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Improving fruit/vegetable behaviors as a social determinant of health among children: A systematic review

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ABSTRACT

The national school lunch program (NSLP) supports nutrition, a social determinant of health, by improving children's access to healthy meals, yet many still fall short of recommended fruit and vegetable (F/V) intake. This systematic review examines 21 school-based interventions (2018-2025) in NSLP-participating schools aimed at improving F/V behaviors (i.e., consumption, selection, and waste). Using behavioral economics and Kahneman's system 1 (intuition-based) and system 2 (knowledge-based) thinking systems to organize results, 18 interventions (86%) improved at least one F/V behavior. System 1 interventions (n = 12) were most effective, improving all F/V behaviors regardless of setting or duration. System 2 interventions (n = 4) had mixed results, with one worsening F/V behavior. Mixed interventions (n = 5) showed variable outcomes. System 1 interventions that improve appeal of F/V and cafeteria food environments can improve F/V behaviors in children. These interventions did not require classroom time, large investments from school districts, and may save money and reduce waste.

Keywords: social determinants, health equity, lunch, behavioral economics, children, school, nutrition

INTRODUCTION

The dietary guidelines for Americans, 2020-2025, recommend that children consume 4-5 cups of fruit and vegetables (F/Vs) daily as part of a healthful diet [1, 2]. Consumption of fruits and vegetables are important to a healthy diet and are associated with prevention of many chronic conditions like hypertension, type 2 diabetes, and obesity [2-6]. Despite this, most Americans, including children fall short of the recommended servings [2-6]. Additionally, children from low-income families, minority groups and those living in rural areas are more likely to consume less fruits and vegetables than children from families with higher income levels [7, 8]. These children also face increased risks of chronic conditions due to overlapping social determinants of health [9]. Researchers have started to identify that social determinants of health in children often present in overlapping patterns, with multiple factors occurring together [9]. For example, children from communities experiencing economic disparity had more exposure to poor environmental conditions (e.g., air pollution and heat), problematic built environments, and more exposure to racism and discrimination [9]. Children in the most economically disadvantaged communities also experienced the poorest health outcomes [9].

Health promotion through access to healthy foods during childhood is critical for the early intervention of chronic diseases [10]. Most children spend their time (7-8 hours a day) in school, consuming at least one meal at school per day. This makes school lunch an ideal leverage point for improving nutrition, a key social determinant of health. In 1946, the national school lunch program (NSLP) was established under the national school act to provide balanced meals to students and ensure their basic nutritional needs are met during the school day [11].

The NSLP plays a central role in advancing food and nutrition security by increasing access to nutritious meals and reducing food insecurity among children. In 2023, NSLP served approximately 4.6 billion lunches, providing nearly 71% of those lunches at a free/reduced rate, costing approximately $17.2 billion per year [1]. Children experiencing food insecurity, those from low-income families, and minority populations more frequently rely on school lunch for a significant amount of their nutrition [1, 12].

Since the start, NSLP standards have required fruits and vegetables to be served to students [13]. Overtime, the NSLP has gone through many changes including shifting from daily requirements to weekly targets in 1994 [13]. In 1981, it also allowed schools to operate in an "offer vs. serve" model, which allowed students to choose three of five meal components [14]. This model also addressed food waste, an ongoing expensive cost of NSLP [5, 14]. In 2010, the NSLP underwent massive changes with the passage of the healthy hunger-free kids act (HHFKA). HHFKA improved nutritional standards across all

Early results of this systematic review were presented in a virtual poster presentation at the Association of Maternal and Child Health Programs Annual Conference in 2024.

food components, including increasing required serving size and variety of fruits and vegetables [15, 16].

A 2022 report from the U.S. Department of Health and Human Services emphasized the importance of ensuring accessibility and affordability of healthy foods to improve social determinants of health across life stages [17]. The HHFKA, under the NSLP, achieved this; however, improving access to healthy foods does not guarantee consumption [17]. HHFKA faced criticism due to reports of increased food waste following its implementation [14, 18]. In 2015, the U.S. Department of Agriculture (USDA) updated the "offer vs. serve" model to require that one component must be a fruit or vegetable [14, 19]. The "offer vs. serve" model is mandatory in high schools and optional in elementary and middle schools. The "offer vs. serve" model can reduce food waste, increase student choice, and ensure daily F/V selection [19]. Then, the child nutrition program flexibilities of 2017 was implemented to continue efforts to reduce food waste. This policy loosened some mandates in HHFKA but left F/V requirements at lunch unchanged [20]. F/V waste is a considerable issue for schools. Between 30-60% of F/Vs are thrown away [3], and approximately 80% of vegetables in rural schools are wasted [7].

Improving school lunch policy can have meaningful health outcomes for children. A recent study found since implementation of HHFKA, there has been a significant decrease in BMI z-score among children and adolescents [21]. Body Mass Index (BMI) is a screening tool that assesses weight relative to height (kg/m^2). In children and adolescents, BMI is interpreted using age-and sex-specific percentiles to account for growth patterns. The BMI Z-score, or standard deviation score, identifies overweight and obesity compared to a reference population for ages 2-19 years old [22]. The authors also observed a reversal in the previously stagnant adolescent BMI z-score trends following the implementation of HHFKA [21]. Decreased BMIz were also found in populations of lower economic status [21]. Although this study does not account for other activities that can affect childhood and adolescent obesity, it suggests school lunch policy can be effective and have meaningful outcomes for children.

LITERATURE REVIEW

Since 2018, there have been seven systematic reviews that describe interventions, programs or policies aimed at improving food behaviors (i.e., consumption, selection, waste) at school [23-29]. These reviews included interventions conducted prior to HHFKA implementation, lacked population-level conclusions, or limited their scope by including only certain strategies, or specific food behaviors in their analyses.

One systematic review in [24] categorized interventions using behavioral economics theory and Daniel Kahneman's use of system 1 and system 2 thinking. According to Kahneman, decisions made using system 1 level thinking are quick, intuition based and rely on heuristics or bias to inform decisions [30]. Due to this, decisions using system 1 thinking are easily influenced by outside influences as well as existing knowledge base (system 2). System 2 level thinking relies on cognition, knowledge, and judgement [30]. Without improving knowledge base (system 2), quick decisions (system 1) can often be incorrect [30]. For this reason, it is important to understand how interventions that seek to improve knowledge can change behavior.

Table 1. Examples of interventions included in this review are categorized into system 1 or system 2

Examples
System 1: designed to improve appeal
Slicing fruits and vegetables
Convenient, eye level placement
Posters/signs/table tents (designed for appeal)
Praise, encouragement, fist bumps
Role modeling
Incentives (individual and whole group)
Cafeteria improvements (lighting)
Improve taste (spices, including cultural preferences, chef prepared, scratch cooking)
Taste testing
Healthy food only quick checkout lane
Emoticons
Choice, variety
Stickers (cute/kid characters) on packaging
Creative names
System 2: designed to improve knowledge and skills
Nutrition education
Food labelling
Displayed food facts (designed for education not for appeal)
Wellness programs
Gardening skills
Cooking skills
Food sustainability education

This systematic review included K-12 school cafeteria lunch interventions (n = 48) conducted between 2012-2017 [24]. Interventions that used small nudges to influence choice were categorized as system 1. Examples included slicing, placement changes, posters, role modeling, incentives, and taste enhancements. System 2 interventions relied on knowledge and high-level decision-making, such as nutrition education and skill training (i.e., cooking and gardening). Additional examples of system 1 and system 2 interventions are found in **Table 1**. Interventions that used a mix of both system 1 and system 2 methods, were categorized as "mixed" [24].

