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Starting complementary feeding with vegetables only increases vegetable acceptance at 9 months: a randomized controlled trial

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ABSTRACT

Background: Starting complementary feeding (CF) with vegetables only may improve vegetable acceptance throughout childhood.

Objectives: We aimed to test whether exposure to vegetables only during the first 4 wk of CF increases later vegetable acceptance compared with a control group receiving fruit and vegetables.

Methods: In this randomized, controlled, parallel-group study, 117 Auckland infants received either vegetables only (veg-only, $n = 61$) or a combination of fruit and vegetables (control, $n = 56$) for a duration of 4 wk, starting from the first day of CF at ∼4–6 mo of age. The primary outcome measure was intake of target vegetables (broccoli, spinach) provided by the study at 9 mo of age. Daily intake of vegetables (FFQs) at 9 mo was a supporting measure. Infants' iron status (serum ferritin, hemoglobin) was examined at all time points.

Results: The veg-only infants consumed more broccoli and spinach than controls [mean difference (95% CI): 11.83 (0.82, 22.84) g, $P = 0.036$ and 10.19 (0.50, 19.87) g, $P = 0.039$, respectively]. Intake of pear was comparable among intervention groups ($P = 0.35$). At 9 mo, veg-only infants consumed target vegetables at a faster rate [mean difference (95% CI): broccoli, 3.37 (1.26, 5.47), $P = 0.002$; spinach, 4.12 (0.80, 7.45), $P = 0.016$] and showed greater acceptance for target vegetables [mean difference (95% CI): broccoli, 0.38 (0.07, 0.70), $P = 0.019$; spinach, 032 (0.04, 0.60), $P = 0.024$] than controls. The rate of eating and acceptance of pear was comparable among intervention groups ($P = 0.42$ and $P = 0.98$, respectively). Also, veg-only infants consumed more vegetables than controls [86.3 (52.5, 146.3) compared with 67.5 (37.5, 101.3) g, respectively, $P = 0.042$]. Introducing vegetables as the first food was not associated with 9-mo iron status.

Conclusions: Providing vegetables as first foods increased vegetable intake at 9 mo of age and may be an effective strategy for improving child vegetable consumption and developing preferences for vegetables in infancy. *Am J Clin Nutr* 2022;116:111–121.

Keywords: infants, weaning, introducing vegetables, food preference, vegetable intake

Introduction

Vegetables are an important part of the diet as they provide nutrients needed for growth, development, and overall health (1, 2). Growing Up in New Zealand found low adherence to eating fruit (37%) and lower adherence to eating vegetables (33%) twice or more times daily at 9 mo old; some children (12%) consumed vegetables less than daily or never (3). Other studies report more children eating fruit compared with vegetables (4–7). In the United States, children's consumption of fruit but not vegetables has increased (8), and the Feeding Infants and Toddlers Study study showed that consumption of dark green vegetables is particularly low among infants (9). Reasons for poor vegetable intake are many and range from infant preferences for sweet/energy-dense foods over more bitter-tasting, low-energy density foods to simple lack of access, maternal dislike, or cultural practices (5). Indeed, many families are accustomed to providing fruit and sweet/starchy vegetables to infants as first foods (10–14). A focus on improving vegetable consumption (quantity and variety) as early as possible is desirable (4, 15), especially as eating habits, including vegetable preferences, track into adulthood (16–18).

In May 2016, the British Nutrition Foundation met with leading infant feeding experts to discuss a "vegetables-first"

Grant support from Massey University.

Supplemental Figures 1–2 and Supplemental Tables 1–3 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

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Abbreviations used: CF, complementary feeding; COVID-19, coronavirus disease 2019; CRP, C-reactive protein; Hb, hemoglobin; ICC, interclass correlation coefficient; RCT, randomized controlled trial; SF, serum ferritin; Veg-only, vegetables-only intervention group.

Received November 5, 2021. Accepted for publication March 29, 2022.

First published online June 9, 2022; doi: https://doi.org/10.1093/ajcn/nqac080.

approach (19) to complementary feeding (CF), which refers to the prioritization of vegetable-only first foods from the moment solid food starts to complement breast milk and/or infant formula, thus capitalizing on infants' particular willingness to try new foods and establish a preference for vegetables. The evidence base was considered sufficient to start recommending the approach as a strategy to improve vegetable acceptance throughout childhood, which some authorities such as the National Health Service, UK (NHS) (20) and the European Society for Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) (21) now reflect in their current messaging. However, further longitudinal randomized controlled trials (RCTs) are needed to improve international consensus (19, 22–24) as the few studies examining a vegetables-first approach, although compelling, are limited by factors including short follow-up periods, small samples, and the use of control groups that do not necessarily reflect common practices (25–28). In addition, none of these intervention studies have reported infants' iron status (25–28), which is problematic given the high risk of iron deficiency at this age (19).

This RCT investigates the effect of starting CF with vegetables only on vegetable acceptance compared with a combination of fruit and vegetables. Secondary objectives included infants' acceptance of vegetable-only first foods at the start of CF and the iron status of these infants. We hypothesized that introducing vegetable-only first foods at the start of CF would result in greater vegetable acceptance at 9 mo of age compared with introducing combined fruit and vegetables. It was predicted that infants would accept vegetable-only first foods and that the intervention would have no negative impact on their iron status.

Methods

Experimental design

This study was an RCT comprising a 4-wk intervention at the start of CF with the primary endpoint assessed at 9 mo of age. Follow-up data will be collected at 12, 24, and 36 mo of age. A detailed protocol has been published (29).

Outcomes

The primary outcome was intake (grams) of target vegetables (broccoli and spinach) at 9 mo of age. Supporting analyses at 9 mo included liking of vegetables, as measured by a 5-point mother-rated Likert scale, frequency of positive/negative behaviors as reported by mothers, rate of eating (g/min), rate of acceptance (video coding), and daily vegetable intake reported via an FFQ. Intake and liking of fruit were measured at 9 mo for comparison with vegetables.

Secondary outcomes included *1*) intake and liking of the study foods on weeks 1 and 4 of the intervention and *2*) infant iron status at 9 mo of age through assessment of hemoglobin (Hb), serum ferritin (SF), and C-reactive protein (CRP), as measured by standard blood capillary analysis.

