Improving the school food environment for the prevention of childhood obesity: What works and what doesn't

Elisa Pineda^{1,2} | Josefina Bascunan¹ | Franco Sassi¹

¹Centre for Health Economics & Policy Innovation (CHEPI), Imperial College Business School, London, UK

²School of Public Health, Imperial College London, London, UK

Correspondence

Elisa Pineda, Centre for Health Economics & Policy Innovation (CHEPI), Imperial College Business School, London SW7 2AZ, UK, and School of Public Health, Imperial College London, London W6 8RP, UK.
Email: e.pineda@imperial.ac.uk

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Summary

The food environment has a significant influence on dietary choices, and interventions designed to modify the food environment could contribute to the prevention of childhood obesity. Many interventions have been implemented at the school level, but effectiveness in addressing childhood obesity remains unclear.

We undertook a systematic review, a meta-analysis, and meta-regression analyses to assess the effectiveness of interventions on the food environment within and around schools to improve dietary intake and prevent childhood obesity. Estimates were pooled in a random-effects meta-analysis with stratification by anthropometric or dietary intake outcome. Risk of bias was formally assessed. One hundred papers were included. Interventions had a significant and meaningful effect on adiposity (body mass index [BMI] z score, standard mean difference: -0.12 , 95% confidence interval: 0.15 , 0.10) and fruit consumption (portions per day, standard mean difference: $+0.19$, 95% confidence interval: 0.16 , 0.22) but not on vegetable intake. Risk of bias assessment indicated that $n = 43$ (81%) of non-randomized controlled studies presented a high risk of bias in the study design by not accounting for a control. Attrition bias ($n = 34$, 79%) and low protection of potential contamination ($n = 41$, 95%) presented the highest risk of bias for randomized controlled trials.

Changes in the school food environment could improve children's dietary behavior and BMI, but policy actions are needed to improve surrounding school food environments to sustain healthy dietary intake and BMI.

KEYWORDS

dietary intake, interventions, obesity, policies, school food environment

1 | INTRODUCTION

Obesity is a complex public health issue that requires large-scale and population-based solutions.^{1–3} Schools are the places where children spend most of their time and have access to a significant part of the food they eat; therefore, they are key settings for the prevention of obesity.⁴ The food environment exerts important influences on

dietary intake and the prevention of childhood obesity.^{5,6} The food environment is defined as a combination of physical, economic, political, and sociocultural surroundings as well as opportunities and conditions that influence food choice.⁷ It encompasses geographic access, food availability, food affordability, and food quality.⁷

The food environment within schools includes canteens, kiosks, and vending machines,⁸ whereas the food environment around or

Abbreviations: BMI, body mass index; CI, confidence interval; cQED, controlled quasi-experimental design; MD, mean difference; OR, odds ratios; PICO, population, intervention, comparison, and outcome framework; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; QED, quasi-experimental design; RCT, randomized controlled trial; RoB 2, version 2 of the Cochrane risk of bias tool for randomized trials; ROBINS-I, Risk of Bias in Non-Randomized Studies of Interventions; SEP, socioeconomic position; SSB, sugar-sweetened beverages; STOP, Science & Technology in childhood Obesity Policy project.

outside schools includes the location and concentration of food retailers such as convenience stores, take-aways, and fast-food outlets.⁹ Vending machines within schools and fast-food outlets around schools have been associated with low dietary quality and higher body mass index (BMI) among children.^{10,11} Other reviews^{12–15} have focused on policies that target the provision of food or physical activity programs. A previous review of the effectiveness of school food environment policies¹⁶ included a meta-analysis of studies published up to 2014 for a range of food and nutrient intakes but did not detect significant effects on total calorie intake.

Several studies published in the past seven years have identified effects of school food environment policies on children's BMI, providing an opportunity to capture a broader range of effects of such policies. Therefore, we have designed a new systematic review, meta-analysis, and meta-regression aimed at assessing the effectiveness of school food environment interventions in the prevention of childhood obesity, with a focus on adiposity and dietary intake outcomes, based on studies published up to 2020. In this review, we define school food environment interventions as programs, strategies, guidelines, policies, or laws that modify food choice architecture, built environment, or a physical aspect of the food environment, within or around schools, aimed to prevent childhood obesity. Food choice architecture and physical aspects of the food environment refer to all related aspects of how food choice is framed and how it influences food selection, including school ambience modifications, placement, presentation, availability, and accessibility of food within or around schools.¹⁷

2 | METHODS

2.1 | Search strategy

We systematically reviewed the effects of school food environment interventions aimed at improving children's obesity-related outcomes and identified features of interventions of the food environment within and around schools that enable or impede their implementation or effectiveness. The search strategy was based on the population, intervention, comparison, and outcome (PICO) framework shown in Table 1. We included school food environment interventions that aimed to prevent obesity and improve food choice selection (e.g., increased consumption of fruit and vegetables) through modifications of the school's built or physical food environment, food choice architecture, modification and implementation of guidelines, or direct food provision (Table 1). The search strategy was designed in consultation with a specialist subject (health) librarian from Imperial College London. CINAHL, Embase, Global Health, MEDLINE, SciELO, and Cochrane databases were searched for relevant articles published in scholarly journals until January 2020 through keyword searches (Table S1). Additional articles were added using a snowballing approach. The search strategy was refined by conducting a sensitivity analysis in Embase with a test set of 10 key papers selected from existing systematic reviews. The protocol was registered with Prospective Register of Systematic Reviews (PROSPERO, CRD42019125039). A second reviewer conducted a reliability check on 10% of publications.

TABLE 1 Description of the PICO framework implemented for the assessment of effective school food environment interventions for the prevention of childhood obesity

PICO feature	Criteria
Population	Inclusion: School aged children, ≤19 years of age, as defined by the World Health Organization. ¹⁸ Exclusion: Children with a critical illness or severe comorbidities (e.g., diabetes) or special populations (e.g., blind or physically disabled).
Intervention	Interventions that focus on the school food environment and that aim to shape accessibility, affordability, desirability, and convenience of food acquirement and consumption to prevent obesity/improve dietary intake. The school food environment incorporates all the spaces, infrastructure and conditions inside and around the school premises where food is available, obtained, purchased, and/or consumed (e.g., tuck shops, kiosks, canteens, food vendors, and vending machines), also taking into account the provision and nutritional content of food in school grounds. The environment also includes all of the information available, promotion (marketing, advertisements, branding, food labels, packages, promotions, etc.), and the pricing of foods and food products.
Comparison	Comparators may include no intervention, or a comparison of the same group before the implementation of the intervention.
Outcomes	Primary outcomes: Weight and height, fat mass percent, BMI, ponderal index, skin-fold thickness, waist circumference, waist-hip ratio, prevalence of overweight and obesity, BMI z score, dietary intake, and food purchasing. Excluded outcomes: Changes in awareness, knowledge, opinions, or beliefs. Adverse outcomes: Detrimental effects on primary outcomes. Cost to participants (\$ or time), disappointment at failing to decrease obesity-related outcomes, health inequity.

Abbreviations: BMI, body mass index; PICO, population, intervention, comparison, and outcomes.

This step was carried out during the title and abstract revision of papers for their inclusion or exclusion in the review. The reference managing software Rayyan was used to carry out this process. Inter-coder reliability for the 10% of manuscripts with reliability checks was assessed using Cohen's kappa (κ). The 10% reliability check led to 16 conflicts, all resolved after discussion, and the relevant papers were subsequently included for full-text review. The intercoder reliability for the 10% of manuscripts for this review indicated a reliability of 85% ($\kappa = 0.85$).

2.2 | Data extraction

After study selection, the following information was extracted from each retrieved article: type of document, school setting, country,

number of intervention components, type and elements of intervention, analytical sample size, age groups, ethnicity and socioeconomic position (SEP) of population, baseline and follow-up outcome measures, obesity measure, inclusion of physical activity, statistical method of assessment, study design, intervention duration, effectiveness of intervention, sustainability of intervention, main findings, and study limitations. Reported outcomes were taken directly from published studies.

2.3 | Statistical analyses

We conducted random-effect meta-analyses to investigate the impact of interventions on BMI z score (relative weight for child age) and fruit and vegetable intake. These three outcome measures are key in assessing changes in weight and dietary intake associated with obesity¹⁹; additionally, these outcomes facilitate translation into policies and actions. These outcomes are also the most often reported measures of the impacts of school food environment interventions, which allows wider comparisons between studies and interventions. The numbers of studies using different outcome measures were too small to undertake meta-regressions on those outcomes with reliable estimation of the effects of moderators.²⁰

We reported the mean difference (MD) between the intervention group and the control group of BMI z score and fruit and vegetable intake outcomes when values were available (preferentially);

alternatively, baseline and follow-up time points were considered for each outcome (Figures 2–4).

