The effects of school gardens on fruit and vegetable consumption at school: A randomized controlled trial with low-income elementary schools in four U.S. states

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ABSTRACT

This randomized controlled trial examines the effects of a school garden intervention on children’s fruit and vegetable (FV) consumption at school over two years. We randomly assigned schools to the intervention group that received gardens and related curriculum (n = 24) or to the waitlist control group that received gardens and curriculum at the conclusion of the study (n = 22). Children in second, fourth, and fifth grade at baseline (n = 2767) in low-income schools (n = 46) in four U.S. States (Arkansas, Iowa, New York, and Washington) participated. The intervention comprised gardens for each classroom; a curriculum focused on nutrition, plant science, and horticulture, including activities and FV tasting sessions; resources for the school that addressed topics such as soil contamination and food safety; an implementation guide focused on issues related to planning, planting, and maintaining the garden through the year, engaging volunteers, summer gardening, building community capacity, and sustaining the gardening program. FV consumption was measured by photographing lunches before and after children ate, for 2–3 days, at baseline and at each of 3 subsequent periods of data collection during the intervention. FV consumption was calculated using Digital Food Image Analysis. Among children in the intervention, fruit consumption and low-fat vegetable consumption increased from pre-garden baseline to post-garden more than among control group children. Garden intervention fidelity (GIF) also predicted changes in dietary intake, with more robust interventions showing a stronger effect than weaker interventions. GIF-lessons was a particularly potent predictor of change in dietary intake. School gardens modestly increase children’s FV consumption at school.

1. Introduction

Fruit and vegetable (FV) consumption is linked to reduced risk of various diseases ranging from cardiovascular disease to cancer to type 2 diabetes (Holman and White, 2011; Carter et al., 2010; Wang et al., 2014; Aune et al., 2017). However, children in the U.S. do not meet recommended levels of fruit and vegetable (FV) consumption (U. S. Department of Agriculture, U. S. Department of Health and Human

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Services. Dietary Guidelines for Americans, 2020). School gardens are recognized as a public health intervention that may increase children’s intake of FV (Davis et al., 2015; Skelton et al., 2019). Healthy eating is a critical issue among children in low-income communities, as they are particularly at risk for poor diet (Lorson et al., 2009).

Prior studies have examined the impact of school gardens on children’s FV intake; however, results are often compromised by methodological limitations related to research design and measurement (Savio-Roskos et al., 2017; Ohy et al., 2016; Berezowitz et al., 2015; Landry et al., 2021). While exceptions exist (e.g., TX Sprout (Landry et al., 2021) and Project Tomato (Evans et al., 2013)), two common shortcomings in this literature are small sample sizes and short study durations (i.e., weeks or months). A third limitation is a focus on preferences, knowledge, and attitudes regarding FV, rather than dietary intake specifically; or reliance on self-report measures of FV consumption, which threaten construct validity and in turn undermine internal validity. Fourth, many studies fail to include a comparison or control group, and few studies have employed random assignment. As Savio-Roskos and colleagues (2017, p. 1) note in their review of the literature, “Future studies that include control groups, randomized designs and assessments of FV consumption over at least one year are needed to advance the literature on this topic.”

In addition, while studies examining the effects of school gardens on children’s health behaviors have pointed to the relevance of the garden intervention intensity or fidelity as an important predictive factor (Wang et al., 2010; Christian et al., 2014), this variable has not been explicitly measured. The current study includes garden fidelity as a variable and examines the role of lessons versus garden activities—two core components of the garden intervention.

This study aims to examine the influence of a school garden program on children’s FV consumption. By employing a randomized controlled trial with a sample of more than 2,700 children in 46 schools; by measuring FV consumption via photography rather than relying on self-report; by conducting a 2-year longitudinal study; and by operationalizing garden intervention fidelity, this study aims to address key critiques of the literature. Moreover, we focus on the most at-risk population: children in low-income communities. This work is theoretically grounded in the ecological model, which suggests that contexts or “microsystems” such as home and school can shape behavior and development (Sallis et al., 2006; Bronfenbrenner et al., 1998); and in the life course perspective, which emphasizes the importance of intervention early in life to affect lifelong dietary habits and set youth on positive health trajectories (Wethington, 2005).

This study addresses the following research questions:

RQ1. Does a school garden intervention including garden-based curriculum result in increases in children’s FV consumption at school?

RQ2. Does the fidelity of the garden intervention affect changes in FV consumption at school?