Participants

Mother–infant pairs (*N* = 117) participated in the 4-wk intervention (between May 2019 and May 2020, depending on their start date) in Auckland, New Zealand, and were randomly assigned to start CF with vegetables only (veg-only = 61) or

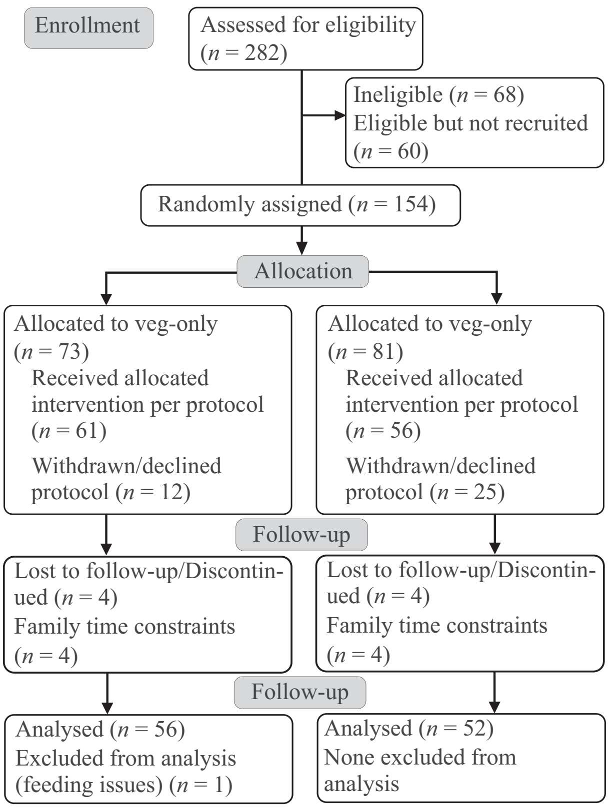

FIGURE 1 Flow diagram of the randomized controlled trial investigating the effects of starting complementary feeding with vegetable-only first foods on vegetable acceptance at 9 mo of age compared with combined fruit and vegetables.

a combination of fruit and vegetable purées (control = 56) (**Figure 1**). Of these, 92% (veg-only, 84%; control, 70%) completed by providing intake data (grams) for the target vegetables (broccoli and spinach) for the primary analysis at 9 mo of age. Loss to follow-up was due to family time constraints (*n* = 8), and 1 infant was excluded from all analyses as they had started consuming PediaSure (Abbott Nutrition) due to feeding issues. Known reasons for being eligible but not recruited included starting CF before the trial commenced, the development of medical concerns (e.g., allergies, reflux), wanting to follow baby-led weaning and have greater control over the types of first foods fed, concerns regarding the heel prick, and/or being too busy. For the analysis of iron status, 76 infant blood samples were collected at 9 mo. After exclusion of 1 infant with inflammation/infection, a final sample of 75 infants was obtained; fewer than anticipated blood samples were primarily due to coronavirus disease 2019 (COVID-19) lockdown periods causing missed appointments (baseline = 1, postintervention = 15, and 9 mo = 33) (**Supplemental Figure 1**). The first participant to complete this study was in September 2019 and last in July 2020. Informed, written consent to participate was obtained during recruitment. All infants met eligibility criteria on trial entry (born ≥37 wk, of normal growth/weight, had not started CF, and had no known food allergies/medical conditions). To be included in the primary analysis at 9 mo, they must have completed the 4-wk intervention as per protocol. Ethical approval was granted by the Massey University Human Ethics Committee: Southern A, Application SOA 18/56.

Procedure

The procedure for the 4-wk intervention is reported in detail elsewhere (29), but a brief description is as follows.

At the start of CF (4–6 mo), infants were randomly assigned to either veg-only or control groups. Infants had not been fed any other complementary foods before commencing the trial. During the 4 wk, the veg-only group received a daily meal rotation of vegetable purées: spinach mixed with 20% potato, potato only, beetroot mixed with 30% potato, and then green bean only (natural sugars ranging from 0.03–3.7 g/100 g). Infants in the control group received a mix of fruit and vegetables, which were sweet in taste and largely apple and pear based: apple mixed with 10% spinach, pear only, pear mixed with 2% beetroot, and then pumpkin only (natural sugars ranging from 6.5–10.8 g/100 g). These foods were labeled by color (e.g., Green A) and code A or B, rather than an ingredient to assist with participant blinding. Mothers fed their infant at home following detailed protocol instructions, including how to record intake and liking of the study foods using a weighed food diary and liking tool, respectively. Given the importance of iron for infants, practical advice on introducing iron-rich meat foods (plain puréed meat, chicken or fish) was provided, including recipe instructions and videos. All mothers were encouraged to introduce meat, particularly if starting the intervention at 6 mo of age, and could feed these foods freely provided they did not mix them into the study foods. No meat was fed during the first 4 d of the intervention to standardize the protocol and mothers reported if and when meat was introduced using tick box options within a form at the back of the weighed food diary. After the 4 wk, parents were given general advice about infant feeding during the first year of life (including advice on iron) and were free to feed their infant as they wished.

At 9 mo of age, mothers were provided 3 foods (rehydrated weight 80 g each) for their infant to try at home, including broccoli (meal A), spinach (meal B), and pear (meal C), over 3 consecutive days. None listed the ingredients, but mothers were reassured that the foods aligned with New Zealand infant feeding guidelines; the codes A, B, and C assisted with participant blinding and helped mothers feed the foods in the correct order. Mothers were asked to choose the same time each day to provide the meal, making sure that no other solid food had been consumed within 1 h prior. Infants could consume their usual foods and drinks during the rest of the day. Feeding guidelines were similar to those given during the 4-wk intervention. A researcher contacted mothers before the experiment to ensure they understood the guidelines, and mothers were reminded to stop feeding after 3 consecutive spoon refusals. Mothers measured intake and liking of the target foods using the same methods during the intervention. Intake of the target foods only was weighed at 9 mo, but other vegetables and fruit consumed that day were also noted. Mothers reported on factors that may have affected infant feeding each day (e.g., teething, unwell), as well as information on breast/formula milk feeding and medication/supplements via questionnaire items included in the weighed food diary during the intervention and at 9 mo.

Target foods

Vegetables and fruit used in the study for the veg-only and control foods were selected based on availability, infant nutrition guidelines, and sugar content. The target vegetables (broccoli and spinach) at 9 mo were chosen as these are typically disliked and eaten less frequently than sweet vegetables such as carrots, whereas fruit (pear) is typically consumed and liked by infants. In addition, the spinach was the same food provided to the veg-only group, and the pear was the same as given to the control group during the 4-wk intervention; the spinach food only contained 20% potato to improve feasibility of manufacture. These foods were considered familiar within the respective groups, but neither group had tasted broccoli within the first 4 wk of CF. Only 3 foods were tested at 9 mo to reduce participant burden. Throughout this study, parents were unaware as to which group they had been originally assigned (because foods were named for their color not their content).