Equivalent estimates were combined, and a pooled estimate and confidence interval (CI) for the treatment effect was extracted or calculated when possible. Meta-analyses were carried out to assess the effect of school food environment interventions on children's BMI z score and dietary intake. Effect sizes were calculated when data were missing. Results are presented by study design. All statistical analyses were conducted in Stata 16.0 (College Station, TX: StataCorp LP).

2.4 | Meta-regression analyses

To assess heterogeneity, meta-regression analyses were carried out in studies that assessed intervention and control differences or baseline and follow-up differences for BMI z score, fruit intake, and vegetable intake. Pilot studies, non-peer-reviewed studies, and studies that did not clearly state differences between intervention and control groups, or baseline and follow-up measures, were excluded from the meta-analyses. Meta-regression analyses tested the association of study design (quasi-experimental design [QED] or randomized controlled trial [RCT]), type of study (scientific article, pilot study, policy, or program), school setting (internal, external, or both), country (United States, China, Latin American countries, European countries, Middle Eastern countries, United Kingdom, and others), components (single

FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart of study selection process

FIGURE 2 School food environment interventions and their effect on BMI z score. Study ID: Author, year, intervention period, sample size (N); I/C: Intervention versus control; F/B, Follow-up versus baseline. Solid squares represent study specific continuous changes in reported intakes and lines 95% confidence intervals (CIs). The vertical line represents pooled effect size (ES) and open diamond the corresponding 95% CI. Multicomponent strategies were included only if the food environment policy was a major component. QED, quasi-experimental design; RCT, randomized controlled trial

component and multicomponent), type of intervention (vending machines, fruit and vegetable provision, breakfast provision, food placement, food modification, fruit provision, and guidelines), duration of the intervention in years (continuous variable), sex (boys, girls, or both), SEP (considered or not considered in intervention), and physical activity (considered or not considered in intervention). Mean effect sizes and 95% CI were calculated for intervention and control differences from baseline to follow-up for BMI z score, fruit intake, and vegetable intake. Analyses were carried out in Stata 16.0 (College Station, TX: StataCorp LP).

2.5 | Quality and risk of bias assessment

A risk of bias assessment was carried out using the version 2 of the Cochrane risk of bias tool for randomized trials (RoB 2) for RCTs and the Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) for non-randomized studies to determine the grading quality, certainty of evidence, and strength of recommendations.

For RCTs, eight components were evaluated: randomization, allocation concealment, baseline outcome measurements, baseline

characteristics, attribution bias, allocation knowledge, contamination protection, and selective reporting. An intervention was considered to have an overall high risk of bias if ≥ 4 bias components were high risk, medium risk if 3 components were high risk, and low risk of bias if < 3 bias components were high risk.

For non-RCTs, recorded as QED studies, risk of bias assessment was summarized into (1) selection bias (representation of exposed, baseline characteristics and baseline outcome). One point was given if the study sample was representative of the population, participants had a healthy weight with normal variations by sociodemographic characteristics, if baseline characteristics were not statistically significant or differences were controlled for in analyses, and if there was evidence that the outcome of interest was controlled for at baseline. Next is (2) comparability (adjusted confounders and extra confounders). One point was given if the study controlled for main confounders associated with childhood obesity and respective outcomes (e.g., SEP) and if the paper included covariates that could mediate or moderate the relationship of interest (in addition to including basic covariates such as age, gender, and SEP). Risk of bias assessment was also summarized into (3) study design. One point was given if controls were implemented and if control groups were in the same population. (4) Last

FIGURE 3 School food environment interventions and their effect on vegetable intake meta-analysis plot. Study ID: Author, year, intervention period, sample size (N); I/C: Intervention versus control; F/B: Follow-up versus baseline. Intakes represent habitual (not just in-school) consumption. Solid squares represent study-specific continuous changes in reported intakes and lines 95% confidence intervals (CIs). The vertical line represents pooled effect size (ES) and open diamond the corresponding 95% CI. Multicomponent strategies were included only if the food environment policy was a major component. QED, quasi-experimental design; RCT, randomized controlled trial

is outcome (outcome ascertain and follow-up). One point was given if the outcome of interest was obtained objectively and if the paper reported the sample attrition rates and/or discussed the implications of follow-up rates. An overall score was generated for each intervention study, which represented the sum of obtained points in relation to selection bias, comparability, study design, and outcome measure.

3 | RESULTS

The search strategy retrieved 4,307 studies, and searches in the gray literature and reference lists of included studies led to 63 additional papers (Figure 1). The full text of 177 papers was checked against eligibility criteria, and 100 peer-reviewed papers were selected.

The revised literature consisted of 76% interventions, 14% policies, 3% government programs, 6% pilot studies related to food environment interventions and obesity, and 1% other related literature. In terms of setting, 92% of studies focused on the food environment within schools or food choice architecture interventions (e.g., the relative availability and presentation of different foods), whereas 4% focused on the food environment around schools. Most

interventions were carried out in the United States (53%), 10% in the United Kingdom, 6% in Norway, and 6% in Latin America. In terms of the interventions, 63% involved a single component, such as food provision, whereas 37% encompassed multiple components. For single-component interventions, $n = 31$ (49% out of the $n = 63$ single-component interventions) were effective in the reduction of BMI or in the increase of fruits and/or vegetables, whereas for multicomponent interventions, $n = 21$ (57% out of 37 multicomponent interventions) were effective in health outcome improvements. No statistically significant association was found between the number of components and intervention effectiveness when looking at all anthropometrical and dietary outcomes together (Pearson chi-squared = 1.22, $p = 0.270$). Most of the interventions (60%) involved the direct provision of food (e.g., breakfast, lunch, snacks, or fruit and vegetables), 5% introduced or modified dietary guidelines in schools, and 9% modified existing school meals. Thirty-one percent of the interventions addressed aspects of the school food environment other than meals, such as the regulation of vending machines and kiosks or food stores, introduction of cafes, snack bars, or fruit and vegetable buffets. Thirty-seven percent of the studies tested interventions addressing both diet and physical

FIGURE 4 School food environment interventions and their effect on fruit intake. Study ID: Author, year, intervention period, sample size (N); I/C: Intervention versus control; F/B, Follow-up versus baseline. Intakes represent habitual (not just in-school) consumption. Solid squares represent study specific continuous changes in reported intakes and lines 95% confidence intervals (CIs). The vertical line represents pooled effect size (ES) and open diamond the corresponding 95% CI. Multicomponent strategies were included only if the food environment policy was a major component. QED, quasi-experimental design; RCT, randomized controlled trial

activity. Values do not add to 100% as multicomponent interventions used multiple approaches.

Regarding effectivity, 51% of interventions reduced BMI or improved dietary intake; however, only 24% of the effective interventions (51%) showed a sustained improvement regarding fruit and vegetable intake or the reduction of BMI/BMI z score after conclusion of the intervention (e.g., food provision). From food provision type interventions ($n = 60$), 32% were effective in the increase of healthy food consumption. For internal school food environment interventions ($n = 25$), 12% were effective and 3% had a partial effect in the reduction of BMI. A summary of the reviewed school food environment intervention characteristics may be found in Table 2.

3.1 | Meta-analysis results

Three meta-analyses were carried out. The first focused on BMI z score and included $n = 5$ studies, which provided 12 measured observations. The second focused on fruit intake and included 22 studies, which provided 53 observations. The third focused on vegetable intake and included $n = 13$ studies, with a total of 23 observations. The characteristics of the studies included in meta-analyses are shown in Table 3. Figures 2–4 present forest plots of meta-analyses regarding policy interventions on school food environments aimed at decreasing BMI z score and increasing fruit and vegetable intake in children. Forest plots have been stratified by study design to explore