2. Method

Study design and procedure. In this longitudinal cluster randomized controlled trial, schools were randomly assigned to receive the garden intervention or to serve in the waitlist control group that received gardens at the end of the study. Baseline (Wave 1) data were collected in Fall followed by garden implementation ~6 months later (Spring) and three waves of follow-up data collection during the ongoing intervention: Wave 2 at 8 months (late Spring), Wave 3 at 12 months (Fall), and Wave 4 at 20 months (late Spring). The research protocol was reviewed and deemed exempt by the Cornell University Institutional Review Board because the study’s interactions with children are educational measures of curriculum implemented and the remaining activities are observations of public behavior (45 CFR46.101). This article represents one component of the Healthy Gardens, Healthy Youth (HGHY), USDA People’s Garden study examining the effects of school gardens on various outcomes (Wells et al., 2014a,b, 2015, 2018).

The Intervention. The HGHY intervention was delivered by teachers and/or Cooperative Extension educators. The intervention comprised four components: (1) A garden that was either a 4’ x 8’ raised bed or a container garden kit for each participating classroom of 15–20 children (i.e., 3–4 raised beds per school). (2) Educators were given access to a curriculum toolkit of 40 lessons—20 tailored for children in grades 2–3 and 20 for grades 4–6 (HGHY curriculum). The curriculum toolkit was created based on a review of 17 extant garden curricula and focused on nutrition, horticulture, and plant science. Criteria employed to select curricula included: experiential learning; age-appropriate content related to nutrition, food, and gardening; research-based; alignment with educational standards; and STEM (Science, Technology, Engineering and Math) focused. Selected lessons addressed topics such as planting planning, planting seeds, germination, watering, maintenance, harvesting, and food preparation; and included snacking and tasting events throughout the growing season. Two lessons came from “Got Veggies,” a garden-based nutrition education curriculum that aims to increase children’s FV consumption (Community Ground Works) and two lessons from “Growing Healthy Kids” focused on nutrition education and the connection to plant parts (Oregon State University). Throughout the intervention period, lessons were typically delivered weekly during the school day either in the classroom or in the garden. Aside from the lessons, educators led various activities in the garden such as planting, weeding, and harvesting. (3) Resources for the school included information about soil contamination, food safety and similar topics. (4) A garden implementation guide provided schools with information about planning, planting, and maintaining the garden throughout the year; summer gardening; volunteer engagement; and building community capacity.

Schools and Classes. This study targeted low-income schools (i.e., at least 50% of students qualifying for free or reduced-price meals (FRPM)) that did not already have gardens. Forty-six schools in Arkansas, Iowa, Washington, and New York State participated. Fig. 1 illustrates the school recruitment procedure and sample sizes. Schools in each region were randomly assigned to intervention or waitlist control. The total number of classes in year 1 was 159. In most schools, 4 classes participated in the study (mean classes per school = 3.5). Classes comprised 2nd, 4th and 5th graders at baseline who advanced to 3rd, 5th, and 6th grades respectively over the course of the study. The youngest group received the grades 2–3 curriculum; the older children received the 4th-6th grade curriculum.

2.1. Constructs and measures

2.1.1. FV consumption at school

Given the limited reliability and validity of self-report measures of children’s dietary intake (Kristal et al., 2005; Livingstone et al., 2004; Merson et al., 2017; Rockett and Colditz, 1997; Warren et al., 2003), the dependent variable, FV consumption at school, was measured by photographing children’s lunch trays before (“pre”) and after (“post”) they ate lunch. Photography has been used in the past to measure children’s diet (Archundia Herrera and Chan, 2018; McCloskey et al., 2019; Elliott et al., 2021; Winzer et al., 2018) and was combined, in this study, with the use of Digital Food Image Analysis (DFIA) software (Todd et al., 2017). Due to the scope of this study (i.e., ~30,000+ meals assessed from more than 2700 children x 4 waves of data collection x 3 days per wave) and the fast pace of the typical elementary school cafeteria (Caruso and Rosenthal, 2020), photography was deemed the most practical and valid data collection method 1; rather than, for example, weighed plate waste. DFIA-derived estimates of serving size and percentage consumed of fruit and vegetable items have been validated

1 Digital observation has been established as a reliable method for assessment of both serving size and consumption and has been validated against weighed measures (Williamson et al., 2003; Williamson et al., 2004).
against dietitians’ estimates from lunch tray photo pairs, as assessed by Spearman correlations (Todd et al., 2017; Williamson et al., 2004; Williamson et al., 2003). Using DFIA, in this study, FV consumption is operationalized by both (a) grams of FV consumed and (b) percentage (proportion) of FV served that was consumed.

