugar” OR “calorie” OR “protein” OR “milk” OR “dairy” OR “dietary behaviour” OR “diet pattern” OR “healthy eating” OR “diet” OR “Food” OR “snacks” OR “processed” OR “beverage”) AND (“Review” OR “Meta-analysis” OR “research synthesis” OR “Meta synthesis”)

Web of Science: 2405

("School health service" OR "school" OR "Peer-led" OR "Teacher-led") AND ("Adolescent" OR "Children" OR "Student" OR "young-adult" OR "teenage" OR "youth" OR "Young people") AND ("Healthy diet" OR "nutrition" OR "Fruit" OR "Vegetable" OR "sugar" OR "calorie" OR "protein" OR "milk" OR "dairy" OR "dietary behaviour" OR "diet pattern" OR "healthy eating" OR "diet" OR "Food" OR "snacks" OR "processed" OR "beverage") AND ("Review" OR "Meta-analysis" OR "research synthesis" OR "Meta synthesis")

JBI Database of Systematic Reviews and Implementation Reports: 128

("School health service" OR "school" OR "Peer led" OR "Teacher led") AND ("Adolescent" OR "Children" OR "Student" OR "young adult" OR "teenage" OR "youth" OR "Young people") AND ("Healthy diet" OR "nutrition" OR "Fruit" OR "Vegetable" OR "sugar" OR "calorie" OR "protein" OR "milk" OR "dairy" OR "dietary behaviour" OR "diet pattern" OR "healthy eating" OR "diet" OR "Food" OR "snacks" OR "processed" OR "beverage") AND ("Review" OR "Meta analysis" OR "research synthesis" OR "Meta synthesis")

Ovid (Embase, Medline, PsycINFO) search strategy: (Keyword)

Ovid (Embase): 4264

1 exp school health service/

2 exp school/

3 exp controlled study/ or exp teaching/ or exp teacher/ or exp peer group/

4 exp student/ or exp high school student/ or exp health student/ or exp middle school student/

5 exp adolescent/

6 exp young adult/

7 exp child/

8 exp feeding behavior/ or exp eating/ or exp health promotion/

9 exp nutrition education/ or exp child nutrition/ or exp nutrition service/ or exp adolescent nutrition/ or exp nutrition/ or exp nutrition policy/

10 exp fruit/ or exp fruit vegetable/ or exp "fruit and vegetable juice"/ or exp fruit consumption/

11 exp vegetable/ or exp vegetable juice/ or exp vegetable consumption/

12 exp sugar intake/ or exp sugar/ or exp sugar-sweetened beverage/

13 exp high calorie diet/ or exp calorie/ or exp low calorie diet/

14 exp protein intake/ or exp protein/

15 exp milk/

16 exp dairy product/

17 exp dietary pattern/

18 1exp diet/ or exp healthy diet/

19 exp food composition/ or exp food/ or exp food quantity/ or exp health food/ or exp food addiction/ or exp junk food/ or exp food processing/ or exp processed food/ or exp food intake/ or exp instant food/ or exp food quality/ or exp fast food/

20 exp sweetened beverage/ or exp beverage/ or exp artificially sweetened beverage/ or exp sugar-sweetened beverage/ or exp carbonated beverage/

21 exp systematic review/ or exp review/

22 exp qualitative research/ or exp synthesis/

23 exp meta analysis/

24 1 or 2 or 3

25 4 or 5 or 6 or 7

26 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20

27 21 or 22 or 23

28 24 and 25 and 26 and 27

Ovid (PsycINFO): 688

1 exp School Nurses/ or exp Schools/ or exp School Based Intervention/ or exp Health Education/ or exp Health Promotion/ or exp Adolescent Health/

2 exp Junior High Schools/ or exp High Schools/ or exp Middle Schools/ or exp Schools/ or exp Elementary Schools/

3 exp Computer Assisted Instruction/ or exp Classrooms/ or exp Teachers/ or exp Elementary School Students/ or exp Elementary Schools/ or exp School Based Intervention/ or exp Teaching/

4 exp Health Promotion/ or exp Program Evaluation/ or exp Peers/ or exp Academic Achievement/ or exp Peer Counseling/ or exp Health Education/ or exp Educational Programs/

5 exp Adolescent Behavior/ or exp Adolescent Attitudes/ or exp Adolescent Health/

6 exp Child Care/ or exp Child Behavior/ or exp Child Health/

7 exp Only Children/

8 exp Junior High School Students/ or exp High School Students/ or exp Kindergarten Students/ or exp Middle School Students/ or exp Primary School Students/ or exp Intermediate School Students/ or exp Students/ or exp Nursery School Students/ or exp Elementary School Students/