More than half the interventions discussed in [24] (n = 27) occurred exclusively in elementary schools, the remainder occurred in middle and high school (n = 12) or spanned all three levels (n = 10). Across grade levels, 89% of system 1 interventions and 11% of system 2 interventions were successful [24]. Most elementary school interventions were categorized as system 1, 93% of them considered effective [24]. At the elementary level, 86% of mixed system interventions were effective. In contrast, system 2 interventions at the elementary level were largely ineffective. Interventions at the middle and high school level were fewer in number with less success. Only 6 of 11 middle/high school interventions were considered successful between intervention categories.

The HHFKA was passed in 2010, implementation began in 2012, and by 2015, 93% of schools were complying [22]. Additionally, during this time, the USDA specified F/V requirements in 2015 [19]. It is important to note that 30 of the 48 reviewed studies in [24] were published between 2012-2015, when these school lunch policies passed or were only beginning to be implemented.

With the full implementation of the HHFKA and the inclusion of fruits and vegetables in the "offer vs. serve" model, a current systematic review is needed to identify which interventions have effectively improved F/V behaviors under updated NSLP guidelines. With added variety and choice now required in NSLP, there is a need for a current systematic review since it is unknown if system 1 style interventions will continue to be more successful in improving F/V behaviors than system 2.

Specific Aims/Hypothesis/Objectives

The aim of this systematic review is to assess the effectiveness of system 1, system 2, and mixed-strategy school-based interventions in improving F/V behaviors since 2018. Unlike the study in [24], which did not describe study populations for the studies reviewed, this review considers populations and system-level thinking (i.e., system 1 and system 2). This is essential in identifying effective strategies that best fit specific school populations, as well as address disparities among children that rely on the NSLP for nutrition.

METHODS

Eligibility Criteria

Types of studies

Studies included in this review consisted of school-based interventions targeting F/V behaviors (i.e., consumption, selection, and waste) among elementary and middle school students during school lunch, using quantitative measurements (i.e., weight and observation) to assess these behaviors. This analysis also incorporated qualitative data from focus groups or interviews reported in the reviewed studies. The study designs of reviewed school-based interventions varied and included cross-sectional, pre-/post-experimental, randomized controlled trials (RCTs), and quasi-experimental designs.

Types of participants

The primary population for this review is elementary and middle school students attending schools that participated in the NSLP. Lunch requirements and food environments for elementary and middle schools are similar [1] and may choose to operate under the “offer vs. serve” model [19]. Studies that measured student outcomes but implemented interventions at the staff or cafeteria level were also included.

Types of outcomes

Primary outcomes in this review include interventions that measured changes in F/V consumption, selection, and waste. Measurements included in this review were observations (recorded or photographed), weight, as well as a combination of these methods. Studies that only measured knowledge, values and preferences were excluded. Secondary outcomes for this review include intervention fidelity and school staff feedback.

Outcome definitions

For the purposes of this review, the following definitions were applied:

1. Selection refers to a student’s act of choosing a food item during lunch, as observed or recorded at the point of service [31].
2. Consumption refers to the proportion of the food item eaten, determined by direct observation, photographic records, or pre-/post-tray weighing [31].

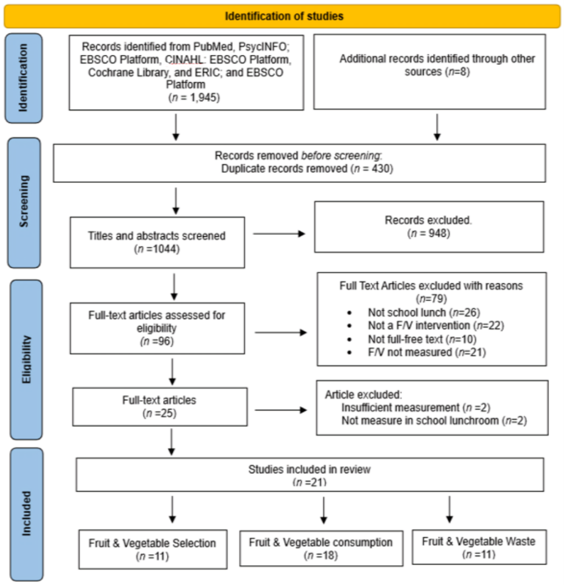

Figure 1. PRISMA flow diagram illustrating the study identification, screening, and selection process [35]

3. Waste refers to the uneaten portion of selected fruit or vegetables, excluding inedible components (e.g., cores and peels) where such exclusions were reported [32].

Information sources

Electronic databases used to identify studies were PubMed, PsycINFO, EBSCO Platform, CINAHL, Cochrane Library, and ERIC. To ensure a thorough search was conducted, additional studies were found using references from other studies or listed as related articles.

Search strategy

Primary search terms included those used in [24] which were “cafeteria intervention,” “cafeteria emoticon,” “child cafeteria intervention,” “cafeteria fruit and vegetable consumption,” “school lunch interventions,” “school lunch,” “cafeteria incentive,” “school lunch incentive,” “school lunch reward,” “school lunch prize,” “health lunch reward,” and “school lunch marketing.”

Additional search terms included “elementary F/V intervention,” “elementary school lunch fruit and vegetable intervention,” “elementary fruit and vegetable nudges,” “school lunch fruit and vegetable plate waste intervention,” and “middle school fruit and vegetable intervention.”

Study selection

Searches on PubMed, PsycINFO, EBSCO Platform, CINAHL, Cochrane Library, and ERIC resulted in 1,945 articles, 1,044 remained after removing duplicates (**Figure 1**). Abstracts were reviewed for these articles; 96 full text articles were assessed, and 21 studies met inclusion criteria. After selection, two studies were excluded because food consumption was measured only by survey response [33, 34]. Two additional studies were excluded because the intervention was tested in university labs rather than school lunchrooms [35, 36]. Eight additional studies were located and four were selected from references and listings of similar articles. A total of 21 articles were selected for this review. Study selection was documented using the 2020 PRISMA flow diagram [37]. These articles were assessed for quality, using the NIH quality tools [38].

Table 2. Quality assessment of controlled interventions studies [36]

	[5]	[8]	[39]	[40]	[41]	[44]	[45]	[46]	[47]	[48]	[49]	[51]	[52]
1. Was the study described as randomized, a randomized trial, a randomized clinical trial, or an RCT?	N	Y	Y	Y	N	N	Y	N	Y	N	Y	Y	Y
2. Was the method of randomization adequate (i.e., use of randomly generated assignment)?	NA	NR	NR	NR	NA	NA	NR	NA	Y	NA	NR	NR	Y
3. Was the treatment allocation concealed (so that assignments could not be predicted)?	NR	NR	NR	N	N	N	N	NR	N	N	N	N	N
4. Were study participants and providers blinded to treatment group assignment?	N	N	N	N	N	N	N	NR	N	N	NR	N	N
5. Were the people assessing the outcomes blinded to the participants' group assignments?	N	Y	Y	N	N	NR	N	NR	N	NR	NR	NR	N
6. Were the groups similar at baseline on important characteristics that could affect outcomes (e.g., demographics, risk factors, co-morbid conditions)?	Y	Y	Y	Y	N	Y	Y	N	Y	Y	N	Y	N
7. Was the overall drop-out rate from the study at endpoint 20% or lower than the number allocated to treatment?	NR	NR	NR	NR	NA	NA	NR	CD	NR	NR	NR	NR	CD
8. Was the differential drop-out rate (between treatment groups) at endpoint 15 percentage points or lower?	NR	NR	NR	NR	NA	NA	NR	NR	NR	NR	NR	NR	NR
9. Was there high adherence to the intervention protocols for each treatment group?	N	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	NR
10. Were other interventions avoided or similar in the groups (e.g., similar background treatments)?	N	NR	NR	Y	Y	Y	NR	NR	NR	NR	NR	NR	NR
11. Were outcomes assessed using valid and reliable measures, implemented consistently across all study participants?	Y	Y	Y	Y	Y	Y	Y	Y	Y	CD	Y	Y	Y
12. Did the authors report that the sample size was sufficiently large to be able to detect a difference in the main outcome between groups with at least 80% power?	N	NR	NR	Y	NR	NR	NR	NR	NR	N	NR	NR	Y
13. Were outcomes reported or subgroups analyzed prespecified (i.e., identified before analyses were conducted)?	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
14. Were all randomized participants analyzed in the group to which they were originally assigned, i.e., did they use an intention-to-treat analysis?	NA	Y	Y	Y	Y	NA	Y	NA	Y	NR	Y	Y	Y

