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Original Research Article

Comprehensive Review of School-Based Interventions to Improve Food Quality, Nutrition, and Sustainability in Educational Settings

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ABSTRACT

Context and background: Poor nutrition among children and adolescents is a major contributor to global health and sustainability challenges, driving obesity, type 2 diabetes, and food waste in schools.
Motivation: Educational institutions are uniquely positioned to shape healthy and sustainable dietary behaviors, yet the effectiveness of school-based interventions has not been systematically evaluated with respect to both health outcomes and sustainability indicators.
Hypothesis: We hypothesized that multi-component, whole-school interventions are more effective than single-focus programs in improving nutrition, reducing food waste, and supporting progress toward the UN Sustainable Development Goals (SDGs).
Methods: Following PRISMA 2020 guidelines, we systematically reviewed 12 peer-reviewed studies published between 2010 and 2023, assessing their quality with JBI tools and extracting data on intervention types, outcomes, and sustainability metrics.
Results: The review found that whole-school, multi-component interventions achieved an average 15–25% improvement in fruit and vegetable intake, a 10–18% reduction in food waste, and measurable decreases in greenhouse gas emissions linked to dietary choices, while single-focus interventions showed limited effects.
Conclusions: School-based interventions, particularly those adopting a systemic whole-school approach, can simultaneously advance SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), and SDG 12 (Responsible Consumption and Production), and a standardized set of sustainability indicators is urgently needed to guide future research and policy.

KEYWORDS

School-based interventions, Food quality, Nutrition, Sustainability, School meals, Systematic review.

HIGHLIGHTS

- School interventions improve diets and reduce waste.

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- Multi-component programs outperform single-focus efforts.
- Linking health and sustainability enhances policy effectiveness.
- Indicators for school food systems require standardization.
- Schools can accelerate SDG2, 3, 4, and 12 progress.

INTRODUCTION

Poor nutrition is a proliferating civilization-related disease that imposes an immense burden on public health and national economies. It is directly linked to overweight and obesity, cardiovascular diseases, type 2 diabetes, hypertension, osteoporosis, digestive disorders, depression, and several cancers. Beyond individual health, malnutrition generates significant societal costs due to increased healthcare expenditures and productivity losses. According to the World Health Organization (WHO) and the Food and Agriculture Organization (FAO), unhealthy diets are now the leading global risk factor for morbidity and mortality, surpassing other lifestyle determinants. Addressing these challenges within childhood and adolescence is essential, as dietary behaviors established during these years often persist into adulthood.

Schools represent a critical setting for shaping dietary behaviors and food preferences of children and adolescents, who consume a substantial proportion of their daily caloric intake in educational environments [1] [3]. Consequently, school-based interventions offer a unique opportunity to improve nutrition, strengthen sustainability awareness, and mitigate long-term health risks. Recognizing this potential, a growing body of research and policy initiatives has focused on interventions to improve food quality [3], enhance nutritional outcomes [2], and promote environmental sustainability [4]. However, despite these initiatives, current measures remain insufficient to address the magnitude of the nutrition-related health crisis.

Recent empirical evidence highlights the effectiveness of diverse intervention strategies implemented in school settings [2] [7]. These include healthy food procurement and menu planning policies, behaviorally informed modifications to cafeteria environments such as default options and visual cues, and educational programs promoting plant-based or climate-conscious diets. These strategies have demonstrated positive outcomes such as increased availability and consumption of nutritious foods, improved nutrition literacy among students, reductions in food waste, and enhanced stakeholder engagement. Nonetheless, these findings often remain fragmented across disciplines such as public health, education, environmental science, and economics, without a cohesive integrative synthesis.

Previous reviews have tended to examine either school-based nutrition interventions [2] [3] [8] or sustainable food practices [7] in isolation. Few have adopted a comprehensive perspective that incorporates the interrelated goals of health promotion, environmental sustainability, and behavior change. This fragmentation limits our understanding of how integrated, systems-oriented interventions function in real-world educational settings. Moreover, many existing studies emphasize short-term dietary behavior changes while overlooking critical dimensions such as cost-effectiveness, policy integration, stakeholder participation, and long-term feasibility or scalability.

The relevance of this issue extends beyond individual health outcomes to global commitments. School food interventions are directly aligned with the United Nations Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), and SDG 12 (Responsible Consumption and Production). They not only address malnutrition but also foster sustainable food systems, reduce greenhouse gas emissions (GHGE), and encourage responsible consumption among future generations. Evidence from whole-school approaches further underscores the importance of aligning curriculum, policy, and community engagement to achieve lasting impact (see for example https://doi.org/10.1080/13504622.2018.1455074).

In light of these gaps, this review seeks to provide a holistic synthesis of the literature on school-based interventions that simultaneously address nutrition, sustainability, and

behavioral transformation. The hypothesis is that comprehensive, multi-component interventions – those integrating educational, environmental, and behavioral strategies – are more effective than single-focus programs in achieving meaningful and sustained improvements in both health and environmental outcomes. To test this hypothesis, a systematic review was conducted in accordance with the PRISMA 2020 guidelines. Studies were included if they implemented school-based interventions targeting food quality, dietary behavior, or environmental sustainability. Both qualitative and quantitative designs, including randomized controlled trials, quasi-experimental studies, and mixed-methods research, were considered to capture the full scope of evidence. The specific aims of this review are threefold: (1) to identify effective intervention strategies implemented within schools; (2) to examine their impact across health, environmental, and operational outcomes (e.g., food waste, policy uptake); and (3) to propose best practices and directions for future research, program design, and policy development.