9 exp Eating Behavior/ or exp Food/ or exp Health Behavior/ or exp Food Intake/ or exp Nutrition/ or exp Diets/ or exp Health Promotion/

10 exp Calories/

11 exp Protein/

12 1exp Food Preferences/ or exp Eating Attitudes/ or exp Food Addiction/

13 exp Sugars/

14 exp "Beverages (Nonalcoholic)"/

15 exp "Literature Review"/ or exp "Systematic Review"/

16 exp Meta Analysis/ or exp Intervention/

17 1 or 2 or 3 or 4

18 5 or 6 or 7 or 8

19 9 or 10 or 11 or 12 or 13 or 14

20 15 or 16

21 17 and 18 and 19 and 20

Ovid (Medline): 350

1 exp School Health Services/

2 exp Schools/

3 exp Peer Group/

4 exp Adolescent Behavior/ or exp "National Longitudinal Study of Adolescent Health"/ or exp Adolescent/ or exp Adolescent Health Services/ or exp Adolescent Nutritional Physiological Phenomena/ or exp Adolescent Health/

5 exp Child Health/ or exp Child Nutritional Physiological Phenomena/ or exp Child/ or exp Child Behavior/ or exp Child Health Services/ or exp Child Nutrition Disorders/

6 exp Students/

7 exp Young Adult/

8 exp Diet, Healthy/

9 exp Nutrition Policy/ or exp Nutrition Assessment/ or exp Nutririon

10 exp "Fruit and Vegetable Juices"/ or exp Fruit/

11 exp Vegetables/

12 exp Sugars/

13 exp Energy Intake/

14 exp Proteins/

15 exp Milk/

16 exp Dairy Products/

17 exp Diet/ or exp Feeding Behavior/

18 exp Food/ or exp Food Addiction/

19 exp Snacks/

20 exp Beverages/

21 exp "Systematic Review"/ or exp "Review"/

22 exp Meta-Analysis/

23 1 or 2 or 3

24 4 or 5 or 6 or 7

25 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20

26 21 or 22

27 23 and 24 and 25 and 26

Supplementary file C

Table: Citation Matrix

	No of overlapping articles	**Calvert, 2019**	**Van Cauwenberghe, 2010**	**Meiklejohn, 2016**	**Alcantara, 2018**	**Champion, 2019**	**Vezina-lm, 2017**	**Bailey, 2019**	**Tallon, 2019**	**McHugh, 2020**	**Rose, 2020**	**Nakabayashi, 2020**	**Sa JD, 2008**	**Melo GRDA, 2017**	**Medeiros 2022**	**Hackman,**	**Pierre**	**Shinde, 2023**
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Aceves-Martins 2017	2	x									x							
Bere E 2006	3	x		x									x					
Birnbaum 2002	3	x		x											x			
Bukhari 2011	3	x													x		x	
Chin 2008		x																
de Visser 2016		x																
Dowd 2015		x																
Dzewaltowski 2009	2	x													x			

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Foley BC 2017	2	x															x	
Gratton L 2007	4	x	x												x	x		
Haerens 2006	4	x		x		x	x											
Hölund 1990		x																
Hoelscher 2016		x																
Lien 2010		x																
Lo E 2008	3	x					x										x	
Lubans 2009		x																
Maatoug 2015		x																
Martens 2010		x																
Mauriello 2010	3	x							x			x						
McCabe 2015		x																
Neumark-		x																

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Sztainer 1995																		
Perry 1987		x																
Ratcliffe 2011	2	x						x										
Revill 2004		x																
Siega-Riz 2011		x																
Tsorbatzoudis 2005	3	x	x													x		
Wang 2015	3	x													x			x
Wilson 2012		x																
Yang 2015	3	x							x					x				
Haerens 2007	6		x	x					x			x	x	x	x			
Hassapidou 1997	2		x												x			
Klepp 1993	2		x					x										

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Martens 2005			x															
Martens 2006			x															
Martens 2008	2		x												x			
Eicchorn 2007			x															
Passmore 2005			x															
Ask 2006			x															
Loughridge 2005			x															
Parker			x															
Prell 2005	2		x	x														
Young			x															
Bjelland 2011				x														
Dewar 2013				x														
Foster 2008	2			x						x								
Hoppu 2010	4			x						x	x				x			

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Lytle 2004	4			x						x			x		x			
Mihas 2009	4			x							x				x		x	
Millar 2011				x														
Te Velde 2008				x														
Dunn 2004					x													
Long 2004	3				x			x	x									
Whittemore 2013	4				x	x	x							x				
Whittemore 2013 (different study)					x													
Cullen 2013					x													
Majumdar 2013					x													