Each child’s school lunch was photographed for three days at baseline and at each of three subsequent waves of data collection (mean 2.4 days per wave, per child), yielding up to 12 (pre-post pairs of) lunch photographs per child over the 2-year study. Lunches from home were excluded from analyses, as were incomplete meals (i.e., photographs that did not capture all food items). A laminated ID “ruler”—with the child’s unique 9-digit ID number designating state, school, class, and individual—was included in both the pre- and post-photographs to ensure correct photograph pairing (Fig. 2). Lunch tray photograph pairs were analyzed using DFIA (Todd et al., 2017) to yield total grams of fruit and grams of vegetables in the total meal and the percentage of fruit and vegetables consumed (i.e., ratio of F intake/ F served; and V intake/ V served). In addition, items containing vegetables were coded as high-fat (i.e., potato salad, french fries) or low-fat (i.e., fresh, frozen, or canned

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2 Dietitians’ ratings of FV servings and FV consumption based on digital photographs are highly correlated with weighed measurements (Williamson et al., 2003; Williamson et al., 2004).
vegetables) to examine consumption of both high-fat vegetables (HFV) and low-fat vegetables (LFV). Examination of HFV and LFV adds nuance to our analyses and has practical merit. Policy makers and researchers have suggested the value of separating of HFV and LFV (U. S. Department of Agriculture, 2012; Cullen et al., 1999).

2.1.2. Garden Intervention Fidelity

To capture the variability of intervention delivery from class-to-class, garden intervention fidelity (GIF) was operationalized based on “garden records” completed by Extension Educators for each intervention classroom. The total GIF (“GIF-sum”) included the number of lessons delivered to the class, the number of FV planted, number of FV harvested, and the number of ways FV were distributed (e.g., eaten as snack in garden; sent home, etc.), in each wave. To examine the influence of the curriculum and the garden components of the intervention independently, two GIF subscales were created: GIF-lessons (number of lessons delivered) and GIF-garden (number of FV planted, FV harvested, and methods of FV distribution). For all GIF measures (GIF-sum and the two subscales GIF-lessons and GIF-garden), categorical levels of intervention were identified—from level 1 (none) to level 4 (robust) to reflect intervention fidelity.

2.2. Statistical Analysis.

Preliminary analyses (i.e., \(\chi^2\) and t-tests) were conducted to assess demographic differences between intervention and control at the school and student level. The sampling design results in a nested structure (i.e., children within classrooms within schools). Analyses to examine RQ1 and RQ2 were carried out in general linear mixed models, which is ideally suited to the analysis of longitudinal nested data. An unstructured error assumption was used, and denominator degrees of freedom computed by the first-order Kenward-Rogers method. The key test for evaluation of FV consumption is the test of the interaction of treatment by time (for RQ1); and fidelity by time (for RQ2), (time is represented by “wave,” i.e., four data collection periods). We partitioned from this interaction key pre-specified contrasts of interest—specifically, the test of treatment (intervention v. control) by time (wave 1 (baseline) versus waves 2, 3, and 4) (a 2 × 2 contrast); fidelity (level 4 versus level 1) by time (wave 1 versus wave 4) and the linear contrast on fidelity levels by wave 1 versus wave 4. Covariates such as sex, race/ethnicity, age, and grade were examined for inclusion in models. The tables show the means and probabilities for these contrasts. Statistical analyses were carried out using SAS.

To examine RQ1, the final model included treatment (control versus intervention), sex of child, and wave (1–4) as fixed classification factors; the interactions among these factors; states as an additional fixed classification factor; and individuals and classrooms as levels of random classification factors.

To examine RQ2, there were three final models, each examining one fidelity variable that substituted for the treatment classification factor. The three fidelity variables (i.e., GIF-sum, GIF-lessons, and GIF-garden) were 4-level classification factors. These models included fidelity, sex of child, and wave (1 versus 4) as fixed classification factors; the interactions among these factors; states as an additional fixed classification factor; and individuals and classrooms as levels of random classification factors. In these models, the comparisons were restricted to Wave 1 versus Wave 4. (This is because the fidelity variables were constructed using all fidelity data through Wave 4, and it is not logical to use data from a later time point to predict an outcome at an earlier time point (e.g., from Wave 4 to predict an outcome at Wave 2 or 3). Other models with different construction of fidelity were examined, but the models presented here best capture the results. We also examined models in which fidelity was included in quantitative form, but again this did not add to the understanding of results.

Power calculations conducted for the original grant application indicated sufficient sample size to detect meaningful treatment mean differences at the level of a 2-way interaction for FV intake outcomes.