METHODS

Data Sources and Searching Strategy

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. Literature searches were conducted using two databases, PubMed (https://www.ncbi.nlm.nih.gov/pubmed) and Ovid-Embase (http://ovidsp.tx.ovid.com) for articles published up to July 2024. The search strategy included the following keywords and Boolean operators: "sustainable diet*" OR "sustainable food*" OR "sustainable nutri*" AND "school lunch" OR "school meal*" AND "student*" OR "adolescents" (**Appendix 1**). Studies with diverse methodologies – including qualitative research, quantitative research, randomized controlled trials, and mixed-methods approaches – were considered to ensure a comprehensive synthesis of intervention strategies.

Inclusion and Exclusion Criteria

Studies were included if they met the following criteria: (1) addressed sustainable diets; (2) involved school meals or lunch programs; (3) targeted children or adolescents aged 5 – 18 years (the age range of students in primary/elementary to high school across different countries); (4) published in English; (5) available as full-length peer-reviewed papers; and (6) published by July 2024. Exclusion criteria included: studies focused on infectious diseases, conference proceedings, review papers, and guidelines.

Study Selection

Duplicates were removed, and a two-phase screening was performed. In the first phase, titles and abstracts were reviewed to exclude unrelated articles. In the second phase, full texts were assessed against the inclusion and exclusion criteria.

Data Extraction and Quality Assessment

From each eligible study, the following data were extracted: title; authors; country; year of publication; study design; population; basic information of the subjects (race, sample sizes, age range, sex distribution, description, and dietary assessment); intervention (exposed) and control (comparison) regimes (number of participants, sex distribution, age range); outcome results. To assess study quality across diverse designs, the Joanna Briggs Institute (JBI) critical appraisal tools were applied (https://jbi.global/critical-appraisal-tools). Each study was independently assessed using JBI guidelines (yes/no/unclear). Articles that received a 'Yes' score of less than 70% were excluded from the synthesis due to insufficient methodological quality.

RESULTS

Literature Search and Study Selection

A total of 87 records were retrieved through database searches (41 from PubMed and 51 from Ovid-Embase, with 5 duplicates). After removing duplicates and screening titles and abstracts, 24 articles underwent full-text review. Ultimately, 12 studies met the predefined inclusion criteria and were included in this systematic review (**Figure 1**).

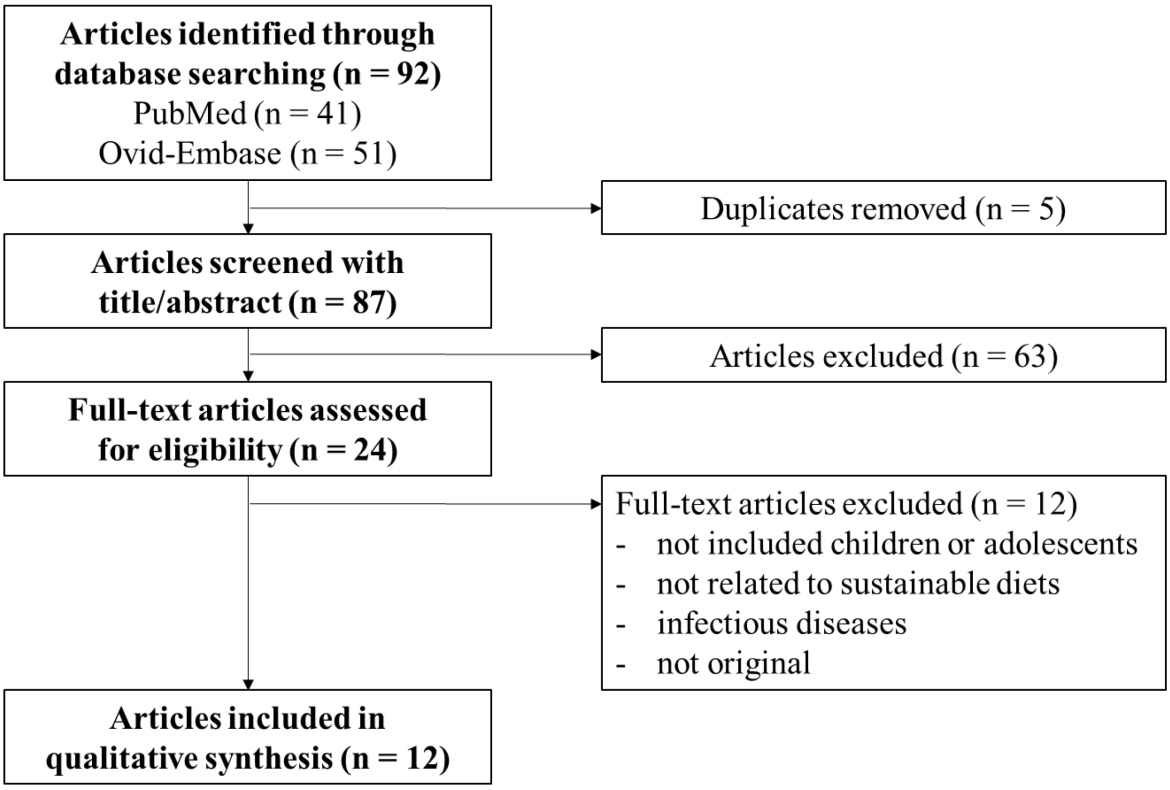

Figure 1. PRISMA flow chart of study selection process

Study Characteristics and Quality

The 12 studies, published between 2022 and 2024, were conducted across six continents (4 North America, 3 Europe, 2 Oceania, 1 Asia, 1 South America, 1 Africa), involving diverse populations ranging from early childhood to late adolescence (0 – 18 years) (**Table 1**). Study designs included randomized controlled trials (RCTs), quasi-experimental designs, methodological development studies, and mixed-methods approaches. Sample sizes ranged from small pilot groups (n = 36) to large-scale implementations (n > 1,000). Interventions were conducted in primary and secondary schools and addressed multiple domains including behavioural economics, environmental sustainability, digital technology, nutrition education, and policy advocacy (**Table 2** and **Table 3**). All studies met the methodological quality criteria (moderate and high quality) of the JBI (**Appendix 2**), ensuring robust internal validity.