All foods provided by the study were freeze-dried powders, which rehydrated with the addition of water to an age-appropriate texture (i.e., mashed or puréed). Recipe instructions asked mothers to add 50 mL water, heat the food in the microwave for three 20-s intervals, stir in between, and then cool for 10 min until it was at a safe temperature for infants to consume. Freeze-drying the foods was preferred as this processing method helps to maintain the original flavor and color of fruit and vegetables (30), and with rehydration, they closely resembled homemade vegetable and fruit purées. Delivering the food in this way made the standardization of feeding conditions possible and reduced participant burden in terms of storage and perishability in the home.

Weighed intake of the study foods

Mothers measured and recorded intake of the study foods only during the first and last 4 d of the 4-wk intervention and then for each target food at 9 mo using provided digital scales (±1 g). Estimated spills or food fallen were recorded using household measures. It was assumed that more food eaten indicated liking, acceptance, and preference of that food compared with other foods provided by the study and that weighed intake was a more objective measure than subjective report (31).

Video-recorded meals

Mothers video recorded each meal using a personal video camera or mobile phone following detailed instructions on where to position the camera (**Supplemental Figure 2**) and how to upload videos to a secure database. These instructions were the same as given during the 4-wk intervention and thus familiar to mothers.

The videos captured the moment when infants opened their mouth as food approached, which reflects rate of food acceptance. To assess rate of acceptance, an independent research assistant who was blinded to the originally assigned groups was trained to score the videos according to a set of coding rules: early acceptance = 3, late acceptance = 2, enforced = 1, and refused = 0. The first 9 spoons were coded, and an average score was calculated by dividing the sum of scores by 9 spoons. A complete 9 spoons could not be coded for some videos due to the feeding session ending following infant cues (19 videos) or because the video was cut short for technical or unknown reasons (10 videos). In these instances, the average scores were calculated using the number of available spoons offered and coded. When the visibility was obscured or obstructed (e.g., by the mother's hand), the spoon was not counted in the analysis. To assess reliability, a second coder then coded a randomly selected 20% of the videos (30 videos from each group); randomization was conducted by the research trials manager using a random-number generator.

Liking assessment

During each recorded feeding session (intervention and 9 mo), mothers rated infant liking using the validated "elaborate method" (32). The tool comprised a pictorial 5-point liking scale (1 = dislikes very much to 5 = likes very much) and a list of 10 positive and 10 negative behaviors per spoon that mothers ticked as they occurred (29). A dietitian provided mothers with guidance on feeding environment and feeding style to adopt and when to terminate the meal (after 3 consecutive refusals). Greater liking was indicated by a greater score on the liking scale, higher percentage of reported positive behaviors, and/or lower percentage of negative behaviors.

Clinic and home visits

After infants had been offered the target foods at home, a researcher met with participants at the laboratory or at home to collect their weighed food diary and measure infants' weight, length, and head circumference. Due to restrictions caused by the COVID-19 pandemic, 36 in-person visits were not possible and mothers were required to measure their infant's anthropometry at home without a researcher present. However, detailed instructions and phone/Zoom support were given to improve accuracy. Food acceptance measures and sample retention seemed minimally affected.

Questionnaires

Upon admittance to the trial, participants were sent a link to an online demographics questionnaire to record information about the mother and infant (e.g., age, ethnicity, parity, education, food availability, infant sex). After completion of each week of the intervention, mothers were emailed a brief check-in questionnaire to measure compliance (e.g., number of days that the intervention food was offered and other food or drink consumed).

At 9 mo, mothers completed an infant FFQ and fruit/vegetable preference questionnaire online. The FFQ was an abbreviated version of a validated questionnaire and measured infants' daily vegetable and fruit intake (33). The total grams consumed over 4 d was divided by 4 to obtain an average daily intake. To assess how often vegetables/fruit were typically offered per day, the sum of frequency was divided by 4 d. Greater frequency and amount eaten of a vegetable reflected greater daily intake of that vegetable. The fruit/vegetable preference questionnaire that was created specifically for this study asked about which vegetables and fruit infants had tried and liked (1 = dislike very much, 5 = like very much) over the past 3 mo. The overall liking scores, as calculated by the sum of liking divided by the number of vegetables or fruit tried, were used to assess daily liking of vegetables and fruit. The frequency categories that mothers had selected were coded based on the lower value of the range as follows: "never" = 0, "tried 1–3 times" = 1, "tried 4–6 times" = 4, "tried 7–9 times" = 7, and "tried 10+ times" = 10. The sum of scores indicated the minimum number of occasions that infants had tried vegetables/fruit since completing the 4-wk intervention.

The FFQ at 9 mo also collected meat intake (beef, lamb, pork, ham, chicken/poultry, fish) and milk feeding history (breast milk/formula milk introduction/cessation, number of feeds per day and amount of milk per feed); however, while this was used to support the milk feeding information provided in the weighed food diary, an accurate assessment of milk intake, such as weighing infants before and after a breastfeed, was not feasible.

Biochemical assessment

Nonfasting capillary blood samples were taken from infants by a registered phlebotomist using a standard "heel prick" test as part of health screening at each visit (baseline, postintervention, and at 9 mo). Indicators of iron status were Hb, SF, and CRP. The phlebotomist assessed Hb using a HemoCue Hb 201+ Analyzer immediately as blood was drawn, and if outside the normal range, the mother was notified and given a referral letter to see their general practitioner (Hb below normal: baseline, $n = 5$; postintervention, $n = 2$; 9 mo, $n = 4$). Aliquots of serum were stored at –80°C until subsequent analysis of SF and CRP at LabTests (Auckland, New Zealand) by their biochemistry department via particle-enhanced immunoturbidimetric assay; this laboratory undergoes regular quality assurance testing by an external agency known as International Accreditation New Zealand. Established cutoffs of Hb $<$110 g/L and SF $<$10 μg/L to assess the presence of iron deficiency and iron-deficiency anemia were used (34–36); a cutoff of $\geq$10 mg/L CRP suggested the presence of infection or inflammation (37–40).

Statistical analysis

We calculated a sample size of 52 participants per group as necessary to detect a clinically significant difference (21-unit difference) in food intake (grams) with a 2-sided 5% significance level and a power of 80% (29). This was calculated based on the findings from Barends et al. (41) and using the following power calculation: $N = 2\alpha^2 K / (\mu_2 - \mu_1)^2$, where N is the sample size required per group, SD is the pooled standard deviation (SD = 38), α is the SD, K is the constant (7.9), and $(\mu_2 - \mu_1)$ is the difference in vegetable intake (grams) between groups (42). A potential 20% dropout rate was accounted for.