TABLE 2 General characteristics of included studies

Reference	Type of document	School setting	Country	Effectiveness	Intervention type	Design and duration	Sustainability
Affenito et al., 2012 ²¹	Scientific article	Within	United States	No	Breakfast provision	QED, 1 y	Not evaluated
Amini et al., 2016 ²²	Scientific article	Within	Iran	Yes	Internal food environment	cRCT, 18 w	Not evaluated
Anderson et al., 2005 ²³	Scientific article	Within	Scotland	No	Fruit and vegetable provision	RCT, 9 m	Yes
Anderson et al., 2005 ²⁴	Opinion article/policy	Within	Scotland	Yes	NA	NA	NA
Arija et al., 2017 ²⁵	Scientific article	Within	Peru	Yes	Breakfast provision	RCT, 28 m	Not evaluated
Arsenault, 2009 ²⁶	Scientific article	Within	Colombia	No	Snack provision	QED, 4 m	Not evaluated
Asada et al., 2016 ²⁷	Policy document	Within	United States	Yes	Snack provision	QED, 1 y	Not evaluated
Asada et al., 2017 ²⁸	Policy document	Within	United States	Yes	Food environment	QED, 1 y	Not evaluated
Ashfield-Watt et al., 2009 ²⁹	Scientific article/pilot study	Within	New Zealand	Yes	Fruit provision	cRCT, 6 m	No
Ask et al., 2009 ³⁰	Scientific article/pilot study	Within	Norway	No	Lunch provision	RCT, 4 m	Not evaluated
Bartlett et al., 2013 ³¹	Policy report	Within	United States	Yes	Fruit and vegetable provision	QED, no C, 1 y	Not evaluated
Bere et al., 2006 ³²	Scientific article	Within	Norway	No	Internal food environment	RCT, 6 m	No
Bere et al., 2006 ³³	Scientific article	Within	Norway	Yes	Internal food environment	RCT, 1 y	No
Bere et al., 2010 ³⁴	Scientific article	Within	Norway	Yes	Internal food environment	RCT, 7 y	Yes
Bere et al., 2015 ³⁵	Scientific article	Within	Norway	Yes	Fruit provision	QED, no C, 7 y	No
Bhave et al., 2016 ³⁶	Scientific article	Outside	India	No	External food environment	QED, 5 y	Yes
Brauchla et al., 2014 ³⁷	Scientific article	Within	United Kingdom	Yes	Snack provision	RCT, 8 w	Not evaluated
Brunello et al., 2014 ³⁸	Scientific article	Outside	Italy	Yes	External food environment	RCT, NA	Not evaluated
Cadzow et al., 2015 ³⁹	Scientific article	Within	United States	Yes	Food provision	QED, 3 y	NA
Cândido Malcata and Espírito Santo, 2012 ⁴⁰	Scientific article	Within	Brazil	Yes	Food provision	QED, 2 y	Yes
Canterberry et al., 2018 ⁴¹	Scientific article	Within	United States	Yes	Food provision/service provider	QED, 8 w	Not evaluated
Cao et al., 2015 ⁴²	Scientific article	Within	China	Partial	Meal modification	cQED, 2y	Yes

(Continues)

TABLE 2 (Continued)

Reference	Type of document	School setting	Country	Effectiveness	Intervention type	Design and duration	Sustainability
Capogrossi, 2017 ⁴³	National program	Within	United States	No	Food provision	QED, 8 y	No
Carlin et al., 2006 ⁴⁴	Scientific article	Within	Italy	Yes	Food provision	QED, 1 y	Not evaluated
Chellappah et al., 2012 ⁴⁵	Scientific article/pilot study	Within	Australia	Yes	Fruit provision	RCT, 5 w	NA
Clark and Fox, 2008 ⁴⁶	Scientific article	Within	United States	No	Food provision	RCT, 1 y	Not evaluated
Clauss et al., 2014 ⁴⁷	Scientific article	Within	United States	Yes	Food environment/labeling/marketing	QED, 7 y	Not evaluated
Cohen et al., 2015 ⁴⁸	Scientific article	Within	United States	Yes	Food environment/choice architecture/meal modification	RCT, 7 m	Yes
Coleman et al., 2012 ⁴⁹	Scientific article	Within	United States	Partial	Internal food environment and food provision	cRCT, 2 y	No
Coyle et al., 2009 ⁵⁰	Scientific article/pilot study	Within	United States	Yes	Fruit and vegetable provision	QED, no C, 1 y	Yes
Crepinsek et al., 2006 ⁵¹	Scientific article	Within	United States	No	Breakfast provision	RCT, 3 y	Not evaluated
Cullen et al., 2007 ⁵²	Scientific article/pilot study	Within	United States	Yes	Internal food environment/vending machines	QED, 6 y	Not evaluated
Cunningham-Sabo et al., 2003 ⁵³	Scientific article	Within	United States	Yes	Staff training/meal modification	QED, 3 y	Not evaluated
Damsgaard et al., 2012 ⁵⁴	Scientific article	Within	Denmark	Not clear on BMI	Food provision/meal modification	RCT, 3 m	Not evaluated
Datar et al., 2017 ⁵⁵	Law	Within	United States	Yes	Internal food environment	QED, NA	Not evaluated
Day et al., 2008 ⁵⁶	Scientific article	Within	Canada	Partial	Food environment and fruit and vegetable provision	QED, 12 w	NA
Domel Baxter et al., 2010 ⁵⁷	Scientific article	Within	United States	No	Food provision	QED, 3 y	Not evaluated
Domel Baxter et al., 2012 ⁵⁸	Scientific article	Within	United States	No	Food provision	QED, 4 y	Not evaluated
Eagle et al., 2013 ⁵⁹	Scientific article	Within	United States	Yes	Environmental change/choice architecture/food modification/vending machine changes	QED, 10 w	Yes
Eriksen et al., 2013 ⁶⁰	Scientific article	Within	Denmark	No	Fruit and vegetable provision	QED, no C, 5 w	Not evaluated

(Continues)

TABLE 2 (Continued)

Reference	Type of document	School setting	Country	Effectiveness	Intervention type	Design and duration	Sustainability
Ermetici et al., 2016 ⁶¹	Scientific article	Within	Italy	Yes	Internal food environment, vending machines	RCT, 2 y	Not evaluated
Fitzpatrick et al., 2017 ⁶²	Scientific article	Both	Canada	Yes	Internal and external food environment	QED, 2 y	Yes
Fogarty et al., 2007 ⁶³	Scientific article	Within	United Kingdom	Yes	Fruit provision	QED, no C, 1 y	No
Foster et al., 2008 ⁶⁴	Scientific article	Within	United States	Yes	Food environment and guideline implementation	RCT, 2 y	No
Fu et al., 2018 ⁶⁵	Policy	Within	Hong Kong	Yes	Internal food environment	QED, 7 y	Yes
Fung et al., 2013 ⁶⁶	Scientific article/policy	Within	Canada	No	Guideline implementation, food provision and modification	QED, 8 y	No
Garcia Gabriel et al., 2009 ⁶⁷	Law/legislation	Within	Brazil	No	Internal food environment	QED, 7 y	Not evaluated
Goldberg et al., 2009 ⁶⁸	Scientific article	Within	United States	Yes	Fruit and vegetable provision	QED, 1 y	Not evaluated
Gortmaker et al. 1999 ⁶⁹	Scientific article	Within	United States	Yes	Fruit and vegetable provision and meal modification	RCT, 2 y	NA
Gortmaker et al., 1999 ⁷⁰	Scientific article/state program	Within	United States	Yes	Fruit and vegetable provision and meal modification	QED, 21 m	NA
Greece et al., 2015 ⁷¹	Scientific article	Within	United States	No	Food environment/choice architecture/meal modification	QED, 1 y	Not evaluated
Guinn et al., 2013 ⁷²	Scientific article	Within	United States	No	Food provision	QED, 3 y	Not evaluated
Hanks et al., 2012 ⁷³	Scientific article	Within	United States	No	Internal food environment	QED, 8 w	Not evaluated
Hawkings et al., 2018 ⁷⁴	Scientific article	Within	United States	Yes	Food environment	RCT, 28 m	Yes
Heelan et al., 2015 ⁷⁵	Scientific article	Within	United States	Yes	Internal food environment	QED, 6 y	Not evaluated
Hennessy, 2014 ⁷⁶	Laws	Within	United States	Yes	Food provision	QED, 2 y	Not evaluated
Herscovici et al., 2013 ⁷⁷	Scientific article	Within	Argentina	Yes	Food provision/service provision	QED, 6 m	Yes
Himes et al., 2003 ⁷⁸	Scientific article	Within	United States	Yes	Food provision and meal modification	RCT, 3 y	Yes
Hollar et al., 2010 ⁷⁹	Scientific article	Within	United States	Yes	Meal modification	QED, 2 y	Yes
Hollar et al., 2015 ⁸⁰	Conference presentation abstract	Within	United States	Yes	Snack provision	QED, 24 w	Yes
Holmes et al., 2016 ⁸¹	Policy document	Within	United Kingdom	Yes	Food provision	QED, 4 w	Not evaluated

(Continues)

TABLE 2 (Continued)