3. Results

3.1. Descriptive Statistics.

All 46 participating schools were low-income, with an average of 70.67% of the children participating in FRPM at baseline. Table 1 summarizes participants’ characteristics (n = 2767). At baseline, participants were 1398 2nd graders and 1369 4th–5th graders; 50.7% were girls. The average age of participating children in the intervention schools was 8.33 years and 8.27 years in the control schools. Just over half (51.2%) of the children were white; 20.3% African American, 14.9% Hispanic, 4.2% Asian, and 9.4% Native American, multi-racial or “other.”

RQ1: Do school gardens affect children’s FV consumption at school? We examined the main effect of school gardens on FV consumption in two ways: changes in grams consumed and changes in percent consumed. For both grams consumed and percent consumed, we consider fruit and vegetables as well as HFV and LFV, individually.

Grams of FV consumed. As shown in Table 2, results suggest that, compared to children in the control group, the intervention group children showed a greater increase in fruit consumption (in grams) from wave 1 to waves 2, 3, 4 (p < .001). On average, children in the intervention group increased their fruit consumption from 71 g to 88 g while the control group increased from 85 g to 89 g. There were no significant differences in changes in vegetable consumption (grams), HFV, or LFV.
**Table 1**

Participant Characteristics at Baseline. Values are Ns (percentages) (n = 2767).

|                | Intervention | Control | Total | Significant Difference I vs C^b |
|----------------|--------------|---------|-------|---------------------------------|
|                | n = 1489     | n = 1278 | n = 2767 |                                 |
| Grade          |              |         |       |                                 |
| Lower (2nd)    | 740 (49.7%)  | 658 (51.5%) | 1398 (50.5%) | 0.348                           |
| Upper (4th / 5th) | 749 (50.3%)  | 620 (48.5%) | 1369 (49.5%) |                                 |
| Gender         |              |         |       |                                 |
| Boy            | 712 (47.8%)  | 651 (50.9%) | 1363 (49.3%) | 0.102                           |
| Girl           | 777 (52.2%)  | 627 (49.1%) | 1404 (50.7%) |                                 |
| Ethnicity      |              |         |       |                                 |
| White          | 607 (49.6%)  | 596 (46.6%) | 1203 (51.2%) | 0.110^c                         |
| African American | 223 (18.2%)  | 255 (20.0%) | 478 (20.3%) |                                 |
| Hispanic       | 191 (15.6%)  | 158 (12.4%) | 349 (14.9%) |                                 |
| Asian          | 53 (4.3%)    | 46 (3.6%) | 99 (4.2%) |                                 |
| Native American | 14 (1.1%)    | 9 (0.7%)  | 23 (1.0%) |                                 |
| Multiracial    | 15 (1.2%)    | 8 (0.6%)  | 23 (1.0%) |                                 |
| Other          | 120 (9.8%)   | 54 (4.2%) | 174 (7.4%) |                                 |
| Age^d          | 6            | 10 (0.7%) | 14 (1.1%) | 24 (0.9%)                       | .002** |
|                | 7            | 549 (36.9%) | 498 (39.1%) | 1047 (37.9%)                   | |
|                | 8            | 187 (12.6%) | 149 (11.7%) | 336 (12.2%)                    | |
|                | 9            | 446 (30.0%) | 459 (36.0%) | 905 (32.8%)                    | |
|                | 10           | 267 (18.0%) | 149 (11.7%) | 416 (15.1%)                    | |
|                | 11           | 26 (1.7%)  | 4 (0.3%)  | 30 (1.1%)                      | |
|                | 12           | 1 (0.1%)  | 1 (0.1%)  | 2 (0.1%)                       | |
| Mean Age (at baseline) | 8.33 (1.21) | 8.19 (1.13) | 8.27 (1.18) | .002** |

a. ^2 analyses were used to compare the differences between intervention and control groups.

b. Ethnicity was missing from 418 children; table shows valid percentages (Intervention n = 1223, Control n = 1126, Total n = 2349).

c. ^2 analyses for ethnicity were computed for white versus non-white.

d. Age (at baseline) was missing from 7 children; table shows valid percentages (Intervention n = 1486, Control n = 1274, Total n = 2760).

e. t-tests were used to compare the differences between intervention and control groups.