Note. Y: Yes; N: No; CD: Cannot determine; NR: Not reported; & NA: Not applicable

Table 3. Quality assessment of before-after (pre-post) intervention studies with no control group [36]

	[3]	[4]	[6]	[7]	[12]	[42]	[43]	[50]
1. Was the study question or objective clearly stated?	Y	Y	Y	Y	Y	Y	Y	Y
2. Were eligibility/selection criteria for the study population prespecified and clearly described?	N	Y	N	Y	Y	Y	Y	N
3. Were the participants in the study representative of those who would be eligible for the test/service/intervention in the general or clinical population of interest?	N	N	Y	Y	Y	Y	N	Y
4. Were all eligible participants that met the prespecified entry criteria enrolled?	NR	NA	N	NA	N	N	NR	NR
5. Was the sample size sufficiently large to provide confidence in the findings?	CD	Y	Y	Y	CD	Y	CD	Y
6. Was the test/service/intervention clearly described and delivered consistently across the study population?	Y	Y	Y	Y	Y	Y	Y	Y
7. Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants?	Y	Y	Y	Y	Y	Y	Y	Y
8. Were the people assessing the outcomes blinded to the participants' exposures/interventions?	NR	N	N	NR	NR	NR	NR	NR
9. Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis?	N	NA	NA	NA	N	NR	NR	NR
10. Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes?	Y	Y	Y	Y	Y	Y	Y	Y
11. Were outcome measures of interest taken multiple times before the intervention and multiple times after the intervention (i.e., did they use an interrupted time-series design)?	Y	Y	Y	Y	Y	Y	Y	Y
12. If the intervention was conducted at a group level (e.g., a whole hospital, a community, etc.) did the statistical analysis take into account the use of individual-level data to determine effects at the group level?	NA	NA	NA	NA	NA	NA	NA	NA

Note. Y: Yes; N: No; CD: Cannot determine; NR: Not reported; & NA: Not applicable

Table 2 shows the quality assessment of controlled interventions studies [36].

Table 3 shows the quality assessment of before-after (pre-post) intervention studies with no control group [36].

RESULTS

Study Characteristics

This review includes 21 studies of any design [3-8, 12, 39-52]; however, 13 of these studies included control groups [5, 8, 38-40, 43-48, 50, 51]. Most studies occurred at the elementary level (n = 16) [3-6, 8, 12, 39, 40, 43-45, 47, 49-52], four took place at both elementary and middle schools [7, 41, 42, 48], and one occurred exclusively at a middle school [46].

Studies varied greatly in number of participants and measurements taken. Studies included 98-2,700 students, and one compared information at the school level (n = 14 schools). Those that included tray measurements to measure consumption, selection, or waste varied between 313-7,112 total trays [3, 4, 7, 8, 12, 39, 42, 47]. Most studies (n = 14) used observation-based measurements including the use of

Table 4. Reviewed intervention studies (system 1)

R	Intervention	Duration	Population	Offer vs. serve	Design	Measurement method	Results
[3]	Role model (adult), incentives, praise	20 weeks	Grades K-5/ school (n=1) in rural Oregon, trays N=797 (pre n=566, post n=231), 57% non-White 90% free/reduced lunch	"Choice"	Cross-sectional , no control group (quasi-experimental)	Food pre-portioned 1/2 cups (weighed to determine base weight). Pre-lunch photo (every 5-7 tray) and post lunch photo. Measured in 25% increments.	Increased F/V consumption, increased V selection, decreased F/V waste
[4]	Sliced apples	4 months	Elementary school (n=1) in rural Illinois, trays N=313 predominantly White	K-2 serve 3-5 offer	Pre/post (non-experimental)	Pre-weighed for base weight. Trays weighed as left line, post-lunch weighed to nearest .5g.	Increased F consumption, decreased F waste
[6]	Sliced apples	3 days	Grade Pre K-5 /schools n=2 N=920, community eligibility	"Selection"	Pre/post, no control group (quasi-experimental)	Waste weight subtracted from selection	F selection not significant, increased F consumption, decreased F waste
[7]	Creative names, decoration, taste test, flavor stations	1 year	Rural K-8 /schools (n=3) free/reduced lunch, primarily White students n=760 trays measured N=1,255	S1/S2-serve S3-offer	Quasi-experimental	Quantitative: food waste weighed to nearest .5g (random trays weighed) Qualitative: interviews with staff	Increased F consumption, decreased V consumption, decreased F waste, increased V waste
[8]	Salad bar	1 month	1-5 grade/schools (n=6) in Virginia >90% Black or Latino, title 1 school, trays n=1,559	Offer (not K)	Crossover randomly matched pairs (experimental)	Observation/photo for (pre/post) salad bar items. Observe spoodles taken (1/4 cup). Line selected food weighed (pre). Post measurement: observed in 20% increments	Increased V consumption, increased F selection, increased F waste
[12]	Salad bar	1 month	4th & 5th grade/schools (n=2) in urban Virginia, trays N=728 (pre n=282, post n=443) >95% Black, title 1 schools	Offer (not K)	No control group (quasi-experimental)	Observation/photo for (pre/post) salad bar items. Observe spoodles taken (1/4 cup). Line selected food weighed (pre). Post measurement: observed in 20% increments	Decreased F/V selection, decreased F/V consumption, decreased F/V waste
[39]	Salad bar	1 month	K-5 grade/ schools (n=7) in Virginia, 35% White, 31% Latinx, 15% Asian American, 11% Black title 1, trays N=5,674	Offer	Random match controlled	Observation/photo for (pre/post) salad bar items. Observe spoodles taken (1/4 cup). Line selected food weighed (pre). Post measurement: observed in 20% increments	Increased F consumption, increased F/V selection, increased F waste
[41]	Chef enhanced (improve taste)	2 years	Grades 3-8 /schools (n=8) in urban, Massachusetts (4 control n=445, intervention n=864) (N=1,309) 67.2-84% Hispanic 95% free/reduced lunch	"Selection"	Matched control (quasi-experimental)	Plate waste weighed pre/post	Increased F/V consumption
[42]	Smarter lunch movement training(creative names, food placement, improved environment (lights, smile, trash)	1 month	K-8/ schools (n=15) in Northeast U.S., 67.7% Hispanic, 22.6% Black community eligible NE US/ 22.6% Black 67.7% Hispanic trays n=9,258	Offer	Non-controlled trial (quasi-experimental)	Food weighed to nearest .1g (weighed 10% of trays)	IncreasedF/ V selection, decreased F/V waste
[47]	Table tent F/V fast facts (8 designed, switched out each day)	10 days	Grade 1-5/ schools (n=4) in NE Georgia, trays N=7,112 (2) community eligible schools, predominantly Black (2) non-eligible/high SES schools-predominantly White	Offer	RCT (experimental)	F/V proportioned or whole. Observed- 1/2 serving increments (selected not eaten, half eaten, eaten all)	Increased F/V selection in high SES schools, increased F/V consumption in high SES schools
[50]	Stickers on F/V bags, incentives (cheap toys)	10 days	Grade 1-5/ schools (n=2) mostly Hispanic, title 1 schools, >90% free/reduced lunch	Offer	No control group (quasi-experimental)	F/V proportioned or whole. Observed- 1/2 serving increments (selected not eaten, half eaten, eaten all)	Increased F/V selection, increased F/V consumption
[52]	Fit game: earn more of the comic book style story (incentive)	8 weeks	Grades K-5/schools n=4 in Utah N=1,859 (control n=978, intervention n=881) pair 1-predominantly White, 45-53% free/reduced lunch pair 2-50% White, 36% Hispanic 73-75% free/reduced lunch	Offer	RCT (experimental)	Before lunch food weighed. After lunch waste & unserved subtracted to determine consumption, photos taken before/after *skin carotenoid concentrations on parents who opted in, scanned twice if different scanned again. Post and then FU 3 month later	Increased F/V consumption *higher carotenoid concentrations, even at 3M F/U