The data were tested for normality using the Kolmogorov–Smirnov test, the Shapiro–Wilk test, and normality plots. Nonnormally distributed data were transformed into approximate normal distributions by logarithmic or square root transformations. The data were reported appropriately as mean (SD) for normally distributed data; transformed data were back-transformed from summary statistics into geometric mean (95% CI), nonnormally distributed data were described as median (25th, 75th percentiles), and categorical data were presented as frequencies.

The primary analysis, comparing the effects of treatment on the average intake of target foods (broccoli, spinach, and pear) at 9 mo, as well as secondary outcomes, was conducted using pairwise mixed-effects longitudinal models. Treatment (veg-only compared with control) and target foods were included as fixed effects, and participant was included as a random effect to account for the repeated measures within individuals. The interactions between intervention group × target food and between intervention group × time (for the change over time, 4-wk postintervention) were also tested. When significant main effects or interaction effects were observed, post hoc analysis with Bonferroni adjustments were performed. The assumptions for linear mixed-model analysis (including normal distribution of residuals, homoscedasticity, and multicollinearity) were tested, and no violation was identified (all assumptions were met). As the post hoc tests, parametric and nonparametric tests (depending on the normality of data distribution) were performed. For parametric tests (dependent and independent samples tests), the assumptions of normality of distribution of data (as mentioned above) and homogeneity of variance (using Levene's test) were tested. Spearman ρ correlations were used to examine the relation between food intake and secondary measures of food acceptance. To assess the comparability of 2 coders' coding of rate of acceptance of meals (in a subset of videos, 30 from each group), 3 sets of interclass correlation coefficient (ICC, one for each meal type: broccoli, spinach, and pear) were performed. ICC estimates and their 95% CIs were calculated using a single-rating, absolute-agreement, 2-way mixed-effects model. The average score given per participant was used for the reliability analysis, rather than the scores of each spoon. ICC values <0.5, 0.5 to <0.75, 0.75 to <0.90, and ≥0.90 were considered poor, moderate, good, and excellent reliability, respectively (43).

The primary analysis (as per protocol) involved all participants who provided data on target food intake at 9 mo of age. Infant data from the feeding sessions were excluded from analysis if infants were unwell on the day of testing with evidence of affected appetite (e.g., mother reported "has a cold so not keen on solids"; $n = 4$). Outliers, as detected by boxplots, were examined but remained plausible and thus not removed. Infants with CRP concentrations ≥10 μg/L at 9 mo were excluded from the entire iron status analysis ($n = 1$); infants with CRP concentrations ≥ 10 μg/L at baseline ($n = 2$) and postintervention ($n = 1$) were excluded from the iron studies relating to that time point.

Statistical analysis was performed using SPSS version 25.0 (IBM Corp.). All statistical tests were 2-tailed with an α value of $P < 0.05$.

Results

Participants

Mother and infant characteristics are presented in **Table 1**. One infant in the control group was taking iron supplements at the start of CF. Regarding the primary outcome, a larger proportion of mothers who did not complete the trial were multiparous compared with completers ($P = 0.06$). Regarding the iron study, infants who did not complete the trial were older at day 1 ($P = 0.07$) and faster eaters ($P = 0.02$) than completers.

Intake—target foods

Analysis of the average intake of target foods revealed a significant effect of intervention group ($P = 0.009$) and target foods ($P < 0.001$) but no group × target foods interaction effect ($P = 0.31$) (**Figure 2**). The analysis showed a greater intake of broccoli and spinach in the veg-only group than the control group, mean difference (95% CI) of 11.83 (0.82, 22.84) g, $P = 0.036$ and 10.19 (0.50, 19.87) g, $P = 0.039$, respectively. The intake of pear was comparable across both intervention groups, mean difference (95% CI) of 3.65 (−4.03, 11.34) g, $P = 0.35$. Within the veg-only group, the average intake of broccoli was comparable to the intake of pear, but spinach intake was lower than pear, mean difference (95% CI) of −1.75 (−1.65, 18.37) g, $P = 1.00$ and −10.11 (−19.98, −0.24) g, $P = 0.043$. However, within the control group, the average intake of both vegetables was lower than the intake of pear, mean difference (95% CI) of −10.05 (−20.39, 0.28) g, $P = 0.06$ for broccoli and −17.53 (−28.00, −7.05) g, $P < 0.001$, for spinach.

Mother-rated liking—target foods

Overall liking of target foods, as rated by mothers, did not differ between group ($P = 0.98$) but differed by target foods ($P < 0.001$) (**Figure 3**A). The analysis revealed no group × target food interaction effect on liking of foods ($P = 0.48$). In both groups, pear was rated as significantly more liked than broccoli and spinach (all $P < 0.001$).

Behavior and rate of eating

Frequency of reported positive and negative behaviors recorded during the meals did not differ between groups ($P > 0.05$) but differed among target foods ($P < 0.001$) (**Table 2**). The analysis revealed no group × target food interaction effect on positive and negative behaviors ($P = 0.46$ and $P = 0.76$, respectively). Rate of eating of target foods differed between groups ($P = 0.013$) and by target foods ($P < 0.001$), but no group × target food interaction effect on the rate of eating was detected ($P = 0.24$) (Figure 3B). The analysis showed a faster rate of eating broccoli and spinach in the veg-only group than the control group, mean difference (95% CI) of 3.37 (1.26, 5.47), $P = 0.002$ and 4.12 (0.80, 7.45), $P = 0.016$, respectively. The rate of eating pear was comparable across both intervention groups, mean difference (95% CI) of 1.38 (−1.96, 4.72), $P = 0.42$. Within both intervention groups, the eating rate of broccoli and spinach was lower than that of pear ($P < 0.001$).