Reference	Type of document	School setting	Country	Effectiveness	Intervention type	Design and duration	Sustainability
Hoppu et al., 2010 ⁸²	Scientific article	Within	Finland	No	Food environment and snack provision	QED, no C, 1 y	No
Johnson et al., 2017 ⁸³	Scientific article	Within	United States	No	Food environment/salad bars/vegetable provision	QED, 3 y	Yes
Kain et al., 2004 ⁸⁴	Scientific article	Both	Chile	No	Internal food environment	cQED, 6 m	Not evaluated
Kalarchian et al., 2013 ⁸⁵	Scientific article/pilot study	Within	United States	Yes	Food provision	QED, 8 w	Not evaluated
Kimbrow et al., 2010 ⁸⁶	Scientific article	Within	United States	Mixed findings	Food provision and meal modification	QED, 5 y	NA
Liu et al., 2019 ⁸⁷	Scientific article	Within	China	No	Food provision	QED, 1 y	No
Lytle et al., 2014 ⁸⁸	Scientific article	Within	United States	No	Internal food environment	RCT, 2 y	No
Mhurchu et al., 2010 ⁸⁹	Scientific article	Within	New Zealand	NA	Breakfast provision	RCT, 11 m	NA
Mobley et al., 2013 ⁹⁰	Scientific article	Within	United States	Yes, BMI not evaluated	Internal food environment	QED, 3 y	Not evaluated
Moore et al., 2008 ⁹¹	Scientific article assessment of policy	Within	United Kingdom	Mixed findings	Fruit sale	RCT, 1 y	No
Nanney et al., 2016 ⁹²	Policy	Within	United States	No	Internal food environment	QED, 2 y	No
Nanney et al., 2016 ⁹³	Scientific article	Within	United States	NA	Breakfast provision and place of provision change	RCT, 2 y	Not evaluated
Nanney et al., 2016 ⁹⁴	Scientific article	Both	United States	Yes	Internal and external food environment	QED, 6 y	Yes
Perry et al., 1999 ⁹⁵	Scientific article/state program	Within	United States	No	Meal modification	cQED, 7 m	Yes
Powel et al., 1983 ⁹⁶	Scientific article	Within	Jamaica	No	Food provision	RCT, NA	NA
Ramírez-López et al., 2005 ⁹⁷	Scientific article	Within	Mexico	Mixed findings	Breakfast provision	QED, 9 m	Not evaluated
Ransley et al., 2007 ⁹⁸	Scientific article	Within	United Kingdom	Yes	Fruit and vegetable provision	QED, no C, 2 y	No
Reilly et al., 2018 ⁹⁹	Scientific article	Within	Australia	BMI not evaluated	Internal food environment	QED, 6 m	Yes
Reinaerts et al., 2008 ¹⁰⁰	Scientific article	Within	Netherlands	Yes	Fruit and vegetable provision	QED, no C, 8 m	NA
Ritchie et al., 2015 ¹⁰¹	Scientific article	Within	United States	No	Breakfast provision	RCT, 1 y	Not evaluated
Schwartz et al., 2016 ¹⁰²	Scientific article	Within	United States	Yes	Water provision	QED, 5 y	Not evaluated
Sharma et al., 2010 ¹⁰³	Scientific article	Within	India	No	Lunch provision	RCT, 3 m	No

(Continues)

TABLE 2 (Continued)

Reference	Type of document	School setting	Country	Effectiveness	Intervention type	Design and duration	Sustainability
Sharma et al., 2016 ¹⁰⁴	Scientific article	Both	United States	No, BMI results were not provided	Internal food environment	QED, 2 y	Yes
Spense et al., 2013 ¹⁰⁵	Policy	Within	United Kingdom	NA	Food provision and modification	QED, 2 y	Yes
Story et al., 2003 ¹⁰⁶	Scientific article	Within	United States	Yes	Food modification	RCT, 3 y	Yes
Sudharsanan et al., 2014 ¹⁰⁷	Scientific article	Within	United States	No	Breakfast provision	RCT, 2 y	No
Taber et al., 2013 ¹⁰⁸	Law	Within	United States	Yes	Guideline implementation	QED, 1 y	Not evaluated
Tak et al., 2009 ¹⁰⁹	Scientific article	Within	Netherlands	Yes	Fruit and vegetable provision	QED, no C, 3 y	NA
Te Velde et al., 2008 ¹¹⁰	Scientific article	Within	Norway, the Netherlands, and Spain	Yes	Fruit and vegetable provision	RCT, 2 y	Partial
The HEAL THY Study Group, 2010 ¹¹¹	Scientific article	Within	United States	No	Internal food environment	cRCT, 2 y	Not evaluated
Thomas et al., 2016 ¹¹²	Scientific article	Within	United States	No	Food environment/choice architecture and food provision	RCT, 1 y	No
Vinit and Tremolieres, 1950 ¹¹³	Scientific article	Within	France	No	Milk and dairy products provision	QED, NA	No
Warren et al., 2008 ¹¹⁴	Scientific article	Within	United Kingdom	No	Breakfast provision and modification	QED, NA	Not evaluated
Williams et al., 1998 ¹¹⁵	Scientific article	Within	United States	NA	Food service modification	QED, NA	NA
Williams et al., 2002 ¹¹⁶	Scientific article	Within	United States	No	Food modification	QED, 2 y	Yes
Xu et al., 2017 ¹¹⁷	Scientific article	Within	China	Yes	Food modification	QED, 8 m	Yes
Vilsack, 2012 ¹¹⁸	Opinion article/policy	Within	United States	NA	Dietary guidelines/food provision	NA	NA
Pike and Colquhoun, 2009 ¹¹⁹	Scientific article	Within	United Kingdom	NA	Food provision	Observational	No
Young et al., 2013 ¹²⁰	Scientific article/policy	Within	United States	Yes	Fruit and vegetable provision	QED, 4 w	Not evaluated

Note: c: control; y: year; m: month; w: week.

Abbreviations: cQED, clustered quasi-experimental design; NA, not available; QED, quasi-experimental design; RCT, randomized controlled trial.

TABLE 3 General characteristics of studies included in meta-analysis and meta-regression analysis

Author	Country	Type of document	Intervention type	Components	Setting	Study design	Intervention duration	Age
BMI z score								
Amini et al., 2016	Iran	S	Internal food environment	Single component	Within	RCT	18 weeks	4th–6th grades, primary school
Amini et al., 2016	Iran	S	Internal food environment	Single component	Within	RCT	18 weeks	4th–6th grades, primary school
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Herscovici et al., 2013	Argentina	S	Internal food environment	Multicomponent	Both	RCT	6 mo	9–11 y
Herscovici et al., 2013	Argentina	S	Internal food environment	Multicomponent	Both	RCT	6 mo	9–11 y
Herscovici et al., 2013	Argentina	S	Internal food environment	Multicomponent	Both	RCT	6 mo	9–11 y
Liu et al., 2018	China	S	Food provision and modification/SSB banning	Multicomponent	Within	RCT	1 y	7–11 y
Xu et al., 2017	China	S	Meal modification	Multicomponent	Within	RCT	8 mo	6–13 y
Fruit intake								
Anderson et al., 2005	Scotland	S	Fruit and vegetable provision	Multicomponent	Within	RCT	8 mo	6–7 y and 10–11 y
Anderson et al., 2005	Scotland	S	Fruit and vegetable provision	Multicomponent	Within	RCT	8 mo	6–7 y and 10–11 y
Ashfield-Watt et al., 2009	New Zealand	Po	Fruit provision	Single component	Within	RCT	1 school term	7–11 y
Barlett et al., 2013	United States	Po	Fruit and vegetable provision	Single component	Within	QED	1 y	4th–6th grade
Bere et al., 2006	Norway	S	Internal food environment	Single component	Within	QED	6 mo	Mean age, 11.3 y, 6th grade
Bere et al., 2006	Norway	S	Internal food environment	Single component	Within	QED	6 mo	Mean age, 11.3 y, 6th grade

(Continues)

TABLE 3 (Continued)

Author	Country	Type of document	Intervention type	Components	Setting	Study design	Intervention duration	Age
Bere et al., 2006	Norway	S	Internal food environment	Single component	Within	QED	1 y	Mean age, 11.3 y, 6th grade
Bere et al., 2010	Norway	S	Internal food environment	Single component	Within	RCT	1 y	Mean age, 11.3 y, 6th grade
Bere et al., 2010	Norway	S	Internal food environment	Single component	Within	RCT	1 y	Mean age, 11.3 y, 6th grade
Bere et al., 2010	Norway	S	Fruit and vegetable provision	Single component	Within	RCT	7 y	6–7 y and 10–11 y
Bere et al., 2015	Norway	S	Fruit provision	Single component	Within	RCT	7 y	6th–7th grade
Bere et al., 2015	Norway	S	Fruit provision	Single component	Within	RCT	7 y	6th–7th grade
Bere et al., 2015	Norway	S	Fruit provision	Single component	Within	RCT	7 y	6th–7th grade
Bere et al., 2015	Norway	S	Fruit provision	Single component	Within	RCT	7 y	6th–7th grade
Day et al., 2008	Canada	S	Internal food environment and fruit and vegetable provision	Single component	Within	RCT	12 weeks	Mean age 10.1 (6.4)
Eagle et al., 2013	United States	S	Internal food environment/choice architecture/food modification/vending machine changes	Multicomponent	Within	QED	10 weeks	Mean age, 11.56 ± 0.47 y
Eriksen et al., 2013	Denmark	S	Fruit and vegetable provision	Single component	Within	QED	5 weeks	6–10 y
Eriksen et al., 2013	Denmark	S	Fruit and vegetable provision	Single component	Within	QED	5 weeks	6–10 y
Eriksen et al., 2013	Denmark	S	Fruit and vegetable provision	Single component	Within	QED	5 weeks	6–10 y
Eriksen et al., 2013	Denmark	S	Fruit and vegetable provision	Single component	Within	QED	5 weeks	6–10 y
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Fogarty et al., 2007	United Kingdom	S	Fruit provision	Single component	Within	QED	1 y	4th–6th grade
Fogarty et al., 2007	United Kingdom	S	Fruit provision	Single component	Within	QED	1 y	4th–6th grade