Note. R: Reference

photographs to verify observations [3, 8, 12, 39, 40, 43-51]; whereas seven studies weighed plate waste [4-7, 41, 42, 52]. Some studies (n = 11) included measurement exclusions such as potatoes, juice, or inedible pieces (apple cores) in measurements [4, 6, 8, 12, 41, 42, 44, 45, 50, 52]. These exclusions were in effort to make measurements more accurate, comparable, or only include non-processed fruits and vegetables in their analyses [4, 45, 50]. Studies using observations varied in strategy and levels of measurement.

Many studies measured consumption (or waste) by recording food on trays in increments 0-100 at levels such as 20%, 25%, or 50% increments [8, 12, 39, 43, 44, 47]. One study that used 25% increments added an additional level of 10% to include students that took at least one bite of their food [43]. The study in [52] combined photo observations and skin carotenoid scans to validate F/V consumption. Studies also varied in the number of times measurements were taken at each point of the study. The study in [8] measured food one day per school per data point (pre-/post-); whereas the study in [48] measured two days per student, and the study in [52] measured food five days per school per data point. Only four studies included a follow-up measurement post intervention. These varied in time post-intervention, ranging from 10 weeks to 5 months after the intervention was conducted [45, 46, 52].

Table 4 shows the reviewed intervention studies (system 1).

Table 5 shows the reviewed intervention studies (system 2 & mixed).

Fruit and Vegetable Behaviors

This review focuses on interventions that affected F/V behaviors (consumption, selection, and waste). For this review, results that were statistically significant ($p < 0.05$) for selection, consumption, or waste of fruits and vegetables were

Table 5. Reviewed intervention studies (system 2 & mixed)

R	Intervention	Duration	Population	Offer vs. serve	Design	Measurement method	Results
[5]-S	Nutrition education (included family F/V take home) (brighter bites program)	16 weeks	Elementary (schools n=3) in Dallas & Houston TX 2 intervention schools N=76, n=1 control n=3,977-81% Hispanic, 13% Black >90% free/reduce lunch	Offer	Pre/post controlled trial, non randomized (quasi-experimental	Before: food weighed for base weight. Pre- selection recorded, Post weighed to nearest .01g.	F/V selection not significant, decreased F/V Waste
[40]-M	Farm to school nutrition ed, advertising local and nutrition	16 weeks	Grade 3-5, schools n=6, Connecticut N=480 50% Hispanic, 31% Black, 85% free/reduce lunch	Offer	Random, control (quasi-experimental)	Survey: attitudes, preference, self-efficacy Selection: Pre/post counting servings prepared and served, standardized by # in line	Selection: not significant different between groups but local increased beet selection pre/post
[43]-M	Nutrition education, taste testing, role modeling, salad bar access	8 weeks	Grades 3 & 5, n=149 in rural Washington, predominately White, 46-61% free/reduced lunch	Unknown	No control (quasi-experimental)	Survey: attitudes and preferences Consumption: Pre/post photos observed consumption in 25% increments	Non-significant consumption
[44]-M	Scratch food (WITS program) and nutrition education	1 year	Elementary schools (N=14) in New York City, NY WITS intervention n=7, control n=7, >90% free/reduced lunch	Offer	Quasi-experimental controlled	Used SOCAFE to record selection and consumption. 0%,10%(bite), 25% increments	Increased F/V consumption
[45]-M	Fit 'n' cool program (character modeling, goal setting (P/A and F/V), posters, letters)	16 weeks	4th & 5th grade/ schools (N=2). In Southwest U.S. N=187 Intervention n=67, control n=92, 98% free/reduced lunch	Selection	RCT (experimental)	Servings selected counted, servings wasted counted	F/V selection not significant F/V consumption not significant
[46]-M	HPHY program-sustainability based education, posters *schools had salad bar access and 30-32 minute lunches	5 months 12-16 classroom days	Grade 6-8, schools n=2 in Colorado 6 graders receiving class instruction n=268, surveyed n=93, 7-8th graders exposed to posters n=650, trays n=1,596, school 1-50% White or Hispanic, school 2-predominantly White	Selection	Mixed methods, control, non-randomized (quasi-experimental)	Qualitative: teacher interviews, poster evaluation Quantitative: surveyed 6th graders. Plate waste tray: Before lunch measure 5 items for base weight, salad bar visually estimated. Post lunch: liquids measured to .5 ounce. Photos waste estimated weight	Decreased F/V waste at 5m F/U
[48]-S	Learning gardens by grow Pittsburg	4 months (semester), can repeat program	2 schools (grades 1, 2, 6, 7) in Pittsburg, PA, student participants n=85, economically disadvantaged	Selection	Control (quasi experimental)	Digital photos taken and analyzed by registered dietitians to measure consumption	F/V consumption not significant
[49]-S	Nutrition education	6 week (bi weekly)	Elementary (schools n=3, classes n=10), Midwest N=98 (intervention n=62, control n=36)	Offer	RCT (experimental)	Before: food weight provided by food service staff Pre/post photos, measured 25% increments	F/V selection not significant, F/V consumption not significant, F/V waste not significant
[51]-S	School garden (HGHY Program)	4 years	Elementary (schools n=46) N=2,767, Arkansas, Iowa, Washington, New York 51% White, 20% Black > 50% (average 70.67%) free/reduced lunch	Serve	RCT longitudinal (experimental)	Pre/post observation with ruler.	Increased F consumption, V consumption not significant

Note. R: Reference; S: System 2; & M: Mixed

considered. Among studies, 18 of 21 had significant improvement in at least one F/V behavior [3-8, 12, 39-42, 44, 46, 47, 50-52]. While three studies did not significantly improve any F/V behaviors [43, 45, 48]. Three additional intervention studies resulted in more food waste but improved consumption or selection [7, 8, 39]. Six interventions improved selection [3, 8, 12, 42, 47, 50], 12 improved consumption [3, 4, 6-8, 39, 41, 44, 47, 50-52], and nine reduced waste [3-7, 12, 42, 46, 51]. Consumption improvement was seen in both fruits and vegetables in six studies [3, 41, 44, 47, 50, 52], whereas four studies only saw improvements in fruit consumption [4, 7, 39, 51]. Two studies that were designed to increase vegetable consumption but improved fruit [7, 52].