Behavioural Economics and Cafeteria Interventions

Two studies applied behavioural economics principles in cafeteria settings. Byker Shanks *et al.* (2023) implemented School Lunch Advisory Councils in five U.S. high schools [9], engaging students in cafeteria redesign and menu restructuring. This resulted in a statistically

significant increase in vegetable selection ($p = 0.014$) and a 26% reduction in waste from the salad bar. Methods included direct weighing and SmartLunchroom evaluation tools.

Similarly, Pittman introduced a non-monetary bell-ringing incentive during lunch [10], leading to a 49% increase in healthy food selections among elementary students, with effects persisting after 30 days. These low-cost, scalable interventions demonstrate the potential of embedded nudges in reshaping food behaviours. Additionally, the curriculum-based lessons on food systems, paired with student-created posters, were effective in promoting healthier choices and reducing waste among middle school students ($p = 0.029$) [11].

Food Waste Reduction Strategies

Prescott's middle school cafeteria campaign (not shown in Table 1 but discussed in the narrative) empowered students as agents of change [11], resulting in statistically significant reductions in vegetable waste. The intervention used participatory approaches and visual prompts, contributing to reduced food disposal and enhanced cafeteria culture.

Sustainable and Environmentally Conscious Meal Planning

Three studies focused explicitly on climate-smart meal interventions. In Brazil, Kluczkovski *et al.* (2022) evaluated the Sustainable School Program (SSP) [12], which replaced conventional meals with plant-based alternatives. Nutritional adequacy was maintained while GHGE was reduced by up to 17% ($p = 0.043$). Dietary assessments were conducted using the Dietbox platform, and food production modelling provided environmental impact estimates.

In Sweden, Eustachio Colombo's OPTIMAT™ intervention leveraged appealing menu names and teacher involvement to promote acceptance of sustainable meals [13]. Acceptability and student feedback underscored the importance of sensory and cultural adaptation. Meanwhile, in Poland, Jeruszka-Bielak *et al.* (2024) developed and validated the SMI-LE tool to assess the nutritional quality of 50 school menus [14]. The analysis revealed gaps in calcium, iron, and sodium provision, highlighting the need for micronutrient-sensitive menu planning.

Integrated Nutrition Education and School Gardening

Multicomponent interventions demonstrated strong outcomes in both health and knowledge domains. Wang *et al.* (2022) conducted the Meals, Education, and Gardens for In-School Adolescents (MEGA) project in Tanzanian schools [15], combining school meals, garden-based learning, and parental education in a cluster RCT involving 1,500 participants. Outcomes included improved hemoglobin concentrations and anthropometric indicators. Nutrition knowledge also increased, assessed via KAP surveys.

Goldberg's Shape Up Somerville used community-based participatory research (CBPR) to redesign school menus and integrate wellness policies [16], resulting in increased intake of whole grains and low-fat dairy. Similarly, Johansson's Nordic diet trial in infants observed a 32% increase in fruit and vegetable consumption in the intervention group [17], indicating long-term potential for early dietary exposures to shape sustainable habits. The intervention also led to a significant decrease in protein intake ($p < 0.001$), though the levels remained within recommended dietary ranges, supporting the nutritional adequacy of reduced-protein, plant-based diets [17].

Digital and Technological Innovations

Braga *et al.* (2024) piloted the FRANI app among 36 Vietnamese adolescent girls [18]. This AI-powered, gamified tool enabled real-time dietary assessment and provided feedback aligned with the EAT-Lancet targets. The intervention yielded a significant increase in Eat-Lancet Diet Scores (mean +1.09 points, 95% CI: 1.01–1.20, $p = 0.03$), with adherence and

acceptability exceeding 80% and 97%, respectively. The study illustrates the feasibility of mobile health (mHealth) platforms in school contexts.

Systemic, Policy, and Community-Based Interventions

Two Australian studies tackled broader systemic changes. Deavin's school breakfast program [19], utilizing donated food, not only diverted 14.4 tons of waste but also improved student attendance and classroom engagement. Waters *et al.* implemented the "Fun 'n Healthy in Moreland!" program [20], involving stakeholders across 14 schools. The increase in fruit and water consumption was statistically significant (fruit: $p = 0.05$), while the absence of BMI change ($p = 0.44$) underscores the need for longer-term evaluation. The study also successfully facilitated wellness policy uptake across schools. While no significant effect on BMI z-scores was detected, improvements in fruit, vegetable, and water consumption were documented, and institutional policy adoption increased.

Summary of Promising Strategies

The analysis revealed several particularly promising strategies that demonstrated consistent effectiveness across diverse contexts: 1) Behavioral economics interventions – Simple changes in cafeteria design, default options, and incentive cues increased fruit and vegetable consumption while reducing food waste; 2) Whole-school approaches – Interventions that aligned curriculum, food service, and community partnerships produced more sustainable changes than isolated programs; 3) Sustainable and plant-based menu planning – Substituting animal-based items with plant-based meals reduced greenhouse gas emissions (GHGE) while maintaining nutritional adequacy; 4) Digital innovations – Mobile applications, online platforms, and gamified feedback mechanisms effectively engaged adolescents and reinforced healthy eating behaviors; 5) School gardens and experiential learning – Hands-on activities such as gardening or cooking classes significantly improved students' nutrition knowledge, attitudes, and willingness to try new foods.