(Continues)

TABLE 3 (Continued)

Author	Country	Type of document	Intervention type	Components	Setting	Study design	Intervention duration	Age
Fogarty et al., 2007	United Kingdom	S	Fruit provision	Single component	Within	QED	1 y	4th–6th grade
Foster et al., 2008	United States	S	Internal food environment and guideline implementation	Multicomponent	Within	RCT	2 y	4th–6th grade
Gortmaker et al., 1999	United States	Pr	Fruit and vegetable provision and meal modification	Multicomponent	Within	QED	21 mo	5th grade students
Gortmaker et al., 1999	United States	Pr	Fruit and vegetable provision and meal modification	Multicomponent	Within	RCT	21 mo	5th grade students
Gortmaker et al., 1999	United States	Pr	Fruit and vegetable provision and meal modification	Multicomponent	Within	RCT	21 mo	5th grade students
Hopppu et al., 2010	Finland	S	Internal food environment and snack provision	Multicomponent	Within	QED	1 y	8th grader, mean age 13.8 y
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Moore et al., 2008	United Kingdom	Po	Fruit sale	Single component	Within	RCT	1 y	9–11 y
Moore et al., 2008	United Kingdom	Po	Fruit sale	Single component	Within	RCT	1 y	9–11 y
Perry et al., 1999	United States	Pr	Food modification	Multicomponent	Within	QED	2 mo for 4th grade and 3 mo for 5th grade, follow-up 2 mo	4th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade

(Continues)

TABLE 3 (Continued)

Author	Country	Type of document	Intervention type	Components	Setting	Study design	Intervention duration	Age
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	QED	10 mo	4th–7th grade
Reinaerts et al., 2008	Netherlands	S	Fruit and vegetable provision	Multicomponent	Within	QED	8 mo	Mean age 8 y
Tak et al., 2009	Netherlands	S	Fruit and vegetable provision	Single component	Within	QED	3 y	9–10 y, 4th grade
Tak et al., 2009	Netherlands	S	Fruit and vegetable provision	Single component	Within	QED	3 y	9–10 y, 4th grade
Te Velde et al., 2008	Norway, the Netherlands and Spain	S	Fruit and vegetable provision	Multicomponent	Within	RCT	2 y	10–13 y, 5th–6th
Vegetable intake								
Anderson et al., 2005	Scotland	S	Fruit and vegetable provision	Multicomponent	Within	RCT	8 mo	6–7 y and 10–11 y
Barlett et al., 2013	United States	Po	Fruit and vegetable provision	Single component	Within	QED	1 y	4th–6th grade
Bere et al., 2010	Norway	S	Fruit and vegetable provision	Single component	Within	RCT	7 y	6–7 y and 10–11 y
Cohen et al., 2015	United States	S	Internal food environment/choice architecture/meal modification	Single component	Within	RCT	3 mo	3rd–8th grade
Cohen et al., 2015	United States	S	Internal food environment/choice architecture/meal modification	Single component	Within	RCT	7 mo	3rd–8th grade
Cohen et al., 2015	United States	S	Internal food environment/choice architecture/meal modification	Single component	Within	RCT	7 mo	3rd–8th grade
Cohen et al., 2015	United States	S	Internal food environment/choice architecture/meal modification	Single component	Within	RCT	7 mo	3rd–8th grade

(Continues)

TABLE 3 (Continued)

Author	Country	Type of document	Intervention type	Components	Setting	Study design	Intervention duration	Age
Crepinsek et al., 2006	United States	S	Breakfast provision	Single component	Within	RCT	3 y	2nd–6th grade
Eagle et al., 2013	United States	S	Internal food environment/choice architecture/food modification/vending machine changes	Multicomponent	Within	QED	10 weeks	Mean age, 11.56 ± 0.47 y
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Ermetici et al., 2016	Italy	S	Internal food environment/vending machines	Single component	Within	QED	2 y	Middle school students
Lytle et al., 2004	United States	S	Internal food environment	Multicomponent	Within	RCT	2 y	Primary school students
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	RCT	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	RCT	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	RCT	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	RCT	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	RCT	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	RCT	10 mo	4th–7th grade
Ransley et al., 2007	United Kingdom	S	Fruit and vegetable provision	Single component	Within	RCT	10 mo	4th–7th grade
Reinaerts et al., 2008	Netherlands	S	Fruit and vegetable provision	Multicomponent	Within	QED	8 mo	Mean age 8 y
Tak et al., 2009	Netherlands	S	Fruit and vegetable provision	Single component	Within	QED	3 y	9–10 y, 4th grade
Te Velde et al., 2008	Norway, the Netherlands and Spain	S	Fruit and vegetable provision	Multicomponent	Within	RCT	2 y	10–13 y, 5th–6th

Note: Type of document: S, Scientific article; Pi, Pilot study; Po, policy document; Pr, programme; QED, quasi-experimental study; RCT, randomized controlled trial. Three meta-analyses were carried out. The first focused on BMI z score and included $n = 5$ studies, which provided 12 measured observations. The second focused on fruit intake and included 22 studies, which provided 53 observations. The third focused on vegetable intake and included $n = 13$ studies, with a total of 23 observations.

TABLE 3 (Continued)

Author	Sex	Physical activity	Statistical method	Effect size	LCI	UCI	Sustainability
BMI z score							
Amini et al., 2016	Both	Yes	ANCOVA, t tests or Wilcoxon or Mann–Whitney tests (continuous variables), Chi-squared or Fisher's exact probability tests (categorical variables).	−0.08	−0.42	0.26	Not evaluated
Amini et al., 2016	Both	Yes	ANCOVA, t tests or Wilcoxon or Mann–Whitney tests (continuous variables), Chi-squared or Fisher's exact probability tests (categorical variables).	0.02	−0.12	0.16	Not evaluated
Ermetici et al., 2016	Boys	Yes	ANCOVA	−0.04	−0.23	0.15	Not evaluated
Ermetici et al., 2016	Boys	Yes	ANCOVA	−0.22	−0.42	−0.03	Not evaluated
Ermetici et al., 2016	Girls	Yes	ANCOVA	−0.2	−0.32	−0.09	Not evaluated
Ermetici et al., 2016	Girls	Yes	ANCOVA	−0.39	−0.56	−0.22	Not evaluated
Ermetici et al., 2016	Both	Yes	ANCOVA	−0.18	−0.27	−0.09	Not evaluated
Herscovici et al., 2013	Girls	Yes	T test, ANOVA, McNemar chi-squared test	0.02	−0.12	0.08	Yes
Herscovici et al., 2013	Boys	Yes	T test, ANOVA, McNemar chi-squared test	−0.03	−0.11	0.06	Yes
Herscovici et al., 2013	Both	Yes	T test, ANOVA, McNemar chi-squared test	−0.28	−0.5	−0.06	Yes
Liu et al., 2018	Both		ANOVA	0.02	−0.08	0.11	Not evaluated
Xu et al., 2017	Both	Yes	ANOVA	−0.15	−0.18	−0.11	Not evaluated
Fruit intake							
Anderson et al., 2005	Both	No	Univariate analysis of variance	0.500	−0.2400	1.24	No
Anderson et al., 2005	Both	No	Univariate analysis of variance	0.950	0.4100	1.49	No
Ashfield-Watt et al., 2009	Both	No	General linear mixed model	0.300	0.2000	0.40	No
Barlett et al., 2013	Both	No	Regression discontinuity	0.260	0.1100	0.41	Not evaluated
Bere et al., 2006	Both	No	Linear mixed models	0.520	0.0400	1.00	No
Bere et al., 2006	Both	No	Linear mixed models	−0.510	−1.5568	−0.46	No
Bere et al., 2006	Both	No	Linear mixed models	−0.200	−0.7100	0.31	Yes
Bere et al., 2010	Both	No	Linear mixed models	−0.390	−1.7043	−0.34	Yes
Bere et al., 2010	Both	No	Linear mixed models	−0.260	−1.6065	−0.21	Yes
Bere et al., 2010	Both	No	Linear mixed models	0.580	0.0300	1.13	Yes
Bere et al., 2015	Both	No	Linear mixed models	0.340	−0.0100	0.68	No
Bere et al., 2015	Both	No	Linear mixed models	0.440	0.1000	0.77	No
Bere et al., 2015	Both	No	Linear mixed models	1.310	0.2000	2.43	No
Bere et al., 2015	Both	No	Linear mixed models	1.520	0.4000	2.65	No
Day et al., 2008	Both	No	ANOVA	0.970	−0.0100	1.95	NA
Eagle et al., 2013	Both	Yes	Paired t tests	0.090	0.0400	0.14	Yes
Eriksen et al., 2013	Both	No	Two-way analysis of variance (general linear model [GLM])	0.000	−1.0000	1.00	Not evaluated