"Offer vs. Serve" Model

In considering improved lunch policy and the addition of "offer vs. serve" model, most studies (n = 19) indicated that schools chose to operate in "offer" or alluded to offer by describing lunch food "selection" or "choice" [3-8, 12, 39-47, 49, 50, 52]. Four of these studies included variance in offer vs. serve by grade level or participating school [4, 7, 8, 12].

Among these, 15 studies in schools operating in "offer" model improved at least one fruit or vegetable behavior [3-8, 39-42, 44, 46, 47, 50, 52]. The ability to assess the influence of the "offer vs. serve" model on intervention effectiveness varied.

Factors such as variability of offer vs. serve by grade level and school buildings, as well as varying intervention fidelity could limit conclusions about the "offer vs. serve" model. The study in [7] reported significant improvements in at least one F/V behavior in two of the three intervention schools that operated in the "offer" model. Variability of "offer vs. serve" differed by grade level in [4]; however, the authors did not provide disaggregated data by grade level to be able to compare differences. Additionally, in two studies that were classified as "offer", excluded kindergartners because they were not permitted to use the salad bar. Authors did not clarify if these students were provided choices in the lunch line [8, 39].

Intervention Characteristics & System-Level Thinking

Interventions were categorized into "system 1," "system 2," and "mixed" similarly to the study in [24]. Most interventions in this analysis included aspects of system 1 methods. Twelve interventions were system 1, four were system 2 interventions, and an additional five were categorized as mixed.

System 1 interventions

System 1 strategies that enhanced the appeal of fruits and vegetables and improved the cafeteria food environment were effective in promoting healthy behaviors. Most system 1 interventions included multi-food components and multiple strategies. Strategies to address the food environment included improving food placement, enhancing cafeteria environment (e.g., smiling, greetings and adequate lighting), and displaying posters/table tents to encourage selection and consumption. Strategies that enhance the appeal of fruits and vegetables included providing choice (i.e., salad bar), improving taste (e.g., chef-enhanced and spice stations), using creative names (e.g., "brilliant broccoli"), slicing, role modeling, providing praise or incentives. Among studies that used incentives (n = 3), the type of incentive and method of earning them varied. Incentives such as cheap toys, stickers [50] and raffle tickets for prizes like t-shirts and smoothies [3] were earned for F/V consumption at the individual-child level. Whereas students in the fit game intervention RCT study earned their incentive as a student body by meeting vegetable consumption goals [52]. Fit game students were exposed to a dramatic comic book style story that was displayed on cafeteria screens during lunch. While at lunch, students were tasked with helping heroes defeat villains by eating vegetables. By meeting their group-level vegetable consumption goal, they received more of the story. Both F/V consumption increased even though vegetables were the target of this intervention. Researchers noted that some students mistakenly ate fruit, misidentifying them as vegetables or misunderstanding the goal [52].

System 2 interventions

Interventions that relied on system 2 thinking were much smaller in number (n = 4) and two improved at least one F/V behavior. There were two system 2 studies that used school garden interventions. One of them, the healthy garden healthy youth program, was designed to improve garden and nutrition knowledge [51]. The program was evaluated in a 4-year longitudinal RCT study and improved fruit consumption [51]. Although overall vegetable consumption did not significantly improve, there were differences between types of vegetables. The study in [51] reported a significant but marginal 4% increase of "low fat vegetables" (fresh/frozen) consumed by students receiving the intervention. There were no significant differences, however between intervention and control groups for consumption of "high fat vegetables" (fried) [51]. Learning gardens by grow Pittsburg, another school garden intervention, taught nutrition and cooking skills. Compared to control schools, F/V selection and consumption were not significantly improved among children in this study [48]. The authors reported less food waste; however, this result was attributed to school-level policies rather than the Learning Gardens intervention and therefore was not included in this review's results [48].

The study in [5] evaluated the brighter bites program and found that compared to control schools, intervention schools wasted less F/Vs. The brighter bites program was a 16-week classroom-based nutrition education program that included take-home fruits and vegetables and family cooking demonstrations [5]. Although F/V selection did not increase by the end of the intervention, selection decreased in control schools during the same period [5].

One system 2 intervention lacked significant results by the end of the study. This intervention was a 6-week classroom-based nutrition education program [49]. Although teachers were included in its' design, the authors concluded the program lacked translatable, or practical knowledge to guide students in their decision making [49]. Unlike the other interventions discussed in this review, there were no references to food related activities that involved actual food [49].

Mixed interventions

Mixed interventions combined components of both system 1 and system 2 methods (n = 5). These interventions were multi-component and had multiple goals. One mixed intervention is a locally grown, farm to school intervention that combined food advertising and a garden-based nutrition education curriculum, to improve vegetable selection [40]. In this RCT, intervention schools were assigned to an advertising message group (i.e., locally grown produce and nutrition messages). Overall, vegetable selection was not significantly different between advertising groups. Specific groups based on advertising message however, increased selection in specific vegetables between pre/posttest [40]. For example students in the "locally grown produce" advertising group consumed significantly more beets, and students who were in the "nutrition message" advertising group consumed more zucchini [40].

Two quasi-experimental studies that used control groups were successful at improving at least one fruit or vegetable behavior. First, the wellness in the schools program, also referred to as the WITS program, included improving lunch food quality by cooking from scratch, added water stations to the cafeteria, nutrition education and physical activity [44]. This intervention increased F/V consumption in students receiving the intervention [44]. The healthy planet healthy youth program included food sustainability lessons and activities (poster making/displaying) improved F/V waste [46].

"Fit n' cool," program, another mixed intervention evaluated through RCT, used goal setting and character modeling to improve physical activity and F/V consumption [45]. Colorful posters with multi-cultural active characters like, "strong Samanatha eats berries to help her ride her bike," were displayed school-wide and students were given daily letters discussing physical activity and F/V goals. The daily letter included information about the fruit or vegetables of the day, along with a group-level goal to increase consumption by 10% each week. However, students did not receive individual feedback. In addition to the posters and personalized letters, physical activity promotion included daily activities, recess reminders, and individually based goals per week to increase steps using ongoing measurements on piezoelectric activity monitors. Results for F/V consumption were not significant [45]. In contrast, physical activity significantly improved in step counts and time engaged in moderate to vigorous activity [45].

Lastly, the study in [43], a non-controlled study combined nutrition education, taste-testing, and access to salad bars to improve F/V consumption and nutrition education followed California's power plus! campaign [43]. Lessons included information about MyPlate, portion size, and health outcomes related to F/V consumption. Although survey data showed improvement for preferences and knowledge, consumption was not significantly improved [43].

Intervention duration and system thinking

Intervention duration varied greatly across studies, ranging as short as three days to as long as four years. Most lasted one month to five months (n = 9), with four lasting less than a month and four extending at least one school year. Both system 1 and system 2 interventions varied in duration. System 2 interventions ranged from 1 month to 4 years. System 1 interventions were successful at all intervention duration lengths, whereas effective mixed interventions tended to last longer than 3 months. Although system 2 interventions were largely ineffective, those that did show significant improvements (n = 2) were longer. For example, the brighter bites program which included nutrition education at school and included take-home fruits and vegetables lasted 16 weeks [5] and the healthy garden healthy schools program a school garden intervention, lasted four years [51].