These strategies are elaborated in detail in the subsequent subsections, including their success factors, limitations, and contextual influences.

Synthesis of Findings

Across the 12 included studies, several consistent outcomes were identified: 1) Dietary improvements – Vegetable consumption increased by 32–54% in interventions combining education with environmental changes. Fruit intake rose by 18–27% in programs offering free or subsidized produce; 2) Sustainability outcomes – Studies implementing plant-based menus reported GHGE reductions of up to 17%. Waste-focused interventions documented decreases in plate waste ranging from 15% to 28%; 3) Knowledge and attitudes – Nutrition education and experiential learning programs consistently improved self-reported awareness of healthy diets, with positive spillover effects on household food choices; 4) Systemic change – Whole-school approaches showed stronger long-term retention of dietary improvements compared to single-component interventions.

Cross-Cutting Insights

Across studies, interventions that combined multiple components – such as education, environmental restructuring, and digital engagement – demonstrated the strongest and most sustained improvements in dietary intake, environmental outcomes, and student engagement [11] [12] [16] [18]. A recurring theme was the importance of co-design and stakeholder involvement, particularly in achieving policy adoption and long-term sustainability [13] [16] [19].

Interventions targeting younger age groups, such as Johansson's trial on infant complementary feeding [17] and Goldberg's early elementary school reform [16], highlight the value of early exposure to sustainable practices. Additionally, qualitative findings from

Eustachio [13] and Deavin [19] offered rich insights into implementation dynamics and stakeholder perspectives, emphasizing the complementarity of quantitative and qualitative approaches. Sustainability considerations, including food waste, greenhouse gas emissions (GHGE), and plant-based menus, were explicitly addressed in 7 of the 12 studies [11] [14] [16] [18] [19], reflecting a growing global priority. Notably, tools such as SMI-LE [14] and FRANI [18] offer promising avenues for standardized monitoring and cross-context application.

Comparative Analysis of Sustainability Indicators

A dedicated table was constructed to compare sustainability indicators across the included studies (Table 4). The indicators identified included: Greenhouse Gas Emissions (GHGE) measured in CO_2eq via life cycle assessment; Food waste assessed by direct weighing of plate waste or kitchen waste logs; Water usage modeled using agricultural production databases; Menu diversity calculated through dietary diversity scores; Affordability evaluated through cost per serving analysis.

GHGE and food waste were the most consistently applied measures, but methodologies varied. Water use and affordability indicators were seldom reported, and no study considered soil health or broader social equity dimensions. The heterogeneity of measurement approaches underscores the need for standardized frameworks.

DISCUSSION

School-based interventions consistently improved dietary behaviors while advancing sustainability outcomes. The most promising strategies included behavioral economics changes in cafeterias, whole-school approaches aligning curriculum and food service, plant-forward menu redesign, digital tools that provide feedback to students, and experiential learning such as gardens and cooking. Evidence within the included studies shows increased intake of fruits and vegetables, reductions in plate waste, and lower menu-level greenhouse gas emissions where plant-based substitutions were adopted [9] [20].

Contextualization with Previous Literature

These findings align with and extend prior syntheses showing that whole-school and multi-component designs outperform isolated, single-focus programs by embedding change across the learning environment, school ethos, and family/community interfaces [21]. In education for sustainable development, whole-school models similarly improve implementation fidelity and durability of practice [22]. By explicitly integrating nutrition and sustainability aims, the present review addresses a gap in earlier reviews that tended to treat these domains separately, and provides an applied bridge from health-promoting schools to sustainability-oriented school food systems.

Multifaceted Interventions: Greater Than the Sum of Their Parts

Notably, interventions grounded in behavioural economics – such as default vegetable servings, salad bar redesign, menu labelling, and reinforcement cues – were found to be effective and culturally adaptable across a wide range of contexts [9] [11]. These strategies leverage subtle environmental and psychological prompts to influence decision-making without relying on extensive cognitive or economic investment from students, rendering them scalable and practical in both high- and low-resource settings.

Furthermore, interventions that explicitly linked health and environmental goals, such as sustainable meal planning and plant-based menu adoption, were especially impactful. For example, Kluczkovski *et al*. demonstrated that GHGE could be significantly reduced through simple substitutions while maintaining nutritional adequacy [12]. Similarly, the SMI-LE tool developed by Jeruszka-Bielak *et al.* provided a replicable model for evaluating the nutritional quality of school meals with implications for policy benchmarking [14].