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Fraticelli 2016					x													
Turnin 2016	3				x			x			x							
Brick 2015.						x												
Brick 2017	2					x						x						
Velicer 2013						x												
Casazza 2007	2					x			x									
Ezendam 2012	2					x								x				
Frenn 2003						x												
Frenn 2005	2					x			x									
Lana 2014						x												
Mauriello 2006						x												
Muzaffar 2019	2					x						x						
Prochaska 2004						x												
Bae 2012							x											

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Bauhoff 2014							x											
Blum 2008							x											
Bogart 2011	2						x										x	
Casazza 2006							x											
Collins 2014							x											
Contento 2010	2						x										x	
Cordeira 2012							x											
Cradock 2011							x											
Cullen 2008							x											
da Silva 2011							x											
Davis 2007							x											
Dubuy 2014	2						x										x	
Greece 2011							x											

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Jones 2014							x											
Lao LS 2011							x											
Malbon 2012							x											
McGoldrick 2006							x											
Nanney 2014							x											
Nanney 2016							x											
Neumark-Sztainer 2010							x											
Patel 2011							x											
Pbert 2013							x											
Singhal 2010							x											
Smith 2014							x											
Teufel 1998							x											

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Thiele 1989							x											
Winett 1999							x											
Wing 2015							x											
Woodward-Lopez 2010							x											
Wordell 2012							x											
Yildirim 2013							x											
Dewhurst 2011								x										
Dewhurst 2008								x										
Gracey 1996								x										
Jaenke 2012								x										
Morgan 2010								x										
Pendergast 2012								x										

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Ronto 2016								x										
Ronto 2016 (different study)								x										
Ronto 2016 (different study)								x										
Slater 2013								x										
Zhou 2016								x										
Petralias 2016								x										
Tsartsali 2009								x										
Mirmiran 2007								x										
Venter 2010								x										
Gewa 2013								x										

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Øverby 2012								x										
Leal 2011								x										
Osler 1993								x										
Chapman 1997								x										
Evans 2012								x										
Gans 1990								x										
Huang 2004								x										
Jarpe-Ratner 2016								x										
Larson 2006								x										
Laska 2012								x										
McAleese 2007	2							x					x					
Miller 2014								x										
Pirouznia 2001								x										

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Schober 2016								x										
Trexler 1993								x										
Williams 2016								x										
Caraher 2013								x										
Ronto 2017								x										
Swaminathan 2009								x										
McKinley 2005								x										
Chatterjee 2016								x										
Lukas 2011								x										
Bohm 2015								x										
Bohm 2016								x										
Rees 2010	4								x		x			x	x			
Maes 2011	2								x					x				

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Bech-Larsen 2013	2								x					x				
Räihä 2012	2								x		x							
Chamberland 2017									x									
Chung 2018									x									
Tumin 2016									x									
Nicklas 1998	2									x					x			
Bessems 2012	2										x				x			
Singh 2009											x							
van Nassau 2014											x							
Viggiano 2015											x							
Carfora 2016											x							
Ermitisi											x							

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Busch 2016											x							
Spence 2014											x							
Ensaff 2015											x							
Ardik 2016											x							
Kastorini 2012											x							
Sahingoz 2019											x							
Hovdenak 2019											x							
Souza 2019											x							
Sevil 2019											x							
Campos 2012											x							
Yusop 2018												x						
Toral 2012	2											x						x
Lana 2013												x						
Jalambadani												x						

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	SaJD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Gur 2019												x						
Freen 2003												x						
Freen 2005												x						
Filgueiras 2018												x						
Di Noia 2008												x						
Boff 2018												x						
Bere 2007													x					
O'Neil 2002													x					
Gortmaker 1999													x					
Lubans 2012														x				
Sharma 2015														x				
Thompson 2009														x				
Baños 2012														x				

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Amani 2006	2														x			x
Amaro 2006															x			
Bjelland 2015															x			
Cunha 2013	2														x			x
Forneris 2010															x			
Francis 2010															x			
Ghaffari 2019															x			
Gray 2015	2														x		x	
Ickovics 2019															x			
Ochoa 2017															x			
Anderson 2005																x		
Angelopoulos 2009																x		
Beaulieu 2012																x		

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Jemmott 2011																x		
Karimi 2013	2															x		x
Kothe 2011																x		
Kothe 2012																x		
Prelip 2018																x		
Spiegel 2006																x		
Arlinghaus 2017																	x	
Baskin 2009																	x	
Contento 2007																	x	
Gray 2016																	x	
Lee 2013																	x	
Duncan 2019																	x	
Fahlman 2008																	x	