Rate of acceptance—video coding

Rate of acceptance of target foods differed between groups ($P = 0.05$) and by target foods ($P < 0.001$), and there was a group × target food interaction effect on the rate of acceptance ($P = 0.012$) (Figure 3C). The rate of acceptance of broccoli and spinach was faster in the veg-only group than the control group, mean difference (95% CI) of 0.38 (0.07, 0.70), $P = 0.019$ for broccoli and 032 (0.04, 0.60), $P = 0.024$ for spinach. The rate of acceptance of pear was comparable across both intervention groups ($P = 0.98$). Within the veg-only group, although the rate of acceptance of broccoli was comparable to that of pear, the

TABLE 1 Characteristics of mothers and infants by originally assigned group[1]

Characteristic	Veg-only	Control	Total
4-wk intervention, *n*	61	56	117
Infants' age on day 1, wk	23.5 ± 2.5	23.7 ± 2.7	23.6 ± 2.6
Sex (female)	33 (54)	27 (48)	60 (51)
9 mo of age, *n*	56	52	108
Infants			
Sex (female)	29 (52)	26 (50)	55 (51)
Age, mo	9 (8, 9)	9 (9, 9)	9 (8, 9)
Weight,[2] kg	8.9 ± 1.0	9.0 ± 0.9	9.0 ± 1.0
Length,[2] cm	72.8 ± 3.1	71.9 ± 2.8	72.4 ± 2.9
Head circumference,[2] cm	45.7 ± 1.5	45.7 ± 1.5	45.7 ± 1.5
Exclusive breastfeeding duration, mo	5.0 (2.5, 5.0)	5.0 (1.5, 5.0)	5.0 (2.0, 5.0)
Milk feeding type[3]			
Breast milk only	22 (39)	26 (50)	48 (44)
Infant formula only	19 (34)	12 (23)	31 (29)
Both breast/formula milk	15 (27)	14 (27)	29 (27)
Mothers			
Age, y	33 ± 4	34 ± 5	33 ± 4
Education			
Below university	2 (4)	6 (12)	8 (7)
University or higher	54 (96)	46 (88)	100 (93)
Ethnic origin[4]			
NZ European and others	53 (95)	45 (87)	98 (91)
Māori and Pacific Island	3 (5)	3 (6)	6 (6)
Others (e.g., Chinese, Indian)	4 (7)	5 (10)	9 (8)
Primiparous (first-time mothers yes)	43 (77)	38 (73)	81 (75)
Protocol compliance,[5] d/wk	6 (5, 7)	7 (5, 7)	6 (5, 7)

[1]Data presented as mean ± SD, number (%), or median (25th, 75th percentile) unless otherwise indicated. NZ, New Zealand; veg-only, vegetables only.
[2]Sample sizes: weight (veg-only, $n = 51$; control, $n = 51$), length (veg-only, $n = 47$; control, $n = 49$), and head circumference (veg-only, $n = 47$; control, $n = 49$). Missing data due to COVID-19 restrictions. Anthropometry measures for infants included in the iron analysis ($n = 75$) were weight, 9.2 ± 1.0 kg; length, 72.5 ± 2.5 cm; head circumference, 45.9 ± 1.3 cm.
[3]Describes milk feeding type over the 3 d of feeding the target foods at 9 mo of age.
[4]Multiple answers were possible.
[5]Refers to the number of days per week that mothers offered the study foods; 2 cases missing.

acceptance rate for spinach was slower, mean difference (95%) of −0.09 (−0.33, 0.15), $P = 1.0$ for broccoli and −0.32 (−0.56, −0.08), $P = 0.005$ for spinach. However, within the control group, the acceptance rate of both vegetables was slower than that of pear ($P < 0.001$ for both broccoli and spinach). The ICC (95% CI) for broccoli, spinach, and pear was 0.97 (0.92, 0.99), 0.99 (0.97, 0.10), and 0.99 (0.97, 0.10), respectively.

Correlation between intake and liking

Measured intake significantly correlated with mother-rated liking and rate of acceptance (**Supplemental Table 1**). Intake was also significantly correlated with percentage of reported positive/negative behaviors, rate of acceptance, and rate of eating, although intake of pear did not correlate with negative behavior ratings among the veg-only group (Supplemental Table 1).

Daily vegetable intake

Daily intake of vegetables as derived from the FFQ was significantly higher among infants in the veg-only group compared with controls: 86.3 (52.5,146.3) compared with 67.5 (37.5,101.3) g, $P = 0.043$, respectively (**Figure 4**). Daily intake of fruit did not differ between groups: veg-only, 75.1 (35.0,159.4) g; controls, 86.3 (33.7,128.8) g, $P = 0.770$. There was no difference in the number of occasions that vegetables had been tried over

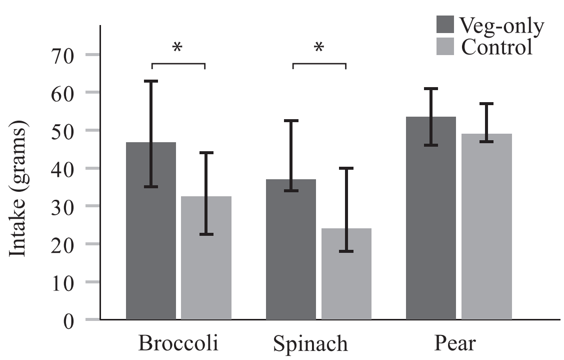

FIGURE 2 Intake of the broccoli, spinach, and pear foods during the 3-d experiment among infants. Mixed-model analysis was performed. Broccoli (veg-only, $n = 51$; control, $n = 49$), spinach (veg-only, $n = 54$; control, $n = 47$), and pear (veg-only, $n = 54$; control, $n = 48$). Data presented as median with 95% CI for consistency. Veg-only, vegetables-only. $^*P < 0.05$.