Thinking System and Populations

Nearly all studies included populations that face health disparities including minority groups, populations of low SES or high populations of students receiving free/reduced school lunch. These studies included relatively large populations of students who were Black or Hispanic, or occurred in title 1 or community eligible schools. Community eligible schools are in communities with high poverty and are granted the ability to provide lunch cost free to the entire school population regardless of individual family status.

Free/reduce lunch or low-income populations

Most studies included populations that qualified for free/reduce lunch. 18 studies included schools with most students qualifying for free-reduced lunch, identified as “title one,” “community eligible”, or described as “low income.” The majority (n = 11) of these studies were considered system 1 interventions and 10 of them were successful at improving at least one fruit or vegetable behavior. One system 1 intervention paired community eligible schools with non-eligible schools, in a RCT lasting 10 days. The community eligible schools did not have statistically significant F/V improvements compared to the high SES schools [47]. The authors suggested this could be due to home F/V exposure differences related to socio-economic status [47]. Additionally, two out of three system 2 interventions and two out of four mixed interventions that included this population were successful at improving at least one fruit or vegetable behavior.

Minority populations

Among studies that specifically included minorities (at least 40% of the population) in their study population (n = 12), most interventions were categorized as system 1; however three interventions were system 2 and one was categorized as mixed. These interventions were largely successful improving at least one behavior, across system levels. Specifically, six of out eight system 1, two out three system 2 and the single mixed intervention all improved at least one fruit or vegetable behavior. The system 1 intervention that used table tents to display fun facts about F/Vs did not have significant effects on the community eligible schools, which were also predominantly Black [47]. The intervention, however, was successful in improving F/V selection and consumption in the non-eligible schools which were predominantly White [47].

Fruit and Vegetable Behaviors (Results) by System-Level Thinking

Results of reviewed intervention studies varied in magnitude for each F/V behavior (i.e., selection, consumption, waste) and system-level thinking category. Intervention studies with statistically significant results ($p < 0.05$) were more numerous and tended to be categorized as system 1 interventions. Increases in selection of fruits and vegetables ranged from +15.60% to +54.23% or reported as increases of +0.44 cups or +0.17 servings in these studies [3, 8, 39, 42, 47, 50]. F/V consumption increases ranged from 8.7% to 148% or reported as +10.66 g to +15.67 g, and +0.36 cups [3, 4, 6-8, 39, 41, 44, 47, 50-52]. Decreases in fruit or vegetable waste ranged from -7.11% to -66%, or reported as -0.27 cups, or -10.5 g to -49.6 g [3-7, 12, 42, 46].

Conversely, some interventions had adverse or non-significant results for F/V behaviors. One intervention decreased fruit or vegetable selection by 16% [12], and three did not significantly change selection [6, 41, 49]. Two interventions reduced fruit or vegetable consumption 20-48% [7, 12], and four did not significantly change consumption [43, 45, 48, 49]. These were predominantly system 2 or mixed interventions.

Table 6 shows the system 1 intervention study outcome measures, magnitude, and effect size.

Table 6. System 1 intervention study outcome measures, magnitude, & effect size

R	Outcome measured	DE	Significance	Magnitude	Effect size
[3]	Fruit consumption	↑	Yes ($p < 0.01$)	+11.1%	Not reported
	Fruit waste	↓	Yes ($p < 0.001$)	-16%	Not reported
	Vegetable selection	↑	Yes ($p < 0.001$)	+16%	Not reported
	Vegetable consumption	↑	Yes ($p < 0.01$)	+8.7%	Not reported
	Vegetable waste	↔	No (p value not reported)	N/A	Not reported
[4]	Fruit consumption	↑	Yes ($p < 0.001$)*	+21.5% to 27.7%	β = 21.5 (3 months), β = 27.7 (4 months)
	Fruit waste	↓	Yes ($p < 0.001$)*	-27.7g to - 49.6g	Not reported
[6]	Fruit selection	↔	No (t[2] = -0.48, $p < 0.05$)	N/A	Not reported
	Fruit consumption	↑	Yes ($p < 0.001$)	148%	Not reported
	Fruit waste	↓	Yes ($p < 0.05$)	-66%	Not reported
[7]	Fruit consumption	↑	Yes ($p < 0.05$)*	+14.2 to 20.6%*	β = 14.2 to 20.6*
	Fruit waste	↓	Yes*	-10.5 to -19.4g*	Not reported
	Vegetable consumption	↓	Yes ($p < 0.001$)*	-5.8 to -20.1%	β = -5.8 to -20.1*
	Vegetable waste	↑	Yes*	+4.9 to +19.4%	Not reported
[8]	Fruit selection	↑	Yes ($q = 0.001$)*	+18 to 30.2g (+20 to 31%)	Not reported
	Fruit consumption	**	**	**	Not reported
	Fruit waste	↑	Yes ($q < 0.032$)*	+73%	Not reported

Table 6 (Continued). System 1 intervention study outcome measures, magnitude, & effect size

R	Outcome measured	DE	Significance	Magnitude	Effect size
	Vegetable selection	↔	No (q = 0.33-0.61)*	N/A	Not reported
	Vegetable consumption	↑	Yes (q = 0.022)*	+8.3 to 15.3g (+21 to 40%)	Not reported
	Vegetable waste	↔	No (q = 0.44-0.83)*	N/A	N/A
[12]	Fruit selection	↓	Yes (p < 0.001)	-0.32 cups (-33%)	Not reported
	Fruit consumption	↓	Yes (p < 0.001)	-0.08 cups (-33%)	Not reported
	Fruit waste	↓	Yes (p = 0.016)	-0.24 cups (-41%)	Not reported
	Vegetable selection	↓	Yes (p < 0.001)	-0.37 cups (-35%)	Not reported
	Vegetable consumption	↓	Yes (p < 0.001)	-0.27 cups (-47%)	Not reported
	Vegetable waste	↓	Yes (p < 0.001)	-0.24 cups (41%)	Not reported
[39]	Fruit selection	↑	Yes (p < 0.0001)	+ .45 cups	d = 1.21
	Vegetable selection	↓	Yes (p<0.009	-.04 cups	d = 0.13
	Fruit consumption	↑	Yes (p < 0.0001)	+ .36 cups	d = 0.91
	Vegetable consumption	↑	No (p = 0.647)	N/A	d = 0.04
	Fruit waste	↑	Yes (p < 0.0001)	+.09 cups	d = 0.27
	Vegetable waste	↓	No (p = 0.064)	N/A	d = 0.18
[41]	Fruit selection	↔	No (p = 0.40)	N/A	Not reported
	Fruit consumption	↑	Yes (p = 0.04)	+0.08 cups (+27%)	Not reported
	Vegetable selection	↔	No (p = 0.38)	N/A	Not reported
	Vegetable consumption	↑	Yes (p = 0.005)	+0.12 cups (+63%)	Not reported
[42]	Fruit selection	↑	Yes (p < 0.05)	+1.6%	r = -0.20
	Fruit waste	↓	Yes (p < 0.001)	-13.6%	β = -13.61
	Vegetable selection	↑	Yes (p < 0.001)	+15.6%	r = -0.20
	Vegetable waste	↓	Yes (p < 0.001)	-7.11%	β = -7.11
[47]	F/V selection	↑	Yes (p < 0.001)**	+0.17 serving	Not reported
	F/V consumption	↑	Yes (p < 0.001)**	+0.14 serving (+19%)	Not reported
[50]	F/V selection	↑	Yes (p < 0.0001)	+54.23%	Not reported
	F/V consumption	↑	Yes (p < 0.0001)	+42%	Not reported
[52]	Fruit consumption	↑	Yes (p < 0.001)	+15.67g	d = 0.39
	Vegetable consumption	↑	Yes (p < 0.001)	+10.66g	d = 0.41