** p < .01.

**Table 2**

FV Consumption (grams and percent), by treatment and pre-garden (Wave 1) to post-garden (Waves 2, 3, & 4).

|                      | Intervention | Control | Intervention - Control |
|----------------------|--------------|---------|-----------------------|
|                      | n = 1489     | n = 1278 |                       |
| Grams of FV Consumed |              |         |                       |
| Fruit                | 71.16 (4.40) | 68.35 (4.41) | 85.47 (4.35)          | 89.42 (4.43) | 13.23 (4.71) | 0.005** |
| Vegetable            | 56.25 (3.21) | 66.44 (3.21) | 52.90 (3.16)          | 57.82 (3.23) | 5.27 (3.49)  | 0.132    |
| High-Fat Vegetable   | 34.91 (3.08) | 34.86 (3.06) | 26.71 (2.96)          | 22.59 (3.09) | 4.07 (3.32)  | 0.222    |
| Low-Fat Vegetable    | 27.74 (1.59) | 30.24 (1.64) | 27.67 (1.52)          | 31.99 (1.98) | -1.83 (2.53) | 0.470    |
| Percent of FV Consumed |              |         |                       |
| Fruit                | 57.14 (1.91) | 66.03 (1.96) | 66.44 (1.91)          | 66.04 (1.96) | 9.30 (0.02)  | <0.0001**** |
| Vegetable            | 57.07 (1.93) | 58.11 (1.93) | 60.10 (1.90)          | 57.28 (1.94) | 3.86 (0.02)  | 0.060    |
| High-Fat Vegetable   | 40.16 (2.14) | 42.10 (2.07) | 42.14 (1.98)          | 38.38 (2.08) | 5.70 (0.03)  | 0.021*    |
| Low-Fat Vegetable    | 41.47 (2.12) | 44.98 (2.12) | 51.77 (2.07)          | 47.14 (2.12) | 8.15 (0.02)  | 0.0004**** |

*p < .05, **p < .01, ***p < .001, ****p < .0001.

(p = .13, p = .22, and p = .47, respectively).

**Percentage of FV consumed.** Next, we examined the main effect of the garden intervention on percentage FV consumed. Examination of the percentage of FV consumed allows for a clearer focus on the children’s eating behavior, as percentage FV consumed takes into account the percentage of FV consumed allows for a clearer focus on the children.

There were only marginally significant differences in change in percentage of vegetable consumed or HFV consumed between the intervention and control groups (p = .06 and p = .02, respectively). However, on average, from baseline to follow-up, children in the school garden intervention increased their proportion of LFV consumed, from 41% to 45%, while the control group decreased the proportion of LFV consumed from 52% to 47% (p < .01), indicating a main effect of the garden intervention on the percentage of LFV consumed.

**RQ2:** Does the fidelity of the intervention affect changes in FV consumption at school? Next, to gain insight regarding dose–response relations, the effect of GIF was examined. The overall fidelity (GIF-sum) and fidelity subscales (GIF-lessons and GIF-garden) are examined for significant differences in outcomes among fidelity levels (1, 2, 3, and 4) from baseline to follow-up, indicating the effect of the garden intervention components. The effect of GIF is examined only for percent intervention and control groups.