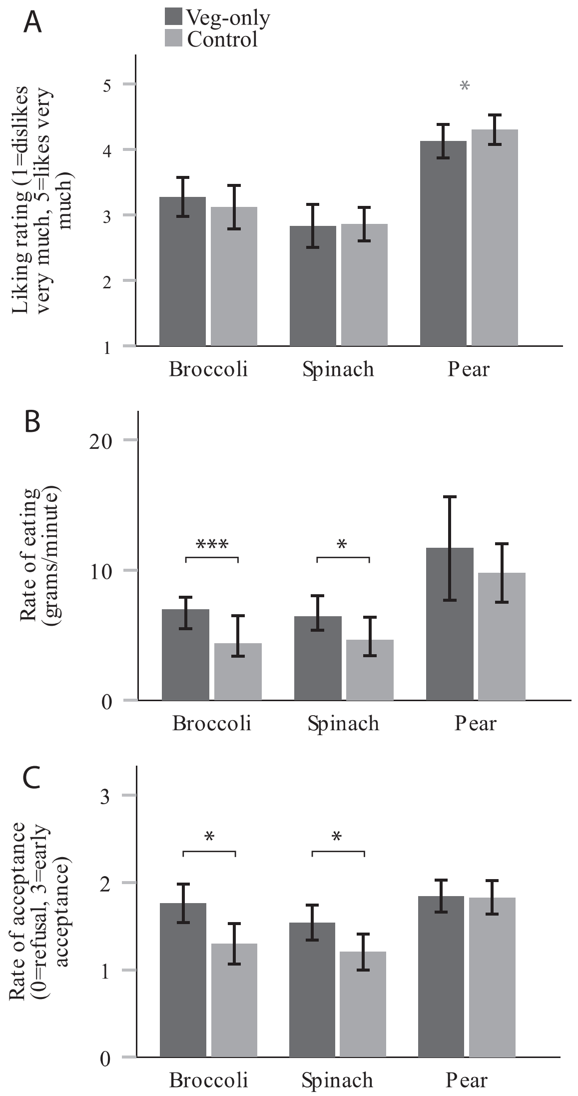

FIGURE 3 (A) Overall infants' liking, as rated by mothers, of target foods: broccoli (veg-only, n = 54; control = 50), spinach (veg-only = 54; control = 50), and pear (veg-only = 56; control = 52). Mixed-model analysis was performed. Data presented as mean with 95% CI. *Significantly higher than broccoli and spinach in both groups (P < 0.001). (B) Rate of eating of target foods: broccoli (veg-only, n = 48; control, n = 48), spinach (veg-only, n = 50; control, n = 46), and pear (veg-only, n = 51; control, n = 46). Mixed-model analysis was performed. The geometric mean was calculated and was similar to the median, and for the sake of consistency, data are presented as median with 95% CI. *P < 0.05, ***P < 0.001. (C) Infants' rate of acceptance of target foods as coded by researcher: 0 = refusal, 1 = enforced, 2 = late acceptance, 3 = early acceptance. Mixed-model analysis was performed. Data presented as mean with 95% CI for consistency. Sample sizes for each target food: broccoli (veg-only, n = 47; control, n = 48), spinach (veg-only, n = 48; control, n = 48), and pear (veg-only, n = 48; control, n = 49). *P < 0.05. Veg-only, vegetables only.

the previous 3 mo between groups: veg-only, 98 ± 37 occasions; controls, 96 ± 38 occasions (mean ± SD), P = 0.710. Fruit had also been tried at a similar frequency between groups: veg-only, 64 ± 35 occasions; controls, 68 ± 33 occasions, P = 0.923.

Daily liking of vegetables

As reported by mothers using the food preference questionnaire, the daily liking of the overall category of vegetables or fruit that infants had tried since completing the 4-wk intervention did not differ between groups (P = 0.26) but was different by food type (P < 0.001). The analysis revealed no effect of group × food type interaction on liking foods (P = 0.36). Generally, vegetables were liked less than fruit (P < 0.001). Within vegetables, leafy (P < 0.001) and nonstarchy vegetables (P < 0.001) were liked less than starchy vegetables.

Exposure to vegetables and fruit after the intervention

According to the food preferences questionnaire, the number of different types of vegetables or fruit that infants had tried over the previous 3 mo did not differ between groups (16 ± 4 and 15 ± 4 types of different vegetables and 13 ± 5 and 14 ± 5 types of fruit in veg-only and control groups, respectively, P = 0.99). However, infants generally tried more different types of vegetables than fruit (16 ± 3.8 compared with 14 ± 4.9 types, P < 0.001). No effect of group × food type interaction on the number of different types of vegetables or fruit tried was identified (P = 0.37). Two infants in the veg-only group and 1 infant in the control group had not tried any green vegetables (broccoli, cabbage, green bean, kale, lettuce, green leafy salad, spinach, sprouted beans) since the 4-wk intervention. Six infants (3 per group) had not tried broccoli, 19 had not tried spinach (8 of these were controls), and none had tried artichoke.

Acceptance of the study foods during the 4-wk intervention

The analysis showed a significant effect of time (P < 0.001) but no effect of intervention group (P = 0.90) and time × group interaction (P = 0.91) on daily intake of study foods. The average daily intake of study foods increased from 19.5 (11.4, 28.4) g and 19.6 (13.6, 32.1) g at baseline to 34.8 (19.4, 66.5) g and 31.8 (19.8, 69.2) g at week 4 in veg-only and control groups, respectively (P < 0.001 for both groups). The analysis showed a significant effect of time (P < 0.001) but no effect of intervention group (P = 0.66) and time × group interaction (P = 0.86) on liking of study foods. Overall liking of the study foods significantly increased after 4 wk in both groups (P < 0.001) from "neither likes nor dislikes" toward "likes," with no group differences. Daily intake positively correlated with overall liking. Frequency of negative and positive behaviors did not differ across intervention groups but differed by time (P < 0.001 and P = 0.05, respectively). Group × time interaction had no effect on both negative and positive behaviors (P = 0.63 and P = 0.83, respectively). Although frequency of reported negative behaviors in both groups significantly decreased over time (both P < 0.001), positive behaviors slightly, but not significantly, increased. Rate of eating was similar and significantly increased for both groups (P < 0.001).

Infant iron status

Most (92%) infants were iron sufficient at 9 mo of age (**Supplemental Table 2**). Median (25th, 75th percentiles) SF

TABLE 2 Percentage of reported positive and negative behaviors toward the target foods[1]

Target foods	Total	Veg-only	Control	Between-group mean difference (95% CI)	*P* value[2]
Positive behaviors, mean ± SD, %					
Broccoli[3]	24.6 ± 15.0	23.7 ± 14.2	25.7 ± 15.9	− 2.0 (−7.9, 3.9)	0.50
Spinach[4]	21.3 ± 13.6	22.2 ± 14.9	20.4 ± 12.3	1.8 (−3.6, 7.1)	0.51
Pear[5]	31.4 ± 15.0	30.5 ± 15.7	32.4 ± 14.3	− 1.9 (−7.7, 3.9)	0.52
Within-group, mean difference (95% CI)					
Broccoli vs. pear	−6.7 (−10.4, −3.0)	−6.8 (−12.5, −1.2)	−6.5 (−11.4, −1.5)		
P value	<0.001	0.01	0.001		
Spinach vs. pear	−10.1 (−13.8, −6.4)	−8.5 (−14.2, −2.9)	−11.7 (−16.6, −6.8)		
P value	<0.001	0.006	<0.001		
				Mean difference (95% CI)	
Negative behaviors, mean ± SD, %					
Broccoli[3]	6.6 ± 6.5	6.5 ± 6.4	6.7 ± 6.6	− 0.1 (−2.7, 2.4)	0.91
Spinach[4]	6.6 ± 6.4	6.8 ± 6.7	6.4 ± 6.1	0.4 (−2.1, 2.9)	0.75
Pear[5]	2.7 ± 4.2	2.4 ± 3.3	3.0 ± 5.1	− 0.6 (−2.3, 1.0)	0.46
Mean difference (95% CI)					
Broccoli vs. pear	4.0 (2.3, 5.6)	4.2 (1.8, 6.5)	3.7 (1.4, 6.0)		
P value	<0.001	<0.001	<0.001		
Spinach vs. pear	4.0 (2.3, 6.0)	4.5 (2.1, 6.8)	3.5 (1.2, 5.7)		
P value	<0.001	<0.001	0.001		