(Continues)

TABLE 3 (Continued)

Author	Sex	Physical activity	Statistical method	Effect size	LCI	UCI	Sustainability
Eriksen et al., 2013	Both	No	Two-way analysis of variance (general linear model [GLM])	0.100	-0.0200	0.22	Not evaluated
Eriksen et al., 2013	Both	No	Two-way analysis of variance (general linear model [GLM])	0.100	-1.0000	1.00	Not evaluated
Eriksen et al., 2013	Both	No	Two-way analysis of variance (general linear model [GLM])	0.100	-1.0000	1.00	Not evaluated
Ermetici et al., 2016	Both	Yes	ANCOVA	0.300	-0.1700	0.77	Not evaluated
Ermetici et al., 2016	Both	Yes	ANCOVA	0.480	0.0900	0.87	Not evaluated
Fogarty et al., 2007	Both	No	T test and Mann-Whitney U test	-4.900	-8.7000	-1.10	No
Fogarty et al., 2007	Both	No	T test and Mann-Whitney U test	-2.800	-7.2000	1.60	No
Fogarty et al., 2007	Both	No	T test and Mann-Whitney U test	0.430	0.1700	0.68	No
Foster et al., 2008	Both	Yes	Generalized estimating equations, t test	0.040	-0.2900	0.37	No
Gortmaker et al. 1999	Both	Yes	Regression modelling	0.180	-0.2100	0.57	No
Gortmaker et al. 1999	Both	Yes	Regression modelling	0.730	0.2200	1.24	No
Gortmaker et al., 1999	Both	Yes	Regression modelling	0.320	0.1400	0.50	No
Hoppu et al., 2010	Both	No	Analysis of variance, Kendall's t-rank correlation coefficient	0.300	-0.0600	0.66	No
Lytle et al., 2004	Both	No	Mixed-model ANCOVA	0.375	0.0380	0.713	No
Lytle et al., 2004	Both	No	Mixed-model ANCOVA	-0.492	-1.0320	0.049	No
Lytle et al., 2004	Both	No	Mixed-model ANCOVA	-0.383	-1.0000	0.233	No
Lytle et al., 2004	Both	No	Mixed-model ANCOVA	-0.326	-0.9100	0.259	No
Lytle et al., 2004	Both	No	Mixed-model ANCOVA	-0.143	-0.7110	0.425	No
Lytle et al., 2004	Both	No	Mixed-model ANCOVA	-0.141	-0.4250	0.144	No
Lytle et al., 2004	Both	No	Mixed-model ANCOVA	-0.060	-0.3090	0.19	No
Moore et al., 2008	Both	No	Regression analysis	0.009	-0.2000	0.38	No
Moore et al., 2008	Both	No	Regression analysis	0.057	-0.1000	0.21	No
Perry et al., 1999	Both	Yes	Mixed-model regression	0.580	-0.1500	1.31	Yes
Ransley et al., 2007	Both	No	Multilevel modelling	-0.200	-0.5500	0.15	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.000	-0.2000	0.30	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.200	0.1000	0.40	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.200	-0.2100	0.61	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.300	0.1000	0.60	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.400	0.2000	0.50	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.460	0.3500	0.58	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.500	0.2000	0.70	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.600	0.4000	0.90	Not evaluated
Reinaerts et al., 2008	Both	No	Likelihood ratio test and Wald statistic setting significance	0.220	0.0370	0.40	Not evaluated

(Continues)

TABLE 3 (Continued)

Author	Sex	Physical activity	Statistical method	Effect size	LCI	UCI	Sustainability
Tak et al., 2009	Both	No	Multilevel linear regression	0.190	0.0300	0.34	Not evaluated
Tak et al., 2009,	Both	No	Multilevel linear regression	0.150	0.0040	0.29	Not evaluated
Te Velde et al., 2008	Both	No	Multilevel linear regression	0.220	-0.1300	0.57	Partial
Vegetable intake							
Anderson et al., 2005	Both	No	Univariate analysis of variance	-0.040	-1.62	1.54	No
Barlett et al., 2013	Both	No	Regression discontinuity	0.060	-0.01	0.13	Not evaluated
Bere et al., 2010	Both	No	Linear mixed models	-0.030	-0.36	0.3	Yes
Cohen et al., 2015	Both	No	Multilevel logistic regression	-0.040	-0.16	0.08	Yes
Cohen et al., 2015	Both	No	Multilevel logistic regression	0.160	0.09	0.22	Yes
Cohen et al., 2015	Both	No	Multilevel logistic regression	-0.050	-0.12	0.01	Yes
Cohen et al., 2015	Both	No	Multilevel logistic regression	0.130	0.05	0.19	Yes
Crepinsek et al., 2006	Both	Yes	Hierarchical mixed-models and logistic regression	0.000	-0.01	0.01	Not evaluated
Eagle et al., 2013	Both	Yes	Paired t tests	0.030	-0.01	0.07	Yes
Ermetici et al., 2016	Both	Yes	ANCOVA	0.260	-0.43	0.95	Not evaluated
Ermetici et al., 2016	Both	Yes	ANCOVA	0.450	0.03	0.87	Not evaluated
Lytle et al., 2004	Both	No	Mixed-model ANCOVA	-0.380	-1	0.23	No
Ransley et al., 2007	Both	No	Multilevel modelling	0.000	-0.14	0.14	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.000	-0.2	0.2	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	-0.200	-0.5	0.1	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.000	-0.3	0.3	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	-0.200	-0.5	0.2	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	0.000	-0.2	0.3	Not evaluated
Ransley et al., 2007	Both	No	Multilevel modelling	-0.300	-0.6	0.1	Not evaluated
Reinaerts et al., 2008	Both	No	Likelihood ratio test and Wald statistic setting significance	0.130	0.06	0.2	Not evaluated
Tak et al., 2009	Both	No	Multilevel linear regression	0.010	-0.09	0.1	Not evaluated
Te Velde et al., 2008	Both	No	Multilevel linear regression	0.110	-0.13	0.36	Partial

Note: Type of document: S, Scientific article; Pi, Pilot study; Po, policy document; Pr, programme; QED, quasi-experimental study; RCT, randomized controlled trial. Three meta-analyses were carried out. The first focused on BMI z score and included $n = 5$ studies, which provided 12 measured observations. The second focused on fruit intake and included 22 studies, which provided 53 observations. The third focused on vegetable intake and included $n = 13$ studies, with a total of 23 observations.

heterogeneity. RCTs of school food environment interventions that assessed changes in BMI z score showed a BMI z score reduction of -0.10 standard deviations from the reference population mean (95% CI: 0.13, 0.07). QED studies showed a BMI z score reduction of -0.20 (standard MD: -0.20 , 95% CI: 0.26, 0.14). The overall effect of the pooled study results shows a statistically significant association between the implementation of the school food environment interventions and a reduction in BMI z score (standard MD: -0.12 , 95% CI: 0.15, 0.10) (Figure 2). No significant findings were identified on changes in vegetable intake (Figure 3); however, the meta-analysis showed a small increase in fruit consumption in school children in RCT studies (standard MD: $+0.20$, 95% CI: 0.14, 0.26), QED studies (standard MD: $+0.19$, 95% CI: 0.15, 0.22), and overall (standard MD: $+0.19$, 95% CI: 0.16, 0.22) (Figure 4). The results represent the standard MD between intervention and control groups at baseline and after the implementation of the intervention.

3.2 | Meta-regression analyses

The characteristics of the studies included in meta-regression analyses are shown in Table 3, which presents author, country, type of document, intervention type, components, setting, study design, intervention duration, age, sex, physical activity inclusion, effect size, lower CI (LCI), upper CI (UCI), and sustainability of the intervention. Results are stratified by outcome (BMI z score, fruit intake, and vegetable intake). Meta-regression analyses showed that there were no statistically significant differences in the intervention effect size according to study design (-0.09 , 95% CI: -0.19 , 0.004 , $p = 0.061$). Monitored program type interventions relying on specific dietary guidelines, such as type of food items that are permitted or banned in the school canteen and regulation on portion sizes, were more likely to be effective in reducing BMI or increasing fruit or vegetable intake than interventions not based on a sustainable program ($\beta = 0.33$, 95% CI: 0.05, 0.60, $p = 0.021$). Pilot studies also showed larger effect sizes. We found no statistically significant differences in meta-regressions between single-component and multicomponent interventions ($\beta = -0.02$, 95% CI: -0.12 , 0.09 , $p = 0.741$). However, interventions that included a physical activity component were more likely to be effective. In terms of types of interventions, fruit and vegetable provision, as well as the provision of fruit only, were statistically significantly associated with higher fruit and vegetable intake. Girls were more likely to increase their fruit and vegetable intake or to reduce their BMI following interventions (Table 4).