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|                | GIF-SUM                               | GIF-LESSIONS                          | GIF-GARDEN                          |
|----------------|---------------------------------------|---------------------------------------|-------------------------------------|
|                | Pre (W1) Mean (SE) | Post (W4) Mean (SE) | W4-W1 Mean Difference (SE) | Pre (W1) Mean (SE) | Post (W4) Mean (SE) | W4-W1 Mean Difference (SE) | Pre (W1) Mean (SE) | Post (W4) Mean (SE) | W4-W1 Mean Difference (SE) |
| **Fruit Consumed (%)** |            |            |            |            |            |            |            |            |            |
| GIF – Level 1 (none)    | 64.61 (0.02) | 65.23 (0.02) | 0.755     | 64.14 (0.02) | 64.44 (0.02) | 0.878     | 65.58 (0.02) | 65.41 (0.02) | 0.928     |
| GIF – Level 2 (modest)  | 61.52 (0.04) | 65.34 (0.05) | 0.422     | 57.80 (0.04) | 59.90 (0.04) | 0.655     | 53.88 (0.04) | 70.90 (0.06) | 0.009     |
| GIF – Level 3 (moderate) | 54.44 (0.03) | 66.27 (0.03) | <0.0001   | 61.61 (0.03) | 75.92 (0.04) | 0.0002    | 57.52 (0.03) | 74.90 (0.03) | <0.0001   |
| GIF – Level 4 (robust)  | 58.53 (0.04) | 70.62 (0.04) | 0.008     | 53.30 (0.04) | 65.95 (0.04) | 0.002     | 57.52 (0.03) | 74.90 (0.03) | <0.0001   |
| GIF4-GIF1 Mean Difference (SE) p-value | 0.159 | 0.198 | 0.021* | 0.012* | 0.00052** | 0.035* | 0.014* | <0.0001**** |
| GIF linear W4-W1 Mean Difference (SE) p-value | 42.44 (0.16) | 0.008** | 49.26 (0.15) | 45.04 (0.15) | 0.0029** |
| **Vegetable Consumed (%)** |            |            |            |            |            |            |            |            |            |
| GIF – Level 1 (none)    | 57.93 (0.02) | 49.07 (0.02) | <0.0001   | 58.56 (0.02) | 49.21 (0.02) | <0.0001   | 58.04 (0.02) | 49.69 (0.02) | <0.0001   |
| GIF – Level 2 (modest)  | 57.91 (0.04) | 56.37 (0.04) | 0.727     | 54.54 (0.04) | 54.42 (0.04) | 0.979     | 54.91 (0.04) | 68.58 (0.06) | 0.024     |
| GIF – Level 3 (moderate) | 53.40 (0.03) | 53.69 (0.03) | 0.914     | 57.14 (0.03) | 55.17 (0.04) | 0.583     | 56.35 (0.03) | 46.42 (0.03) | 0.0075    |
| GIF – Level 4 (robust)  | 54.41 (0.04) | 49.34 (0.04) | 0.237     | 49.64 (0.04) | 53.46 (0.03) | 0.2301    | 50.00 (0.03) | 54.56 (0.02) | 0.669     |
| GIF4-GIF1 Mean Difference (SE) p-value | 3.51 (0.04) | 0.27 (0.04) | 3.78 (0.05) | <0.0001**** | 0.0177 | 0.197 | 0.015* | 3.90 (0.05) |
| GIF linear W4-W1 Mean Difference (SE) p-value | 4.03 (0.04) | 0.947 | 0.416 | 13.18 (0.15) | 37.65 (0.14) | 6.15 (0.14) | 0.06** | 0.37 |
| **High-Fat Vegetable Consumed (%)** |            |            |            |            |            |            |            |            |            |
| GIF – Level 1 (none)    | 41.12 (0.02) | 33.53 (0.02) | 0.0002    | 43.01 (0.02) | 34.29 (0.02) | <0.0001   | 40.78 (0.02) | 33.62 (0.02) | 0.0004    |
| GIF – Level 2 (modest)  | 41.67 (0.04) | 35.03 (0.04) | 0.162     | 30.86 (0.05) | 30.02 (0.04) | 0.883     | 43.10 (0.04) | 50.84 (0.06) | 0.168     |
| GIF – Level 3 (moderate) | 28.38 (0.03) | 44.44 (0.04) | <0.0001   | 32.65 (0.04) | 45.17 (0.05) | 0.008     | 34.60 (0.04) | 37.07 (0.04) | 0.160     |
| GIF – Level 4 (robust)  | 44.64 (0.04) | 41.39 (0.04) | 0.516     | 36.12 (0.04) | 47.91 (0.04) | 0.003     | 40.49 (0.04) | 37.73 (0.04) | 0.536     |
| GIF4-GIF1 Mean Difference (SE) p-value | 3.52 (0.05) | 7.86 (0.05) | 4.34 (0.05) | <0.0001**** | 0.945 | 0.345 | 0.370 |
| GIF linear W4-W1 Mean Difference (SE) p-value | 0.455 | 0.0927 | 0.242 | 0.112 | 4.39 (0.05) |
| **Low-Fat Vegetable Consumed (%)** |            |            |            |            |            |            |            |            |            |
| GIF – Level 1 (none)    | 50.18 (0.02) | 45.68 (0.02) | 0.020     | 49.81 (0.02) | 44.88 (0.02) | 0.008     | 50.93 (0.02) | 46.18 (0.02) | 0.011     |
| GIF – Level 2 (modest)  | 46.25 (0.03) | 42.07 (0.03) | 0.365     | 44.83 (0.04) | 42.68 (0.04) | 0.706     | 38.88 (0.04) | 48.10 (0.06) | 0.142     |
| GIF – Level 3 (moderate) | 40.25 (0.03) | 42.49 (0.03) | 0.417     | 43.32 (0.04) | 50.84 (0.04) | 0.025     | 36.02 (0.03) | 39.50 (0.04) | 0.368     |
| GIF – Level 4 (robust)  | 35.34 (0.05) | 47.03 (0.04) | 0.019     | 31.56 (0.04) | 45.51 (0.04) | 0.0005    | 37.50 (0.04) | 51.40 (0.04) | 0.0007    |
| GIF4-GIF1 Mean Difference (SE) p-value | 14.8 (0.05) | 1.35 (0.04) | 16.19 (0.05) | <0.0001**** | 0.787 | 18.89 (0.04) | 15.70 (0.05) | 0.165 (0.04) |
| GIF linear W4-W1 Mean Difference (SE) p-value | 0.000267** | 0.754 | 0.003** | 18.25 (0.04) | 0.198 ** | 50.23 (0.15) |

*p < .05, **p < .01, ***p < .001, ****p < .0001.
3.1.1. Percent FV Consumed.