[1]Target foods: broccoli (meal A), spinach (meal B), and pear (meal C). Data reported as mean ± SD for consistency. Cell size varies due to missing data or exclusion of unwell infants. veg-only, vegetables only.
[2]Independent *t* test and Mann–Whitney test performed for positive behaviors and negative behaviors, respectively. Significant at the $P < 0.05$ level.
[3]Fifty-three and 50 babies in veg-only and control groups, respectively.
[4]Fifty-two and 51 babies in veg-only and control groups, respectively.
[5]Fifty-four and 51 babies in veg-only and control groups, respectively.

decreased between baseline and 9 mo of age, 91 (58, 262) μg/L at baseline compared with 40 (29, 59) μg/L at 9 mo, $P < 0.001$ (**Figure 5**A). However, mean ± SD Hb remained stable over time, 124 ± 12 g/L at baseline compared with 126 ± 14 g/L at 9 mo, $P = 0.106$ (Figure 5B). There were no significant differences in iron status indicators categories between the veg-only and control groups. Most (93%) infants consumed iron-rich foods (meat, fish, poultry) by 9 mo, and half (53%) were introduced to these foods

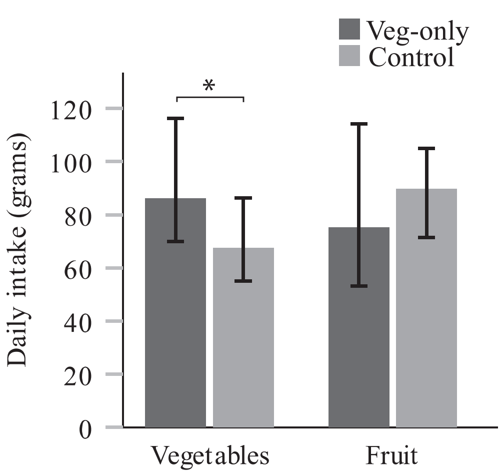

FIGURE 4 Daily intake of vegetables and fruit at 9 mo as reported by mothers. Independent *t* test performed on log-transformed vegetable intake data (veg-only, $n = 53$; control, $n = 49$). Mann–Whitney test used for fruit intake data (veg-only, $n = 53$; control, $n = 51$). Data presented as median with 95% CI for consistency. Veg-only, vegetables only. $^*P < 0.05$.

within the first month of CF (**Supplemental Table 3**), with no differences between intervention groups.

Intervention-related adverse events

There were no reported harms or serious adverse events observed.

Discussion

Infants in this study who received vegetable-only first foods during the first 4 wk of CF consumed more vegetables at 9 mo of age compared with a control group who received a combination of vegetables and fruit. Intake of the target vegetables (broccoli, spinach) was double that of the controls, and daily vegetable consumption at home was 28% higher. The veg-only group consumed the target vegetables more rapidly and accepted the foods at a greater rate than controls, but according to mothers' ratings, infant liking was not different by group. Of the target foods, pear was consumed in significantly greater amounts than broccoli and spinach by controls, whereas the veg-only group ate just as much vegetables as fruit. During the intervention, infants ate and liked vegetable-only first foods to the same extent as the combined fruit and vegetable first foods. Most infants participating in this trial maintained good iron status.

These findings complement results of 3 key RCTs investigating a vegetables-first approach to CF. Barends et al. (26) showed that 19 d of repeated exposure to only vegetable purées at the beginning of CF resulted in a significant increase in vegetable intake at the end of the intervention, compared with exposure to

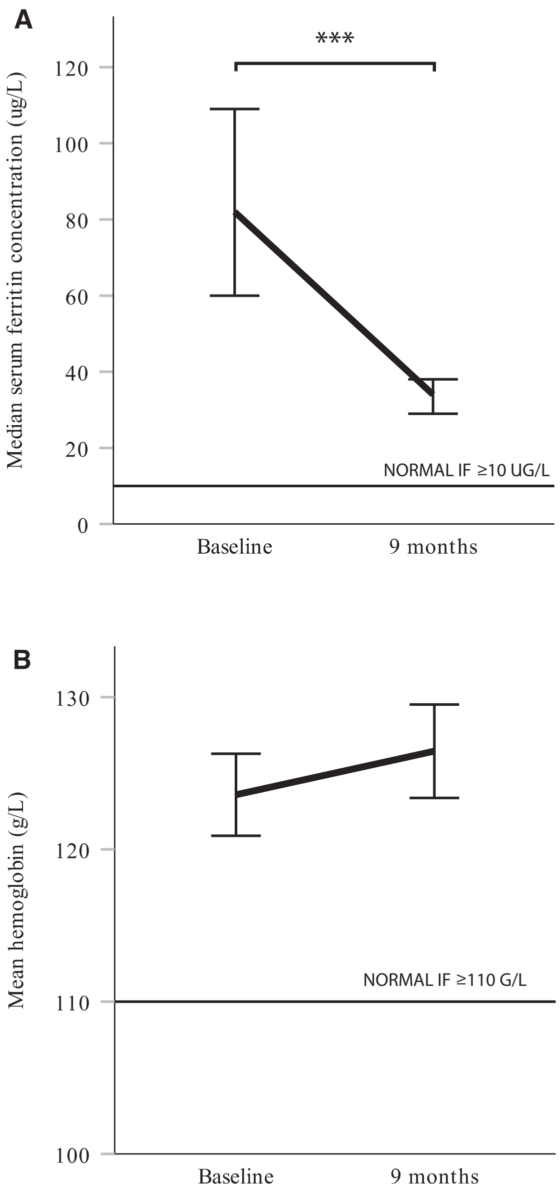

FIGURE 5 Change in (A) serum ferritin and (B) hemoglobin concentration between baseline and 9 mo ($n = 72$). Paired samples t test was used to compare changes in SF and Hb between baseline and 9 mo only because fewer blood samples ($n = 50$) were available postintervention (25 missing due to COVID-19 restrictions). Serum ferritin significantly decreased; median of untransformed data reported as these were similar to geometric mean. Hemoglobin did not change; mean with 95% CI reported as data normal for the primary outcome. Hb, hemoglobin; SF, serum ferritin; veg-only, vegetables only. $^{***}P < 0.001$.