3.3 | Risk of bias assessment

Risk of bias assessment was undertaken for 96% of the intervention studies, and not enough data were available to undertake a risk of bias assessment for 4% of the studies. From the RCT interventions, $n = 38$ (43%) presented a high risk of bias and $n = 5$ (12%) presented a low risk of bias. For the QED studies (55%), $n = 4$ (7%) showed the

highest score of “4,” $n = 7$ (13%) presented a score of “3,” $n = 16$ (29%) presented a score “2,” $n = 16$ (29%) a score of “1,” and $n = 12$ (22%) a score of “0.” The highest risk of bias was found on attrition bias and low protection of potential contamination. There was little evidence of publication bias as evidenced by visual inspection of the plots: estimates from the included studies are distributed equally around the overall estimate for each index used, and studies with both significant and non-significant estimates were included (Tables S2 and S3).

4 | DISCUSSION

Our systematic literature review and meta-analysis focused on 100 school food environment interventions, of which 63% involved a single component and 37% encompassed multiple components. Common intervention approaches included the direct provision of food, changes in dietary guidelines for schools, and modifications of the food environment within schools, such as increasing the visibility of healthy food options, the addition of salad bars or healthy food displays in vending machines and in the canteen or kiosks, and healthy food promotion within the school and bulletin boards. Our systematic review showed that effective strategies to improve dietary intake and reduce BMI in children include the use of clear and precise dietary guidelines and school meal standards in terms of the type, amount, and presentation of foods. An example is requiring a specific number of fruits/vegetables—that at least half of all grains sold/served are whole grains, reductions in products that contain trans fats, and/or restrictions on milk to 1% or skim milk. In the United States, childhood obesity prevalence was found to be lower in states with precise school meal standards that were specific in the requirements of healthy food items and the replacement of unhealthy food options for healthier versions.¹⁰⁸ It was also observed that students in states with schools with nutrition standards versus no nutrition standards consumed fewer calories and less fat and sugar at school and did not gain as much weight compared with students in states with lack or reduced nutrition standards that were not specific in the requirement of fruits and vegetables and the provision of low-fat dairy products and whole grains.^{121–123} In addition, low-income children living in states with precise nutrition standards in schools tended to have less risk of obesity than children in states with no school meal regulations.¹⁰⁸ Precise nutrition standards that increase the quality and nutrition of school meals are a good starting point to tackle childhood obesity.

The pooled effect size resulting from our meta-analysis, for studies using BMI z score as their outcome measure, was -0.12 , reflecting a relatively important effect on the prevalence of obesity in school children, the exact magnitude of which depends on the BMI distribution to which the effect is applied. If applied to the BMI distribution of year 6 children in England, and assuming a uniform shift to the left of the distribution itself, the above effect size would correspond to a reduction of over 2 percentage points of obesity prevalence. In fact, there is at least some evidence in the papers we have reviewed that effects may be larger in children who initially had a

TABLE 4 Meta-regression analyses

Variable	β (95% CI)	p value
Study design		
RCT	Ref	
QED	−0.09 (−0.19, 0.004)	0.061
Type of study		
Scientific study	Ref	
Pilot	0.24 (−0.15, 0.62)	0.022
Policy	0.04 (−0.17, 0.25)	0.722
Program	0.33 (0.05, 0.60)	0.021
School setting		
Within schools	Ref	
Within and around schools	−0.17 (−0.41, 0.06)	0.150
Country		
United States	Ref	
China	−0.12 (−0.40, 0.16)	0.402
Latin America	−0.14 (−0.38, 0.11)	0.280
Europe	0.02 (−0.10, 0.15)	0.716
Middle East	0.14 (−0.14, 0.42)	0.324
United Kingdom	0.08 (−0.06, 0.22)	0.245
Other	0.33 (−0.04, 0.70)	0.085
Components		
Multicomponent	Ref	
Single component	−0.02 (−0.12, 0.09)	0.741
Type of intervention		
Food environment	Ref	
Vending machines	0.002 (−0.18, 0.18)	0.984
Fruit and vegetable provision	0.21 (0.78, 0.34)	0.002
Breakfast provision	0.063 (−0.19, 0.32)	0.631
Food placement	0.10 (−0.08, 0.28)	0.265
Food modification	0.20 (−0.001, −0.41)	0.052
Fruit provision	0.34 (0.15, 0.54)	<0.001
Guidelines	0.10 (−0.37, 0.58)	0.673
Duration (years)		
	0.008 (−0.02, 0.04)	0.628
Sex		
Boys & girls	Ref	
Boys	−0.73 (−0.28, 0.13)	0.487
Girls	0.065 (0.02, 1.28)	0.044
SEP		
Considered	Ref	
Not considered	0.009 (−0.099, 0.12)	0.863
Physical activity		
Considered	Ref	
Not considered	−0.12 (−0.22, −0.12)	0.029

Note: Meta-regression results are indicated as β coefficients and 95% confidence intervals (CI), $N = 95$. Bold values indicate statistically significant ($p < 0.05$) values.

Abbreviations: QED, quasi-experimental design; RCT, randomized controlled trial; SEP, socioeconomic position.

higher BMI,¹²⁴ which would suggest an even larger reduction in obesity prevalence. The pooled effect size for studies that measured fruit intake showed a standard MD of 0.19 portions per day (95% CI: 0.16, 0.22), which would be equivalent to 15 g of fruit per day, assuming that a portion of fruit is equivalent to 80 g.¹²⁵

Sustainability and monitoring of guideline implementation and food provision was also observed to be linked to more effective interventions. Recommendations based on scientific evidence and interventions that facilitate access to healthy and appetizing meals and snacks in schools were associated to better health outcomes.^{108,126} Replacement of ultra-processed and unhealthy alternatives with healthy and palatable options (e.g., vending machines),^{48,124} free and sustainable fruit and vegetable provision,^{33,35} and interventions that involve parents and staff and address physical activity and social inequalities¹⁰⁰ may also contribute to healthier weight-related outcomes among school children.

Unsuccessful interventions were observed to provide foods that were not based on scientific evidence and that may contain elevated amounts of sugar such as fruit juice or cereal. These types of foods may provide some nutrients but tend to be ultra-processed and highly caloric.^{34,127,128} Standards for healthier school meals should be designed to increase fruit and vegetable contents and whole grains and pulses for refined carbohydrates.^{129,130} Interventions focused on increasing vegetable intake were found to be less effective and sustainable.^{32,60,109} Fruit intake may be easier to increase than vegetable intake due to its sweet taste and easier form of consumption and transportation compared with vegetables.⁹⁵ Fruit and vegetable intake were directly associated with the provision of fruits and vegetables and the length of time in which fruits and vegetables were provided as part of the intervention. Therefore, when the fruit or vegetable provision intervention ceased, intake was observed to go down as well.^{29,131}

A frequent limitation in unsuccessful interventions was not addressing social inequalities.^{21,132} Children with a lower SEP are more likely to have a higher risk of obesity than children with a higher SEP.¹³³ This could be due to a higher exposure and accessibility to unhealthy food options and a reduced access to affordable and healthy foods typical in schools that are located in lower income and minority neighborhoods leading to disproportionately high rates of obesity and preventable, diet-related diseases.^{134,135} Sociocultural, political, and historical factors could influence food store preferences and food choices, particularly in ethnic minority populations. Therefore, systemic drivers of social and ethnic inequalities could play a key role in shaping food environments and in access to healthy food and mediate the association with obesity.¹³⁶

According to the meta-regression analyses, monitored program type interventions relying on specific dietary guidelines, such as type of food items that are permitted or banned in the school canteen and regulation on portion sizes, were more likely to be effective in reducing BMI or increasing fruit or vegetable intake than interventions not based on a sustainable program ($\beta = 0.33$, 95% CI: 0.05, 0.60, $p = 0.021$). Although pilot studies also showed larger effect sizes than

intervention and policy studies, this could be due to underpowered studies designed to detect changes (Table 4).