Fruit Consumption: All three GIF components: GIF-sum, GIF-lessons, and GIF-garden were positively associated with fruit consumption \( (p = .0008, \ p = .0008, \text{ and } p = .0029, \text{ respectively}) \). As shown in Table 3, for GIF-sum the percentage of fruit consumed increased <1% from baseline to follow-up in the no-intervention control classes (GIF-sum 1) while among children in GIF-sum levels 2, 3, and 4, the percentage of fruit consumed increased by 4%, 12%, and 12%, respectively. Similarly, analysis of GIF-lessons indicates that fruit consumption did not change among the control classes (GIF-lessons 1) and increased by 2%, 14%, and 13% for GIF-lessons levels 2, 3, and 4, respectively. Finally, the garden component of the intervention fidelity (GIF-garden) results indicate that fruit consumption was unchanged among the control classes (GIF-garden 1) and increased by 17%, 9%, and 17% for GIF-garden levels 2, 3, and 4, respectively.

Vegetable Consumption: Neither GIF-sum nor GIF-garden were statistically significant predictors of percentage of vegetable consumed \( (p = .3765 \text{ and } p = .6637, \text{ respectively}) \). The GIF-lessons component of intervention fidelity was significantly associated with overall change in vegetable consumption \( (p = .0056) \). Vegetable consumption decreased by 9% among the control classes (GIF-lessons), was unchanged for GIF-lessons level 2, decreased by 2% for level 3, and increased by 4% for GIF-lessons level 4.

High-Fat Vegetable Consumption: GIF-sum was a marginally significant predictor of percentage of HFV \( (p = .0395) \) and showed a somewhat irregular pattern. Percent HFV consumed decreased by 8% and 7% for GIF-sum levels 1 and 2, respectively, increased by 16% for level 3, and decreased by 3% for level 4. GIF-garden was not a statistically significant predictor of percentage of HFV consumed \( (p = .6332) \). The GIF-lessons component of intervention fidelity significantly predicted change in HFV consumption \( (p < .0001) \). HFV consumption decreased by 9% among the control classes (GIF-lessons level 1), decreased by <1% for level 2, and increased by 12% for both levels 3 and 4.

Low-Fat Vegetable Consumption: The overall fidelity, GIF-sum, as well as the two subscales, GIF-lessons, and GIF-garden, were positively associated with LFV consumption \( (p < .0012, p < .0001 \text{ and } p = .0011, \text{ respectively}) \). As shown in Table 3, percentage of LFV consumed decreased by 4.5% from baseline to follow-up in the control classes (GIF-sum 1). The percentage of LFV consumed also decreased by 4% for GIF-sum level 2 but increased by 2% and 12% for GIF-sum levels 3, and 4, respectively. Similarly, analysis of GIF-lessons indicates that LFV consumption decreased by 5% among the control classes (GIF-lessons 1), decreased by 2% for level 2, and increased by 9%, and 14% for GIF-lessons levels 3, and 4, respectively. Finally, the garden component of the intervention fidelity (GIF-garden) showed that LFV consumption again decreased by 5% among the control classes (GIF-garden 1) and increased by 9%, 3%, and 14% for GIF-garden levels 2, 3, and 4, respectively.

4. Discussion.

4.1. Interpretation.

Our findings (summarized in Table 4) indicate that the school garden intervention, consisting of both lessons and a garden for each participating class, had a significant, though modest, effect on fruit consumption. The intervention also affected LFV consumption (percentage consumed). There were marginally significant main effects of the garden intervention on percentage total vegetable and HFV consumption. The absence of some hypothesized main effects in this holistic analysis, however, could be due to the weak fidelity of the intervention in some classes.

The examination of GIF provides insight by considering the inevitable variability in intervention fidelity from classroom to classroom. Regarding fruit consumption (percent consumed), when GIF is considered as the predictor, a near-linear pattern emerges. Classes with stronger intervention fidelity exhibit a greater increase in fruit consumption; this is particularly true for GIF-sum and GIF-lessons. With respect to vegetable consumption, GIF-lessons was associated with increases in the percentage of total vegetables, HFV and LFV consumed suggesting that the curricular components more so than gardening components may impact vegetable intake. Results indicate a fairly consistent dose-response pattern for LFV, with GIF-sum, GIF-lessons, and GIF-garden all predicting percentage of LFV consumed.