Note. R: Reference; DE: Direction of effect; *Result was significant in majority of research sites, times measured or intervention strategies; **Denotes conflicting results across research sites; & ↔Designates no change in outcome measure

Table 7. System 2 & mixed intervention study outcome measures, magnitude, & effect size

R	Outcome measured	DE	Significance	Magnitude	Effect size
[5]-S	F/V waste	↓	Yes (p < 0.001)	-48.9g to -15.2g	β = -32.06; 95% CI
[40]-M	Vegetable selection	↑	Yes (p < 0.02)***	***	Not reported
[43]-M	F/V consumption	↔	No (p value not reported)	N/A	Not reported
[44]-M	F/V consumption	↑	Yes (p < 0.001)	+42%	Not reported
[45]-M	F/V consumption	↔	No (p = 0.308)	N/A	Not reported
[46]-M	Fruit consumption	↔	No (p > 0.365)*	N/A	Not reported
	Vegetable consumption	↔	No (p > 0.848)*	N/A	Not reported
	F/V waste	↓	Yes (p = 0.029)	-48% (at 5m follow-up)	Not reported
[48]-S	F/V consumption	↔	No (p = 0.21)	N/A	Not reported
[49]-S	F/V selection	↔	No*	N/A	Not reported
	F/V consumption	↔	No*	N/A	Not reported
	F/V waste	↔	No*	N/A	Not reported
[51]-S	Fruit consumption	↑	Yes (p < 0.001)	+9%	Not reported
	Vegetable consumption	↑	Yes (p < 0.01)***	***	Not reported

Note. R: Reference; DE: Direction of effect; S: Systems 2; M: Mixed; *Result was significant in majority of research sites, times measured or intervention strategies; **Denotes conflicting results across research sites; & ↔Designates no change in outcome measure

Table 7 shows the system 2 and mixed intervention study outcome measures, magnitude, and effect size.

Selection

F/V selection was measured and described in 11 studies. Of these, seven significantly increased selection and six of these were system 1 interventions [3, 8, 39, 42, 47, 50]. One system 1 intervention added stickers to bags of fruits and vegetables and provided cheap incentives increased selection by 54.23% ($p < 0.0001$) [50].

One mixed intervention increased vegetable selection by exposing students to messages about locally grown vegetables or nutritional information. Schools were randomly assigned the advertising group (i.e., local produce or nutritional information) and advertising (signs) were displayed in the lunchroom. Both groups improved selection of specific vegetables (beets and zucchini) but did not have significant differences between each other [40].

Consumption

18 of the 21 studies specifically measured and discussed consumption. A total of 12 of these studies improved consumption [3, 4, 6-8, 39, 41, 44, 47, 50-52]. Of these, seven improved both F/V consumption, four improved fruit consumption only, and one only improved vegetable consumption. Overall system 1 interventions were successful

in improving F/V consumption. In one that improved taste by using chef enhanced meals, sites, schools receiving the intervention consumed 27% more fruit ($p = 0.04$) and 63% more vegetables ($p = 0.005$) compared to control schools [41]. In contrast, in a non-controlled study, one system 1 intervention aimed at increasing vegetable consumption by including strategies such as creative names, spice stations and taste tests significantly decreased vegetable consumption by 5.8% to 22.4% ($p < 0.001$) depending on school and phase of intervention [7]. Seasonality and preparation of vegetables was noted as a possible explanation for these results [7]. Although vegetables were the target of this intervention, fruit consumption increased at two of three schools [7]. In a non-controlled experimental study, compared to whole apples, students consumed 148% ($p < 0.0001$) more sliced apples [6].

Waste reduction

The issue of food waste in schools was addressed in nearly all studies (n = 16), many highlighting the high costs associated with food waste, as well as the goal of getting children to eat more and waste less. Reducing F/V waste was the target of two studies [42, 46], although food waste measured and described in 13 studies. All system-level categories had interventions that reduced F/V waste [3-7, 12, 42, 46]. Brighter bites, a system 2 intervention, reported significantly less waste compared to control schools [5]. Although this intervention had non-significant selection changes, students wasted less of what was selected [5]. The healthy plant health youth program, a mixed system intervention, specifically targeted sustainability topics, including food waste. Students in this intervention wasted 48% ($p = 0.029$) less vegetables five months post intervention, compared to students in the control group. Student surveys indicated they understood food waste was bad for the environment [46]. Among those that measured and discussed waste, two reported significantly more waste after the intervention [8, 39]. Both interventions included access to salad bars and waste varied by intervention site. Given the benefits of salad bars, authors recommend strategies to support student selection in order to reduce food waste [39].

Intervention Study Design and Thinking-System

Intervention studies were assessed using NIH quality assessment tools (see **Table 2** and **Table 3**). There was great variability in methods and study design across reviewed studies. To better understand results within the context of thinking-systems, identifying methodological differences was essential.

Controlled intervention studies

The majority of reviewed studies (n = 13) had methods that included control groups, including RCT and matched control groups [5, 8, 39-41, 44-49, 51, 52]. Interventions with strategies in each thinking-system had nearly equal distribution. All system 1 interventions (n = 5) [8, 39, 41, 47, 52], three of four mixed interventions [40, 44, 46], and only one of four system 2 interventions [51] improved at least one fruit or vegetable behavior.

Intervention studies with no control group

Many reviewed studies (n = 8) did not include control groups [3, 4, 6, 7, 12, 42, 43, 50]. Seven of these intervention studies were considered system 1 and were successful improving at least one fruit or vegetable behavior. For example, Thapa & Lyford observed 2,124 lunch trays from two schools across multiple data collection points (baseline, intervention and post-intervention) for analysis [50]. Students who selected fruits and vegetables increased from baseline to intervention by 9.5% ($p < .0001$) and increased further by 54% ($p < .0001$) post intervention. Consumption of F/V servings also increased from baseline to intervention by 242% ($p < .0001$). Post intervention, this result was not sustained but remained 42% higher than baseline ($p < .0001$). The other study that did not include a control group also had a small sample (n = 149) was considered a mixed intervention and did not improve fruit or vegetable behaviors [43].

School Staff & Students

Staff feedback

Studies that included school staff feedback had common themes. First, interventions that included staff planning or implementation had much more positive feedback from food service staff, teachers, and school leaders. In a food waste intervention, food service workers chose which smarter lunch movement strategies to implement in their lunchrooms [42]. In other studies, school staff liked when interventions fulfilled multiple goals. For example, the school principal in [3] liked that intervention included college student role models because it encouraged F/V consumption and college attendance. Buy-in from food service staff and teachers was crucial for successful intervention implementation. In some studies, a lack of buy-in led to issues with implementation fidelity. For example, the study in [7] reported issues with strategy fidelity across study sites. In one school, a food service worker did not implement the “creative names” (e.g., “brilliant broccoli”) strategy for the same duration, citing concerns that it could be confusing to students and found the sign stands burdensome [7].

Staff feedback relating to feasibility included lack of resources or space to carry out interventions as designed. For example, one food service worker had difficulty implementing the spice station strategy (system 1) due to limited space and the availability of food carts [7]. Teachers involved in healthy garden healthy youth program (mixed intervention), found the program overwhelming [51]. They struggled to complete lessons and had to adapt the intervention curriculum for varying student reading levels [51]. School leaders found it difficult to include school garden interventions in the cafeteria programming (system 2). This was due to space and lack of buy-in by food service staff [48, 51].