only fruit purées. Fildes et al. (28) found UK infants who received a variety of single vegetables as first foods during the first 15 d of CF ate twice as much of a new vegetable (artichoke purée) 1 mo postintervention as infants who started with fruit, vegetables, and infant rice/cereal. In the 2-arm RCT by Hetherington et al. (25), infants who were introduced to vegetable tastes early and gradually (first to milk, then rice cereal) during the first 24 d of CF showed greater intake, pace of eating, duration, and liking of vegetable purées compared with those introduced to plain milk/rice cereal before vegetables. Such evidence suggests that capitalizing on infants' willingness to try new foods at the start of CF and when infants are most sensitive to taste (4–6 mo) (44) has been effective for supporting infants to learn to like and to eat more vegetables.

Infants assigned to the veg-only group in our study had tried 4 different types of vegetable-only first foods several times during the 4-wk intervention and according to infant hunger/satiety cues. Therefore, mechanisms of repeated exposure may have contributed to increased vegetable acceptance (4, 45, 46). The support for responsive feeding given to parents may have also contributed, but this explanation is speculative. More research is needed to determine the optimal feeding conditions for a vegetables-first approach (i.e., parenting style, number/type of vegetable exposures) (45), but our findings have shown that giving infants the opportunity to taste vegetable-only foods more than once at the start of CF, and in a responsive manner, is beneficial for increasing vegetable acceptance.

Despite differences in vegetable intake, mothers in each group perceived their infant to like vegetables equally. Lack of agreement between mothers' ratings of liking and other food acceptance measures (i.e., intake, researcher ratings) is often observed and attributed to response bias or the difficulty of interpreting infant cues (25, 28, 47). Nonetheless, mothers' ratings of liking significantly correlated with all other vegetable acceptance measures. This suggests that infants with greater liking, earlier rate of acceptance, longer duration of eating, and quicker pace of eating consumed more vegetables. The higher rate of acceptance among the veg-only group might be a more accurate result because the parameter relied on spatial rather than temporal criteria, was obtained by a trained researcher, and demonstrated reliability.

Meanwhile, the similar fruit intake and liking observed suggests that offering vegetables without fruit for the first 4 wk of CF has no effect on fruit acceptance in young infants. This might be expected given infants' innate preferences for sweet taste (48–50). Comparable results have been observed elsewhere (26, 27, 51, 52). For example, the study by Fildes et al. (28) found the infants who had started CF feeding with vegetables only ate and liked a novel fruit (peach purée) later and to the same extent as the controls who had previous fruit exposure. Barends et al. (26) found infants' very first intake of fruit was the same for all infants (∼45 g) regardless of their previous vegetable or fruit experience. Such findings are reassuring since consumption of fruit is as important as vegetables during childhood but needs less encouragement compared with vegetables.

Strengths of this novel study include the randomization and retention of a relatively large and adequately powered sample. Feeding sessions were conducted at home following detailed but easy to apply feeding instructions, thus improving the ecological validity findings. Parents may be encouraged by the veg-only infants accepting an additional 2 teaspoons of vegetables during their meal, suggesting findings have practical importance. The quality of video recordings was sufficient for analysis, demonstrating that home-captured video via mobile phone in conjunction with clear instructions could be a useful data collection method. By monitoring infant iron status, we have strengthened our understanding of intervention safety.

Results are not nationally representative and may be limited by social desirability bias, yet convenience sampling improved compliance and the use of a validated FFQ, and several measures of vegetable acceptance improved assessment accuracy. It is not clear whether the higher intake of vegetables at 9 mo is attributable to the CF intervention or due to eating more vegetables daily after the intervention. There is potential for tautology here; those who started CF with veg-only were also offered more vegetables because these were liked, but the degree of vegetable variety was similar between groups. Although the analysis for each outcome was adjusted for multiple comparisons (using Bonferroni correction), no adjustment was made for multiple outcome testing, and thus the risk of type I error and false-positive findings likely increased with multiple testing. Potential bias associated with protocol analysis was also present. The COVID-19 pandemic led to some missing data (iron parameters and anthropometric measures), and thus conclusions drawn about iron or growth remain limited. However, compliance remained high and minimal data were missing for primary measures. There were some differences in characteristics of those who did and did not complete the trials (i.e., being a first-time mother, infants as faster eaters). These findings suggest that the mechanism of missingness is not the result of "missing completely at random," and therefore, some of the missingness can be explained by other variables (e.g., those mentioned above). Last, although infants accepted vegetables as first foods relatively well and most had an acceptable iron status, this was in the context of mothers having received support and advice on infant-led responsive feeding practices and the introduction of iron-rich foods such as meat. The freeze-dried format of the foods compared well to homemade baby food in terms of flavor and texture, and they were more convenient to prepare. In addition, most infants were breastfed. Therefore, results may be dependent on these factors.

In conclusion, this study showed that introducing vegetable-only first foods, rather than a combination of fruit and vegetables, at the start of CF increases vegetable intake by 9 mo of age. Fruit acceptance was not compromised, and it seems that the intervention built upon the "window of opportunity" for flavor learning and acceptance during solid food introduction. A simple and practical message for caregivers could be to offer a variety of vegetable tastes in the early days of CF for improving child vegetable acceptance. Because infants accepted vegetable-only first foods, parents can be reassured that offering vegetables first without the addition of a sweeter fruit flavor will not result in substantial food refusal and food waste. These messages complement and extend, rather than amend, current infant feeding guidelines that recommend iron-rich foods, vegetables, and fruit as first foods. This is because offering vegetables first may enhance vegetable acceptance, but iron remains an essential nutrient for infants and fruit is a nutritious food. Translating this evidence into practice shows promise as the intervention was achieved within the home, although this might be contingent on access to vegetables and resources (e.g., videos, education sessions) to replicate results in a wider population.

We thank research assistant Lesley Savage and Owen Mugridge for conducting phlebotomy.

The authors' responsibilities were as follows—CAC, PRvH, and JPR: designed research; JPR: conducted research, analyzed data, and wrote paper; MMH: provided input to the study design before implementation; HM: provided statistical advice and input; and all authors: read and approved the final manuscript. The authors report no conflicts of interest.

Data Availability

Data described in the manuscript, code book, and analytic code will not be made available because this was not stated in the ethics application.

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