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Fairclough 2013																	x	
Heo 2018																	x	
Irwin 2012																	x	
Irwin 2010																	x	
Kipping 2014																	x	
Lawlor 2011																	x	
Koch 2019																	x	
Lepe 2019																	x	
Li 2010																	x	
Xu 2017																	x	
Olivares 2005																	x	
Tsai 2009																	x	
Tucker 2015																	x	
Zhou 2019																	x	

	No of overlapping articles	**Calvert, 2019**	**Van Cauwenberghe, 2010**	**Meiklejohn, 2016**	**Alcantara, 2018**	**Champion, 2019**	**Vezina-lm, 2017**	**Bailey, 2019**	**Tallon, 2019**	**McHugh, 2020**	**Rose, 2020**	**Nakabayashi, 2020**	**Sa JD, 2008**	**Melo GRDA, 2017**	**Medeiros 2022**	**Hackman,**	**Pierre**	**Shinde, 2023**
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Zhou 2018																	x	
Stock 2007																	x	
El Rayess 2017																	x	
Gittelsohn 2013																	x	
Kohlstatdt 2016																	x	
Kohlstatdt 2015																	x	
Linton 2014																	x	
Luesse 2019																	x	
Molaison 2005																	x	
Wright 2012																	x	
Gittelsohn 2014																	x	

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Sato 2016																	x	
Trude 2018																	x	
Steeves 20198																	x	
Saez 2018																	x	
Bell 2017																	x	
Bogart 2014																	x	
Bogart 2016																	x	
Franken 2018																	x	
Jackson 2010																	x	
Leung 2017																	x	
Nechelles 2007																	x	
Smit 2016																	x	
Tamiru 2016																	x	
Akdemir 2017																		x

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
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Chagas 2020																		x
Brito 2019																		x
Fonseca 2019																		x
Keshani 2019																		x
Leventhal 2016																		x
Lin 2017																		x
Najimi 2013																		x
Sichieri 2009																		x
Sichieri 2013																		x
D. Wang 2013																		x
D. Wang 2014																		x
Stewart 2015																		x

	No of overlapping articles	Calvert, 2019	Van Cauwenberghe, 2010	Meiklejohn, 2016	Alcantara, 2018	Champion, 2019	Vezina-lm, 2017	Bailey, 2019	Tallon, 2019	McHugh, 2020	Rose, 2020	Nakabayashi, 2020	Sa JD, 2008	Melo GRDA, 2017	Medeiros 2022	Hackman,	Pierre	Shinde, 2023
Unique primary studies		**29**	**13**	**11**	**8**	**11**	**36**	**44**	**13**	**4**	**27**	**14**	**7**	**11**	**24**	**11**	**53**	
Yusoff 2012																		x
Yusoff 2013																		x
Dansa 2019																		x
Brito 2015																		x
Ghrayeb 2013																		x
Hosseini 2015																		x
Sharif 2020																		x
Shen 2020																		x
Taghdisi 2016																		x

Supplementary file D

Table: JBI critical appraisal checklist

Author	Year	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Total	Quality
Alcântara CMD et al.	2018	y	y	y	y	n	n	n	n/a	n	n	n	4	medium
Bailey CJ et al.	2019	y	y	y	y	y	y	y	n/a	n	n	y	8	high
Calvert S et al.	2019	y	y	y	y	y	y	y	n/a	n	n	y	8	high
Champion KE et al.	2019	y	y	y	y	y	y	y	y	n	n	y	9	high
Hackman et al	2014	y	y	y	y	n	y	n	n/a	n	y	y	8	high
McHugh C et al.	2020	y	y	y	y	y	y	y	n/a	n	n	y	8	high
Medeiros et al	2022	y	y	y	y	y	y	y	y	y	y	y	11	high
Meiklejohn et al.	2016	y	y	y	y	y	y	y	n/a	n	y	y	9	high
Melo et al.	2017	y	y	y	y	y	y	y	n/a	n	n	y	9	high
Nakabayashi J et al.	2020	y	n	y	y	y	y	y	n/a	n	n	y	7	medium
Pierre CS er al	2021	y	y	y	y	y	y	y	n/a	n	n	y	9	high
Rose K et al.	2021	y	y	y	y	y	y	y	n/a	n	y	y	10	high
Sa JD & Lock K	2008	y	y	y	y	y	y	n	n/a	n	y	y	9	high
Shinde	2023	y	y	y	y	y	y	y	n/a	n	y	y	9	high
Tallon JM et al.	2019	y	y	y	y	y	n	n	n/a	n	n	y	6	medium
Van Cauwenberghe et al.	2010	y	y	y	y	y	y	n	n/a	n	y	y	8	high
Vézina-Im LA et al.	2017	y	y	y	y	y	y	y	n/a	n	y	y	9	high

Questions

1. Were the criteria for inclusion in the sample clearly defined?
2. Were the study subjects and the setting described in detail?
3. Was the exposure measured in a valid and reliable way?