Student engagement & participation

A common theme among interventions that improved F/V behaviors were activities that involved student engagement. Poster making, voting, making creative names, and taste testing were common student-based activities among interventions. Specifically, engagement was a key element of fit game’s intervention which had students participate in the progression of the fit story whereby consuming more vegetables [52]. Additionally, students were also engaged as they tended to school gardens in the healthy garden healthy youth program [51].

CONCLUSIONS & DISCUSSION

Interventions that nudge behavior (system 1) were overwhelmingly more successful in improving F/V behaviors.

All system 1 interventions improved at least one F/V behavior. The success of system 1 interventions in this review is consistent with those found in [24].

Few interventions relied solely on improving nutrition, food, or gardening knowledge (system 2) to improve these behaviors. Due to the limited number of system 2 interventions, it is difficult to form conclusions on their ability to improve F/V behaviors solely on nutrition education or skill development. However, findings from [24], indicate that interventions based on system 2 thinking are generally less successful in enhancing F/V selection, consumption, or reducing food waste. One explanation could be that system 2 decision-making is much more taxing, causing people to default easier, system 1 thinking and decision-making [30]. This is especially true when a person has been mentally engaged in other tasks or decision-making activities [30]. In the context of school lunch, it is plausible that students have already experienced hours of cognitive engagement in class before entering the lunchroom.

Results for mixed interventions in this review are much more limited than the study in [24]. The study in [24] found 86% of mixed interventions to be successful. This contrasts with this review that found 60% of these interventions to improve at least one food behavior.

Limitations

Several limitations should be considered when interpreting the findings of this review. As with any review, publication bias is a concern. School-based interventions with null or negative results may be underreported, especially when conducted internally by school districts or non-academic partners. Due to limited number of published nutrition education intervention studies to improve F/V behaviors, it is difficult to fully conclude success (or lack thereof) of interventions that rely on system 2 strategies.

There was substantial variability across studies. First, reviewed studies used many different methods to measure key outcomes (selection, consumption, and waste). Some used direct weighing of plate waste, while others relied on visual observation or photographic estimation, often with different coding increments. Second, studies also varied in the number of times measurements were taken during an intervention. For example, the study in [8] measured food one day per school per data point (pre-/post-), whereas the study in [52] measured food five days per school per data point. Limited data collection could introduce day level bias. Third, variance in intervention duration also makes comparison challenging. Many interventions were conducted over short periods (often less than four weeks), which may reflect temporary novelty effects rather than sustainable behavior change. Short intervention durations may limit conclusions about long-term effectiveness or sustainability. This limitation is compounded by the fact that few studies [45, 46, 52] included follow-up of any length of time to observe if behavior changes were sustained. Without long-term follow-up, the persistence of observed improvements remains uncertain. These areas of variability reduce the comparability of outcomes and complicates attempts to synthesize intervention effects.

Further limiting conclusions, very few reviewed studies reported effect size. This makes it difficult to evaluate intervention results to provide recommendations for implementation. Future studies should report on effect size to improve interpretation and intervention selection.

Intervention fidelity was discussed in many studies. Some reported inconsistent or deviation of protocol at the school level due to staffing, cafeteria layout, reading level of materials, and time but were not systematically analyzed.

It is also unclear whether factors highly related to socio-economic status like reading levels [53], were considered in intervention design, implementation or analysis of results. Teachers involved in healthy garden healthy youth indicated reading level issues in the intervention's curriculum [51]. Other studies did not discuss aspects of literacy that could have influenced intervention results. The study in [47] had success using table tents in schools with high SES, but not in schools of low SES. It is unclear if differences were possibly due to home exposure as the authors suggest or other factors related to SES such as literacy levels.

Lastly, although some studies mentioned the presence (or lack thereof) of competitive foods (e.g., ala carte or vending machines), it is unclear whether competitive foods contributed to any of the results. The study in [54] found that racial/ethnically diverse schools and those of lower SES had lower rates of competitive foods in the lunchroom compared to White or high SES populations. Prior to HHFKA, competitive foods tended to be lower nutrient quality [54]. HHFKA included nutritional standards for competitive foods [54]. Competitive food offered ala carte or in vending machines could be system 1 influences within the lunchroom and likely influences decision making.

Implications for Schools & Public Health Organizations

Student and staff engagement as well as buy-in were specifically discussed and important aspects of many of the studies reviewed. Although not universally measured or discussed across studies, improvement in F/V behaviors often did not last after the intervention or study ended. This could be due to lack of programming or guidance post study. School-based intervention design should consider school dynamics and restraints so that schools can implement interventions without outside help. Additionally, tailoring interventions to the community requires community engagement [55].

Considering the constraints on time and money in schools, school leaders should consider system 1 interventions when trying to improve F/V consumption, selection, or reduce waste. Compared to system 2 interventions, these strategies require less staffing and do not require classroom time or curriculum to implement. Although some system 1 interventions have associated costs (e.g., incentives, spices, apple slicers, posters), others do not. No cost options include providing praise/fist bumps and improving F/V location within the lunch line. Further, these strategies can be universally used regardless of age, language, and literacy. Additionally, system 1 strategies could be used and switched out periodically to re-nudge students towards improving F/V behaviors.

Considering the role of knowledge in decision making, system 2 or mixed interventions could target specific F/V knowledge needed for students to sort facts from fiction or make good decisions. For example, healthy garden healthy youth was able to improve low-fat vegetable consumption [51]. Although not fully explained, the education portion of the intervention could have targeted differentiating low fat vegetables (carrots) from high fat vegetables (French fries). Additionally, healthy garden healthy youth emphasis on food sustainability helps explain students' knowledge improvement that waste is bad for the environment as well as having significantly less F/V waste at follow-up [46].

Although this review focuses on U.S. based interventions conducted under the NSLP, many high-income countries operate school meal programs that face similar challenges with F/V acceptance, food waste, and dietary equity [56]. Given that system 1 nudges and low-cost environmental modifications are relatively policy-neutral, future research should explore how these interventions perform across diverse educational, cultural, and policy environments. Such comparisons could help identify universally effective strategies and inform broader implementation efforts globally.

In the larger context of intervention selection and implementation, it is worth noting that strategies that were successful in this review were innovative because they prioritized student behaviors (selecting, consuming, reducing waste) and improved the food environment at school. This is in contrast with traditional teacher directed nutrition curriculum interventions, or interventions targeting specific health outcomes associated with healthy nutrition. The study in [57] refer to these kinds of interventions as stealth interventions, which target process motivators that drive behavior. Intervening to improve process motivators can build self-efficacy for behavior changes that can affect health outcomes [57]. Successful process motivators to improve physical activity and eating behaviors are fun, provide choice, curiosity, involve social interactions including social approval and pride [57]. In addition, the theory of triadic influence (TTI) suggests that behavior is caused and can be intervened along three "streams" of influence:

(1) intrapersonal (self-esteem, sense of control, and competencies),

(2) interpersonal (social influences and surroundings, bonds with role models), and

(3) cultural-environmental (interaction and influence of social institutions) [58].

Many of the interventions in this review engaged all three streams included in the TTI by improving F/V appeal for students, enhancing social interactions around food, and changing the ways students engage with the school during lunch. Successful interventions in this review had many of the characteristics suggested by [57, 58] and components of the TTI built into their intervention design. This suggests, along with the results of this systematic review, that interventions to improve F/V behaviors at elementary and middle school lunch do not need to include time intensive curriculums (system 2) but rather can focus efforts on nudging behaviors and improving food environments (system 1).

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