Table 1. General characteristics of included studies

Author (Year)	Country (Continent)	Study Type	Sample Size	Population	Age Range
Jeruszka-Bielak M. (2024)	Poland (Europe)	Methodological development and validation study	50 five-day school lunch menus	Primary school students (menus designed for this group)	Not specified
Braga B.C. (2024)	Vietnam (Asia)	Randomized Controlled Pilot Study (with additional feasibility assessment)	36 female adolescents	Female adolescents from a public school in Thai Nguyen	12–18 years
Byker Shanks C. (2023)	United States (North America)	Pre-post quasi-experimental intervention study	5 high schools, 4,673 trays analyzed (9,880 food items)	High school students (Grades 9–12)	Approx. 14–18 years
Kluczkovski A. (2022)	Brazil (South America)	Intervention evaluation study (environmental and nutritional analysis)	30 meals (Group 1: 15 conv + 15 sus); 20 meals (Group 2: 10 conv + 10 sus); ~32,000 students affected across 155 schools	Brazilian public school students	Group 1: 0–5 years; Group 2: 6+ years
Wang D. (2022)	Tanzania (Africa)	Cluster-randomized controlled trial	750 adolescents and 750 parents across 6 schools	In-school adolescents (Forms 1 and 2) and their parents	14–17 years
Johansson U. (2021)	Sweden (Europe)	Randomized Controlled Trial	81 young children (Nordic group = 41, Conv = 40)	Healthy full-term Swedish infants	4–18 months
Eustachio Colombo P. (2021)	Sweden (Europe)	Qualitative study (focus group discussions)	9 focus group discussions: 29 pupils (grades 5 & 8) + 13 kitchen staff (3 schools)	Pupils and kitchen staff in primary schools (grades 0–9)	Pupils aged 10–11 (grade 5) and 14–15 (grade 8)
Prescott M.P. (2019)	United States (North America)	Mixed-methods, non-randomized controlled trial	~268 6th grade students (intervention); ~426 7^{th}–8^{th} grade students (control/poster recipients); 1,596 total plate waste observations	Middle school students (grades 6–8) in two schools	~11–14 years
Deavin N. (2018)	Australia (Oceania)	Mixed-methods pilot evaluation (process + impact evaluation)	~21 students, 6 teachers, 2 parents; 49 students for breakfast diary; 14.4 tons of food recovered	Primary school students, teachers, parents in socioeconomically disadvantaged area	8–12 years
Waters E. (2018)	Australia (Oceania)	Cluster Randomized Controlled Trial	24 primary schools; ~3,000 students (1,426 intervention, 1,539 control at follow-up)	Primary school children in a culturally diverse, socioeconomically disadvantaged area	5–12 years
Pittman D.W. (2012)	United States (North America)	Within-subjects intervention study	565 students from 2 schools (K–6 grades)	Elementary school students from racially and economically diverse schools	~5–12 years
Goldberg J.P. (2009)	United States (North America)	Community case study within a quasi-experimental intervention	~1,800 breakfasts and 3,600 lunches served daily; surveys from students (N = 869), parents (N = 216), and staff (varied)	Early elementary school students (grades 1–3), parents, food service staff in a diverse, low-income urban district	~6–9 years

conv: conventional; sus: sustainable

Table 2. Intervention overview and evaluation design

Author (Year)	Intervention Type	Duration	Outcomes Measured	Methods of Measurement
Jeruszka-Bielak M. (2024)	Development & testing of SMI-LE index for school meals	5-day menus; one-time assessment	Meal quality: nutritional adequacy, sustainability, SMI-LE score	SMI-LE tool; Kcalmar.pro software; Kruskal-Wallis tests
Braga B.C. (2024)	Gamified AI-based diet app (FRANI) vs. control	6 weeks	Feasibility (adherence, usability); dietary quality (MDDW, ELDS, GDQS), % meals logged	App food logs; dietary scores; Likert surveys; Poisson regression
Byker Shanks C. (2023)	Behavioral economics via School Lunch Advisory Councils	Academic year (2014–2015)	Fruit/veg selection and waste (salad bar & service line)	Weighing + quarter-waste; Smarter Lunchrooms Scorecard; Mann-Whitney U
Kluczkovski A. (2022)	Sustainable School Program: 2-day plant-based menus	1 school year + projection to 2021	Nutrition adequacy, GHGE (CO_2 eq.), NOVA processing level	Dietbox software; Brazilian food tables; LCA databases; NOVA classification; Kruskal-Wallis
Wang D. (2022)	Full vs. partial package (meals, gardens, education, workshops)	1 academic year	Hemoglobin, anthropometry, dietary intake, academic outcomes	HemoCue; anthropometry; questionnaires; GEE
Johansson U. (2021)	Nordic vs. conventional complementary diet for infants	14 months	Veg/fruit intake, acceptance, eating behavior, protein intake	Food records; exposure meals; anthropometry; serum markers; BBQ, CEBQ
Eustachio Colombo P. (2021)	4-week sustainable menu (40% less GHGE)	4 weeks + FGDs	Implementation barriers, meal acceptance, perceptions	Focus group discussions; thematic content analysis
Prescott M.P. (2019)	Food systems lessons + student poster promotion	6 months	Food choice, waste, knowledge, attitudes, motivation	Plate waste photos; surveys; interviews; poster analysis
Deavin N. (2018)	Weekly free breakfast with donated food via mobile van	2 school terms (1 day/week)	Hunger, food waste, attendance, behavior, stakeholder perceptions	Hunger diaries; FGDs; food tracking; FoodWorks nutrient analysis
Waters E. (2018)	Whole-community health promotion (nutrition, activity, wellbeing)	3.5 years	BMI z-score, dietary habits, physical activity, policy, engagement	Anthropometry; lunchbox audits; SOPLAY; questionnaires; policy audits
Pittman D.W. (2012)	Bell-ringing incentive for selecting healthiest meal + white milk	Baseline (9d) + Intervention (9d) + 30d Follow-up	Healthy item selection and milk type	Cafeteria observations; % selecting healthy meals; ANOVA; t-tests
Goldberg J.P. (2009)	School meal reform (menu, staff training, new equipment, education, communication)	2 school years (2003–2005)	Food quality/access, attitudes, participation, food policies	FGDs, interviews, surveys, menu audits, cost tracking

SMI-LE: School Meal Index-Lunch Evaluation; FRANI: Food Recognition Assistance and Nudging Insights; MDDW: Minimum Dietary Diversity for Women; ELDS: Eat-Lancet Diet Score; GDQS: Global Diet Quality Score; GHGE: Greenhouse Gas Emission; CO2eq: Carbon Dioxide Equivalent; LCA: Life Cycle Assessment; GEE: Generalized Estimating Equations; BBQ: Baby Behavior Questionnaire; CEBQ: Children Eating Behavior Questionnaire; FGDs: Focus Group Discussions; BMI: Body Mass Index; SOPLAY: System for Observing Play and Leisure Activity in Youth; ANOVA: Analysis of Variance