4. Were objective, standard criteria used for measurement of the condition?
5. Were confounding factors identified?
6. Were strategies to deal with confounding factors stated?
7. Were the outcomes measured in a valid and reliable way?
8. Was appropriate statistical analysis used?
9. Was the likelihood of bias assessed?
10. Were recommendations for policy and/or practice supported by reported data?
11. Were the specific directives for new research appropriate?

Supplementary file E

Table 1: Categorisation of healthy eating education components using behaviour change technique taxonomy

Author, year	**Feedback and monitoring:** tracking healthy eating include digital and non-digital methods, using self-assessment and external monitoring[a]	**Shaping knowledge:** instructions and experiments to teach and reinforce the adoption and maintenance of healthy eating behaviours[b]	**Associations:** introducing stimuli with the purpose of cueing healthy eating behaviour[c]	**Effectiveness, methodological quality**
Alcântara 2018 (26)		✓	✓	Likely effective; low quality
Melo GRDA 2017 (38)	✓	✓	✓	Likely effective; high quality
Tallon JM 2019 (30)	✓	✓		Likely effective; moderate quality

Footnote: a: apps (to measure and monitor daily food intake), SMS-based diaries (sending timed text prompts for users to report food intake, enabling real-time tracking and feedback on eating behaviour); b: workshops, games, blogs; c: virtual canteen (digital simulation that mimics the experience of selecting and consuming meals in a canteen setting), SMS

Table 2 Categorisation of multi-components using behaviour change technique taxonomy

Author, year	**Feedback and monitoring:** tracking healthy eating include digital and non-digital methods, using self-assessment and external monitoring[a]	**Social support:** Peer support to encourage healthy eating[b]	**Shaping knowledge:** instructions and experiments to teach and reinforce the adoption and maintenance of healthy eating behaviours[c]	**Associations:** introducing stimuli with the purpose of cueing healthy eating behaviour[d]	**Rewards:** **r**ewards for purchasing healthy foods and maintaining healthy eating behaviour[e]	**Antecedents:** restructuring the physical and social environments in school to facilitate healthy eating behaviour[f]	**Effectiveness, methodological quality**
Bailey CJ 2019 (33)	✓		✓	✓		✓	Promising; high quality
Calvert S 2019; (34)	✓		✓	✓	✓	✓	Promising; high quality
Champion KE 2019 (41)			✓	✓		✓	No conclusion, high quality
Hackman 2014 (35)	✓		✓	✓	✓	✓	Promising; high quality
McHugh C 2020 (36)			✓		✓	✓	No conclusion; high quality
Medeiros 2022 (42)			✓			✓	Promising; high quality
Meiklejohn 2016 (37)			✓		✓	✓	No conclusion; high quality
Nakabayashi J 2020 (39)			✓				Promising; moderate quality
Pierre CS 2021 (40)			✓	✓		✓	Likely effective; high quality
Rose K 2021 (28)			✓	✓		✓	Likely effective; high quality
Sa JD & Lock K, 2008 (29)			✓		✓	✓	Promising; high quality
Shinde 2023 (27)	✓		✓	✓		✓	Promising; high quality
Van 2010 (31)			✓		✓	✓	No conclusion; high quality
Vézina-Im 2017 (32)		✓	✓			✓	Promising; high quality

Footnote: a: quiz, self-assessment and evaluation diary; b: parents and family involvement to share experience, challenges and encourage healthy eating behaviour; c: workshops, conference, campaign, cooking classes, games, field visits, blog by health coach for students and workshop, healthy eating information handouts and homework for parents; d: nutri-advice kiosk (stand-alone booth that provides nutrition-related information and personalised advice), entertainments (media shows, drama, puppet shows, visits by inspiring personalities), posters, SMS, emails, counselling via mHealth (nutritional behavioural counselling), healthy eating club, ; e: rewards to adolescents, for healthy eating behaviour, and loyalty programme, coupon for parents); f:

school FV gardening, school food marketing, training for kitchen staff, canteen modification, such as increased availability of healthy foods, reduced fruit prices, involving parents in the school nutrition council group, parents' meeting, invite to school meals, free healthy foods to parents