The finding that GIF is a clearer predictor of FV intake—beyond a mere comparison of garden intervention versus control—is an important finding that prior researchers have hinted at but not quantified explicitly. Christian and colleagues (2014) found, in a RCT examining the impact of school gardens on children’s dietary intake, that gardening, overall, had no significant impact on children’s FV consumption but that in the two (out of 21) schools where the garden intervention was delivered at a high level, there was a significant impact on children’s FV intake. Moreover, Wang and colleagues’ (2010) prospective study of school gardens found that FV intake increased significantly among students exposed to the strongest intervention but decreased among those exposed to the weakest intervention. Similarly, A. Evans and colleagues (2012) report that exposure to multiple components of a garden intervention yields strongest effects on children’s FV intake.

In this study, GIF-lessons had the strongest and most consistent effect on FV consumption. This finding suggests that the curricula were well-selected and engaging. In their review of teaching strategies that promote healthy eating among elementary school children, Dudley, Cotton and Peralta (2015) report that experiential learning strategies have the largest effect on FV consumption.

Our findings indicate that the garden intervention had greater (and more consistent) effects on fruit consumption than on vegetable intake, which is consistent with prior research. In a review of the evidence, C.E. Evans and colleagues (2012) note that in 27 school-based FV interventions, impact on fruit intake is common but impact on vegetable intake is rare. Similarly, Savoie-Roskos and colleagues (2017) report that experiential learning strategies have the largest effect on FV consumption.

While the results presented here provide some encouragement regarding the potential for school gardens to nudge children’s FV consumption upwards, it is important to recognize that impacts of the garden intervention were modest. Even the strongest effects—in the highest GIF groups—were increases of only ~15% of the fruit or vegetable serving. Project Tomato, a similar cluster-randomized controlled trial of 54 English primary schools found no impact on FV intake (Evans et al., 2015). In their review of childhood obesity prevention interventions, Birch and Ventura (2009, p. 575) observe “the largest, most rigorous studies tend to be the least successful.”

Table 4

Summary of Findings for percent consumed of fruit, vegetables, high-fat vegetables and low-fat vegetables.

| Intervention v. Control | Garden Intervention Fidelity (GIF) | GIF-lessons | GIF-garden |
|-------------------------|-----------------------------------|-------------|-------------|
| Percent Consumed:        |                                   |             |             |
| Fruit                   | √                                 | √           | √           |
| Vegetables              | –                                 | X           | X           |
| High-Fat Vegetables     | –                                 | –           | √           |
| Low-Fat Vegetables      | √                                 | √           | √           |

√ = significant, in hypothesized direction;
X = n.s.;
~ = marginally significant.
4.2. Study strengths

This study moves beyond prior research in several ways. The quantification of garden intervention fidelity via GIF is a significant strength and contribution of this study. GIF illuminates the dose–response effects of the intervention, distinguishes the effects of the lesson versus the garden components of the intervention, and differentiates effects of strong, rigorously administered interventions from weak ones. By measuring FV consumption using photography, this study moves beyond self-report measures of dietary intake which enhances construct validity and, in turn, bolsters internal validity. FV intake was also examined separately for F, for V, as well as HFV and LFV. Additional virtues of this study are the RCT design research; the duration of 2 years; a large sample size; and the focus on the most at-risk population, children in low-income communities.

4.3. Study limitations

This study is not without limitations. For some outcome variables, the intervention and control schools differed at baseline. Consequently, some differential changes between intervention and control schools may be attributable to regression to the mean. This weakness, however, is somewhat addressed by fidelity analyses, which move beyond main effects. Moreover, this study does not examine a variety of factors associated with FV intake such as time for lunch, other food served, school food environment, the order of food served, the presentation (e.g., slicing) of fruit that may mediate or moderate the relation between a garden intervention and children’s dietary intake. Regarding external validity, the focus on under-resourced schools in the United States could limit generalizability to a broader range of schools.

4.4. Future research

Greater attention might focus, in the future, on broader contextual factors that may mediate or moderate the effect of a garden intervention on children’s dietary intake. Variables might include those noted above – the order of food served, the time allowed for lunch, the presentation of foods – as well as cafeteria design characteristics such as the shape of tables and the presence of windows. The strength and feasibility of garden–cafeeteria connections also merit examination as plausible mediators. Informal reports from educators and school administrators in this study suggested that linking the school garden to the school cafeteria was challenging due to barriers such as a lack of infrastructure and/or buy-in among cafeteria personnel. Researchers might examine schools that have succeeded in making this connection from garden to cafeteria to understand how barriers can be overcome.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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