Although previous studies have suggested that multicomponent interventions (e.g., environment, education, and services) could be more effective in tackling obesity, our meta-regression results show no statistically significant differences between single-component and multicomponent approaches. This could be due to a low power to detect differences between studies. However, statistically significant differences were found when considering a physical activity component in the intervention. As an example of a multicomponent approach, the EatSmart program implemented in primary schools in Hong Kong¹³⁷ included administrative measures, coupled with the provision and availability of healthy meals and snacks, complementary nutritional education, and advertisement all advocating a healthy eating environment in the school sector by the improvement of the food environment (healthy availability and accessibility of food). The success of this program was associated with school encouragement to initiate and take ownership of policies, structures, and practices to aid students in the development of healthy eating habits, have access to healthier foods during lunch and snack time, restricting the sale of unhealthy food items, engagement in education and promotion on healthy eating, and complying fully with nutritional guidelines established by the accreditation system.¹³⁷ Similarly, a Cochrane review of RCT studies identified that there was some evidence that diet and physical activity interventions combined could reduce measures of adiposity in children aged 0 to 5 years, indicating that a combination of diet and physical activity interventions might reduce adiposity rather than single-component interventions.¹³⁸

Furthermore, according to the meta-regression analyses, girls were more likely to increase their fruit and vegetable intake or to reduce their BMI following interventions compared with boys. This could be due to a higher interest in health and diet and willingness to participate in this type of interventions. Previous studies have found that women may be more susceptible of health information in general and more responsive to nutrition education in particular.¹⁵ In contrast, it is possible that men are more responsive to sports or physical activity interventions. This pleads for future carefully designed studies that offer the child more individually targeted forms of intervention.^{15,124,132,139}

In terms of types of interventions, fruit and vegetable provision, as well as the provision of fruit only, were statistically significantly associated with higher fruit and vegetable intake. However, the meta-analysis showed no statistically significant difference in vegetable intake alone. A low intake of vegetables among children could be linked to a low taste acceptability due to lack of exposure at an early age.¹⁴⁰ Increased meal palatability through the involvement of chefs who developed tasty, attractive, and healthy foods could increase the likelihood of healthy food acceptance by children, which could lead to an increase in fruit and vegetable intake and a decrease in BMI.⁴⁸ However, healthy meal alternatives within schools and their effect on weight and health may not be sustainable if there is an unhealthy food environment around schools competing with the healthy strategies.^{29,112,141}

Unhealthy school food options available on school grounds (e.g., kiosks and vending machines) and obesogenic food environment around schools are key barriers for successful school food environment interventions and the prevention of childhood obesity.^{111,126,142–144} Policy actions could play an essential role to improve surrounding school food environments to sustain healthy dietary intake.

Food and beverage regulations on childhood overweight and obesity showed a significant association between lower BMI z scores, lower odds of overweight or obesity, and better dietary outcomes in geographic areas with a strong food or policy compared with areas with no regulatory policies.^{92,145}

A negative aspect of school food policies was lack of precision in dietary and school environment guidelines in terms of the provision of fruits and vegetables and quality and presentation of available meals and therefore the lack of effective implementation in schools. Another limitation that these policies confront is the political pressures from the food industry, which demand inclusion of food items that can increase the caloric intake of children in schools.¹⁴⁶ Canteen staff and managers in schools require technical and financial assistance to effectively implement evidence-based practices.¹⁴⁶ Among the most common nutrition guideline components that were addressed in policies were the regulation of vending machines,^{59,111,124,144,147,148} school kiosks,¹⁴⁹ and a la carte food options.^{47,71,85,112,116,117,150}

Removal of vending machines or replacements of unhealthy food items with appetizing healthy food options can represent a first step to change the food environment within schools. Continuous monitoring of sales for nutritional quality is important.¹⁵¹ The regulation of vending machines was also associated with a decrease of sugar-sweetened beverage (SSB) consumption in children.¹⁵² However, when SSBs remain available within or around schools, partial SSB restrictions do not appear to be effective in reducing intake.¹⁵³

Even though there was a positive correlation between the modification of the availability of food within schools and the prevention of obesity, studies like the Healthy Experience¹⁵⁴ did not differentiate between the intervention and control group and therefore could not be considered for this review.

Overall, an increase in the availability of healthy and low-calorie foods, eliminating the offer of SSBs, coupled with effective labeling and reduced prices, could potentially facilitate healthier food choices, which could contribute to lower BMIs in school children.¹⁵⁵

4.1 | Comparison with other reviews

Prior reviews of a more varied range of school interventions identified effects of similar magnitude for total fruit and vegetable consumption.^{156,157} However, previous reviews^{156,158,159} did not specifically evaluate potential effects of food choice architecture, within and around school food environment interventions on dietary intake and obesity, and have grouped together highly varied programs potentially leading to biased inferences. Our findings extend these results by specifically evaluating school food environment policies and quantifying

their effects on dietary intakes, as well as separately evaluating direct provision and environmental interventions.

4.2 | Strengths and limitations

Our systematic literature review and meta-analysis addresses interventions related to the built environment, food choice architecture, and direct food provision within and around schools, which makes it a unique study. The review accounts for school food environment interventions in 27 countries, involving middle-income countries that present some of the highest rates of obesity. However, there are various methodological limitations that need to be considered when interpreting the results of this meta-analysis and meta-regression analyses.

First, despite defining strictly our outcome of interest, there was heterogeneity across studies in terms of study design, gender and ethnicity of population, type of intervention, and measure of the health outcome. The robustness of pooled analyses was greatly limited by the heterogeneity of food environment exposures and diet-related health outcomes measured across the studies. Although the majority of studies measured BMI, it was variably reported using the original units (kg/m²) or normalized as a z score (with an inconsistent use of World Health Organization [WHO] Growth Standards), and some studies reported end-line averages, whereas others compared groups with respect to interval changes. In relation to fruit and vegetable intake measures, the revised studies used a wide range of data collection methods, from a single-question food frequency estimate, to multiple-item food frequency questionnaires, 24-h recalls, several days of intake, and food diaries. Given this heterogeneity, study findings are not perfectly comparable, and this must be taken into consideration in interpreting the results of any meta-analysis.

Food environment interventions around schools are complicated and require policy support, which is why it was accounted by few studies (4%).^{104,143,149,160} The food environment around schools could influence children's food choice and affect the effectiveness and sustainability of interventions within schools. Similarly, physical activity was only accounted for in 37% of studies and socioeconomic gradient was not accounted in the models or the population for 50% of studies, which could also affect the effectiveness and bias the potential effect of the interventions on health outcomes. Additionally, food provision and educational systems and schools vary within and across nations, which could contribute to unmeasured heterogeneity. Intensity or success of intervention implementation could modify results, but these are difficult to quantify due to varying systems of food provision services (e.g., differences in how schools prepare, offer, sell, serve, or purchase food) and policy nutritional guidelines. Costs and cost-effectiveness of interventions were generally not reported. Study and method designs were judged to have a high risk of bias for $n = 43$ (81%) of non-randomized controlled studies and $n = 41$ (95%) of RCTs presented a high risk of contamination, which could affect recommendations of effective interventions.

None of the studies disaggregated outcome data based on the discrete dietary and/or environmental components, providing a

limited ability to analyze and understand the food environment-specific effect on health outcomes in school-aged children. Effect of the intervention, particularly on food provision, was highly dependent on the duration of the intervention. Behavior change and effects on BMI and diet-related health outcomes may be dependent on economic viability and sustainability of the effective school food environment interventions (e.g., fruit and vegetable provision).

Furthermore, few studies disaggregated outcome data by age group and gender, which is relevant due to the unique transition from childhood to adolescence, marked by specific physiological changes and increased behavioral autonomy and food choice.¹⁶¹

Lastly, future interventions should focus on effective components of the school food environment that may be amenable to modification, tested in the context of RCTs that are powered to examine effects on health outcomes of public health relevance such as dietary intake, obesity, and the prevention of non-communicable diseases.

5 | CONCLUSIONS

Schools offer many opportunities for developing obesity prevention strategies. Environmental changes that increase the availability of vegetables for children from an early age, the provision of healthy meals with high palatability and attractive presentation, the regulation or banning of vending machines and SSBs, and monitored program type of interventions that include the collaboration, training, education, and integration of key stake holders such as chefs, the school staff, parents, and students to increase acceptability, adaptability, and sustainability according to the local needs could contribute to the improvement of dietary intake, which could influence the reduction of childhood obesity. Limited evidence shows that schools can provide more healthful food options without economical loss by limiting non-healthy foods and improving the salience, taste, attractiveness, and availability of healthy foods.¹⁶²

Achieving a healthier school environment is a long-term project involving multiple strategies of education and incentives, as well as regulation. Long-lasting reforms require involvement from government through enforcement and continuous supervision of the implementation of regulations. Obesogenic food environments around schools remain a key barrier for successful school food environment interventions and the prevention of childhood obesity. The evidence reviewed supports the conclusion that changes in the school food environment can improve children's dietary behavior and BMI, but policy actions are needed to improve surrounding school food environments to sustain healthy dietary intake. Once the food environment is improved, it is easier to modify individual dietary behavior, a crucial step for the prevention of childhood obesity.

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AUTHOR CONTRIBUTIONS

Dr Elisa Pineda conceived and designed the work that led to the submission, acquired data, and played an important role in interpreting the results. She also drafted the manuscript and had full access to the data in the study and final responsibility of the decision to submit for publication.

Josefina Bascunan-Arellano was the second reviewer and contributed to the data extraction of the literature review.

Professor Franco Sassi revised the manuscript, approved the final version, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICT OF INTERESTS

The authors have no conflict of interests to report.

ORCID

Elisa Pineda <https://orcid.org/0000-0002-5210-1538>

Josefina Bascunan <https://orcid.org/0000-0003-0833-3523>

Franco Sassi <https://orcid.org/0000-0001-9773-2117>

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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