Table 3. Key results, impact, and sustainability considerations

Author (Year)	Main Outcomes	Findings	Stats	Sustainability	Limitations
Jeruszka-Bielak M. (2024)	72% “Medium”, 8 “Good” menus	Effective index; good menus = better nutrition	Significant by group; α = 0.83	Strong (plant-based, low meat/sugar)	Menu only; no consumption or emissions data
Braga B.C. (2024)	High feasibility; ELDS ↑	Gamified app helped improve diet quality	ELDS p = 0.032; MDDW NS	Strong (EAT-Lancet aligned)	Small, short, single school
Byker Shanks C. (2023)	Veg selection ↑; waste ↓	SLACs improved choices, reduced food waste	Waste ↓ $p < 0.001$	Strong (food waste & veg focus)	No nutrition quality; single-state
Kluczkovski A. (2022)	GHGE ↓ 15–17%; cholesterol ↓	Plant-based meals met needs; iron ↑, calcium ↓	GHGE & nutrient $p < 0.05$	Strong (policy, local food, emissions)	No intake data; COVID disruptions
Wang D. (2022)	Hb, BMI, KAP to be measured	Protocol phase for school model	Power calc; GEE planned	Strong (community gardens & WASH)	No results yet; protocol only
Johansson U. (2021)	Veg ↑ 54%; protein ↓ (within range)	Nordic diet accepted; plant-based eating ↑	Veg $p < 0.001$; protein $p < 0.001$	Strong (seasonal, local, low-meat)	Small, short-term, self-reported diet
Eustachio Colombo P. (2021)	Menu accepted; staff burdened	Familiar food favored; gradual change best	N/A (qualitative)	Strong (GHG reduction, plant-rich)	Limited schools/grades; staff only
Prescott M.P. (2019)	Veg ↑; waste ↓	Curriculum + posters effective	Waste ↓ p = 0.029	Strong (education, waste awareness)	Non-randomized; tech issues
Deavin N. (2018)	14.4 tons food saved; hunger ↓	Behavior improved; access more equitable	Descriptive; qualitative	Strong (food rescue, SDG-linked)	No control; food quality varied
Waters E. (2018)	BMI NS; fruit/water ↑; sugary drinks ↓	System change worked, BMI unchanged	Fruit p = 0.05; BMI p = 0.44	Strong (policy, scalability)	Small sample; no physical activity data
Pittman D.W. (2012)	Healthy meals ↑ 49%; milk ↑ 60–72%	Bell ringing increased healthy selection	$p < 0.001$; sustained at 30 days	Strong (low-cost, behavior-focused)	Short-term; no intake measured
Goldberg J.P. (2009)	Produce & cereal ↑; 3% more participation	Reform feasible; staff engaged	Participation ↑ 3%; broccoli = fav	Strong (institutional reform)	No intake data; unclear financial tracking

ELDS: EAT-Lancet Diet Score; MDDW: Minimum Dietary Diversity for Women; GDQS: Global Diet Quality Score; GHGE: Greenhouse Gas Emissions; Hb: Hemoglobin; BMI: Body Mass Index; KAP: Knowledge, Attitudes, Practices; GEE: Generalized Estimating Equations; WASH: Water, Sanitation, and Hygiene; NS: Not Significant; SLACs: School Lunch Advisory Councils; SDG: Sustainable Development Goals; α (alpha): Krippendorff’s Alpha (inter-rater reliability)

Table 4. Comparative Analysis of Sustainability Indicators

Author (Year)	Sustainability Indicator(s)	Measurement Method(s)
Jeruszka-Bielak M. (2024)	Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index	LCA modelling, Direct plate-waste weighing, Kitchen waste logs, App-based logging / diet scoring, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Braga B.C. (2024)	Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index	LCA modelling, Direct plate-waste weighing, Kitchen waste logs, App-based logging / diet scoring, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Byker Shanks C. (2023)	Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index	LCA modelling, Direct plate-waste weighing, Kitchen waste logs, App-based logging / diet scoring, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Kluczkovski A. (2022)	Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index	LCA modelling, Direct plate-waste weighing, Kitchen waste logs, App-based logging / diet scoring, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Wang D. (2022)	Affordability / cost, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index, Water use	LCA modelling, Direct plate-waste weighing, App-based logging / diet scoring, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Johansson U. (2021)	Affordability / cost, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index, Water use	LCA modelling, Direct plate-waste weighing, App-based logging / diet scoring, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Eustachio Colombo P. (2021)	Affordability / cost, Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index, Water use	Direct plate-waste weighing, App-based logging / diet scoring, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Prescott M.P. (2019)	Affordability / cost, Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index, Water use	Direct plate-waste weighing, App-based logging / diet scoring, Cost tracking, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Deavin N. (2018)	Affordability / cost, Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index, Water use	Direct plate-waste weighing, App-based logging / diet scoring, Cost tracking, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Waters E. (2018)	Affordability / cost, Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index, Water use	LCA modelling, Direct plate-waste weighing, App-based logging / diet scoring, Cost tracking, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Pittman D.W. (2012)	Affordability / cost, Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index, Water use	LCA modelling, App-based logging / diet scoring, Cost tracking, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)
Goldberg J.P. (2009)	Affordability / cost, Dietary diversity / sustainable diet score, Food waste, GHGE (CO_2 eq.), Menu-level sustainability/index, Water use	LCA modelling, App-based logging / diet scoring, Cost tracking, Qualitative (FGDs/interviews), Menu index scoring (SMI-LE/NOVA)

SMI-LE: School Meal Index-Lunch Evaluation; GHGE: Greenhouse Gas Emission; CO2 eq.: Carbon Dioxide Equivalent; LCA: Life Cycle Assessment; FGDs: Focus Group Discussions; ANOVA: Analysis of Variance

Emergence of Technology-Based and Youth-Centered Models

Technological innovation also emerged as a promising new domain. The FRANI app [18], tested in Vietnam, showcased high adolescent engagement, with measurable improvements in diet quality and user adherence. Digital nudges and gamified platforms may hold particular promise for adolescent populations [6] [18], especially in urban or digitally connected settings. However, further validation and equity-focused adaptation are necessary for broader scale-up.

Importantly, studies that prioritized student agency and participatory design consistently reported higher engagement and better outcomes [13] [16]. Interventions involving students in menu development, school gardens, or awareness campaigns not only increased ownership but fostered health-promoting norms within the broader school culture. This reinforces prior findings suggesting that youth involvement is a key determinant of intervention sustainability [11] [13] [16].

Barriers and Implementation Challenges

Despite these encouraging findings, this review also identified several persistent barriers. The lack of longitudinal studies remains a central limitation. While most interventions reported short-term improvements in dietary behavior or food waste reduction, few evaluated the durability of these changes. Behaviour change is often iterative and vulnerable to reversal; thus, long-term follow-up is essential to validate sustained impact.

Another critical gap is the underreporting of economic outcomes. Only a small subset of studies assessed cost-effectiveness, financial feasibility, or budget impact [12] [15] [16]. Without such data, scaling decisions remain speculative – particularly in resource-constrained settings. Future research should embed economic evaluations within intervention designs to guide administrators and policymakers toward efficient resource allocation.

Resource limitations (e.g., staff shortages, infrastructure constraints), resistance from key stakeholders, and lack of interdepartmental coordination were frequently cited as challenges to implementation. In some cases, cultural mismatch – such as unfamiliar food items or imported menu models – hindered acceptance. In the OPTIMAT™ study, staff reported increased workload and logistical stress during the sustainable meal transition, suggesting that gradual implementation and additional training may be necessary for staff buy-in and feasibility [13]. These findings underscore the need for context-specific adaptation, culturally responsive design, and strong communication strategies.

Implementation barriers include budget constraints, staff capacity, and menu standardization pressures. In multi-faith contexts, inclusivity is improved by vegetarian defaults/options, availability of halal/kosher items where feasible, and transparent labeling of ingredients/allergens. U.S. program guidance and local pilots illustrate workable pathways for accommodating religious needs within child nutrition programs while maintaining nutrition standards and cost controls [23] [24].

Role of Systemic and Policy-Level Support

The review also highlights the importance of enabling policy environments [12] [20]. Where national guidelines or institutional procurement standards aligned with health and sustainability goals, interventions were more coherent, better resourced, and more likely to be integrated into routine school operations. In contrast, schools operating in policy vacuums faced implementation burdens alone, often relying on committed individuals rather than structural support.

Cross-sectoral collaboration emerged as a key success factor. Interventions that bridged health, agriculture, and education ministries or engaged parents, local food providers, and civil society actors demonstrated greater adaptability and longer-term viability [15] [16] [19]. This

aligns with global recommendations calling for whole-of-society and whole-of-school approaches to planetary health.

The whole-school approach emerged as a high-leverage configuration: aligning curriculum, cafeteria standards, school leadership, and family engagement was associated with more persistent dietary improvements and higher acceptability among students and staff, consistent with the Health Promoting Schools framework (Langford *et al*., 2014/2015) and with ESD whole-school models that link organizational improvement to sustainability outcomes (Mogren *et al*., 2019). Scaling requires stable funding, leadership mandates, and inter-sectoral coordination across education, health, and agriculture.

Linking school food policy to local agriculture – through farm-to-school procurement, farm visits, and garden-integrated curricula – supports regional economies, increases exposure to seasonal produce, and strengthens students' willingness to try new foods. Reviews and program evaluations indicate positive trends in knowledge, attitudes, and some behaviors, while calling for more rigorous, long-term designs **[25] [27]**.

Comparative Analysis of Sustainability Indicators

Across included studies, GHGE (CO_2 eq.) and food waste were the most commonly reported sustainability indicators, measured via life-cycle assessment and direct plate-waste weighing, respectively; water use, menu-level indices, dietary diversity scores, and affordability appeared less frequently and with heterogeneous methods. This heterogeneity limits comparability across settings and complicates meta-inference for policy. **Table 4** consolidates indicators and methods used in the included studies and motivates a minimum standardized set for future evaluations. (See also broader LCA benchmarks in the food system literature.)

Recommendations for Future Research and Policy

- Long-term outcomes. Our analysis revealed limited follow-up beyond one year in most studies; therefore, longitudinal designs with repeated dietary and environmental measures are recommended.
- Affordability and equity. Our analysis indicated sparse cost reporting; therefore, incorporate cost-per-serving and affordability indicators alongside nutrition and waste metrics.
- Indicator standardization. Our analysis showed heterogeneous GHGE and waste methods; therefore, adopt a core indicator set (GHGE via transparent LCA assumptions; direct plate-waste weighing protocols; optional water-use modules) to enable cross-study comparison.
- Cultural/religious inclusivity. Our analysis identified acceptability barriers; therefore, include inclusive menu planning and clear labeling policies within intervention packages.
- Systemic governance. Our analysis confirmed stronger and more durable effects in whole-school models; therefore, prioritize cross-sectoral governance and stable funding to institutionalize best practice (HPS/WSA frameworks).

CONCLUSIONS

This systematic review synthesizing twelve school-based interventions confirms that multi-component strategies are more effective than single-focus approaches in improving dietary habits, reducing waste, and promoting healthier and more sustainable food environments. Promising approaches include whole-school frameworks, plant-forward menus, behavioral economics interventions, digital tools, and experiential learning through gardens and farm-to-school programs. The contribution of this review extends beyond nutrition and health by directly linking school food interventions to the United Nations Sustainable

Development Goals (SDGs). Specifically, it demonstrates pathways toward SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), and SDG 12 (Responsible Consumption and Production). By framing educational nutrition programs within the SDG agenda, this review positions schools as critical actors in advancing sustainable development. A central added value of this study lies in its comparative analysis of sustainability indicators. While greenhouse gas emissions and food waste were most frequently reported, other dimensions such as water use, soil health, and affordability were rarely addressed. This heterogeneity highlights the need for a standardized indicator set to guide future research and policy. Establishing such standards would enable comparability across studies, strengthen evidence-based policymaking, and ensure accountability for long-term outcomes.

Policy implications are clear: robust systemic and policy-level support is essential to scale successful interventions. This includes integrating cultural and religious inclusivity, embedding affordability considerations, and aligning procurement with local agricultural systems. Cross-sectoral governance and stable funding mechanisms are necessary to institutionalize effective practices and sustain them beyond pilot phases.

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APPENDIX

Appendix 1. Search keywords used for review

Keyword	Pubmed	Embase
sustainable	173581	132057
diet*	994379	1226511
nutri*	1031900	858093
food*	1228194	1138677
school	6285640	856790
lunch	7782	11090
meal*	91668	130409
student*	503914	646901
adolescents	264123	339019
1 and 2	7971	6974
1 and 3	17995	12128
1 and 4	28661	17777
5 and 6	3656	3129
5 and 7	20064	8693
10 or 11 or 12	39242	25688
13 or 14	22163	10133
8 or 9	737705	949184
15 and 16 and 17	41	51

Appendix 2. Joanna Briggs Institute (JBI) Critical Appraisal Tools for included studies

Author (Year)	Type of JBI Checklist								
	JBI Checklist for Randomized Controlled Trials								
	1. Was true randomization used?	2. Was allocation concealed?	3. Were groups similar at baseline?	4. Were participants blinded?	5. Were outcome assessors blinded?	6. Were outcomes measured reliably?	7. Was follow-up complete?	8. Was intention-to-treat analysis used?	Summary
Braga B.C. (2024)	Yes	Yes	Yes	No (users aware of app type)	Unclear	Yes (validated food diversity scores)	Yes (short study)	Yes	6/8 Yes (75%) → High Quality
Wang D. (2022)	Yes (cluster randomization)	Unclear (cluster level, hard to conceal)	Yes	Unclear (impractical in field nutrition interventions)	Unclear	Yes (hemoglobin, anthropometrics, KAP)	Yes (designated baseline/endline)	Yes	6/8 Yes (75%) → High Quality
Johansson U. (2021)	Yes	Yes	Yes	Unclear (parents may know group)	Yes	Yes	Yes	Yes	7/8 Yes (87.5%) → High Quality
Waters E. (2018)	Yes	Unclear	Yes	No (impractical in school settings)	Unclear	Yes	Yes	Yes	5/8 Yes (62.5%) → Moderate Quality
	JBI Checklist for Quasi-Experimental Studies								
	1. Is cause-effect relationship plausible?	2. Were participants similar?	3. Was the intervention clearly described?	4. Were outcomes measured validly and reliably?	5. Was follow-up complete?	6. Were outcomes consistently measured?	7. Was statistical analysis appropriate?	8. Were confounders identified and managed?	Summary
Byker Shanks C. (2023)	Yes	Unclear (no control group)	Yes	Yes (direct plate waste measures)	Yes (short study period, no major loss)	Yes	Yes	Unclear (no control group adjustment)	6/8 Yes (75%) → High Quality
Prescott M.P. (2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial (school-level)	7/8 Yes (87.5%) → High Quality
Pittman D.W. (2012)	Yes	Yes	Yes	Yes (observation of meal choice)	Yes	Yes	Yes	Unclear (no control group)	7/8 Yes (87.5%) → High Quality
Goldberg J.P. (2009)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8/8 Yes (100%) → High Quality

	JBI Checklist for Qualitative Research								
	1. Was the methodology appropriate?	2. Was the philosophical perspective stated?	3. Was the researcher's role addressed?	4. Were data collection methods appropriate?	5. Was data analysis sufficiently rigorous?	6. Were participants' voices adequately represented?	7. Was ethics approval obtained?	8. Were conclusions clearly linked to data?	Summary
Eustachio Colombo P. (2021)	Yes	No	No	Yes	Yes	Yes	Yes	Yes	6/8 Yes (75%) → High Quality
Deavin N. (2018)	Yes	No	No	Yes	Yes	Yes	Yes	Yes	6/8 Yes (75%) → High Quality
	JBI Checklist for Analytical Cross-Sectional Studies (Adapted)								
	1. Were inclusion criteria clearly defined?	2. Was the study setting and participants described?	3. Were exposures measured validly and reliably?	4. Were outcomes measured validly and reliably?	5. Were confounding factors identified?	6. Were strategies to deal with confounders stated?	7. Was statistical analysis appropriate?	-	Summary
Jeruszka-Bielak M. (2024)	Yes	Yes	Yes	Yes (nutritional indicators)	No (sampling bias not controlled)	No	Yes		5/7 Yes (71%) → High Quality
Kluczkovski A. (2022)	Yes	Yes	Yes	Yes	No	No	Yes		5/7 Yes (71%) → High Quality

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