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# Temporal changes in bio-behavioral and glycemic outcomes following a produce prescription program among predominantly Hispanic/Latino adults with or at risk of type 2 diabetes

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ABSTRACT

In the United States (U.S.), consumption of fresh vegetables and fruits is below recommended levels. Enhancing access to nutritious food through food prescriptions has been recognized as a promising approach to combat diet-related illnesses. However, the effectiveness of this strategy at a large scale remains untested, particularly in marginalized communities where food insecurity rates and the prevalence of health conditions such as type 2 diabetes (T2D) are higher compared to the background population. This study evaluated the impact of a produce prescription program for predominantly Hispanic/Latino adults living with or at risk of T2D. A total of 303 participants enrolled in a 3-month observational cohort received 21 medically prescribed portions/week of fresh produce. A subgroup of 189 participants used continuous glucose monitoring (CGM) to assess the relationship between CGM profile changes and $HbA_{1c}$ level changes.

For 247 participants completing the study (76% female, 84% Hispanic/Latino, 32% with T2D, age 56·6 ± 11·9 years), there was a reduction in weight (−1·1 [-1·6 to −0·6] lbs., $p < 0.001$), waist circumference (−0·4 [-1·0 to 0·6] cm, $p = 0.007$) and systolic blood pressure (SBP) for participants with baseline SBP >120 mmHg (−4·2 [-6·8 to −1·8] mmHg, $p = 0.001$). For participants with an $HbA_{1c} \geq 7.0\%$ at baseline, $HbA_{1c}$ fell significantly (−0·5 [-0·9 to −0·1] %, $p = 0.01$). There were also improvements in food security ($p < 0.0001$), self-reported ratings of sleep, mood, pain (all $p < 0.001$), and measures of depression ($p < 0.0001$), anxiety ($p = 0.045$), and stress ($p = 0.002$) (DASS-21). There was significant correlation ($r = 0.8$, $p = 0.001$) between $HbA_{1c}$ change and the change in average glucose for participants with worsening $HbA_{1c}$, but not for participants with an improvement in $HbA_{1c}$.

In conclusion, medical prescription of fresh produce is associated with significant improvements in cardio-metabolic and psycho-social risk factors for Hispanic/Latino adults with or at risk of T2D.

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## Research in context

*Evidence before this study:* Minimal evidence exists on the effect of vegetable and fruit prescriptions for racial/ethnic minorities living with or at risk of developing type 2 diabetes (T2D). Moreover, longitudinal continuous glucose monitoring (CGM) data among minority populations is scarce.

*Added value of this study:* This study evaluated the effect of medical prescriptions of fresh produce without additional education in an underserved community of predominantly Hispanic/Latino adults with non-insulin-treated T2D or at risk of developing it. Over three months, we observed improvements in cardio-metabolic, psychological, and behavioral outcomes (including food security) as well as validated depression, anxiety, and stress measures. Comparing baseline and conclusion CGM profiles, we did not find significant differences in summary metrics. However, stratifying participants according to $HbA_{1c}$ change, there was a significant association between $HbA_{1c}$ rise and CGM-derived average glucose for those with worsening $HbA_{1c}$.

*Implications of all the available evidence:* Our findings suggest medical produce prescription programs for underserved Hispanic/Latino populations with or at risk of T2D may have bio-behavioral and psychological benefits. Additionally, the use of CGM in this population is feasible and acceptable with the potential to provide novel insights into the progression of dysglycemia.

## 1. Introduction

In the United States (U.S.), suboptimal dietary habits have been associated with poor cardiometabolic health outcomes [1]. A common problem in the U.S. diet is the lack of consumption of fresh vegetables and fruits, with an estimated 10% of the adult population meeting the daily recommended dosage [2]. As a corollary, food insecurity (not having access to sufficient or adequate food to cover basic needs) has also been linked to adverse health outcomes, including type 2 diabetes (T2D), cardiovascular disease, cancer, and mental health problems [3]. Food insecurity in U.S. households is usually a recurrent experience rather than a persistent situation [4]. These cycles of frequent food insecurity can produce compensatory behaviors where episodes of having insufficient meals later result in binge eating episodes of energy-dense foods when available [5]. The intake of high-energy, cheap foods with low nutrient value is a significant risk factor for the progression of T2D [6].

Compounding the issue in the U.S. are documented disparities in the prevalence of T2D among low-income and racial/ethnic minority populations compared to others [7]. For example, T2D is more common among Hispanic/Latino adults compared to the non-Hispanic White population [8]. Moreover, food insecurity is also more common among Hispanic/Latinos than non-Hispanic Whites [4]. Because of this, a higher percentage of Hispanic/Latino households participate in federal-aid programs such as the Supplemental Nutrition Assistance Program (SNAP) [9]. Implementing government programs that aid with purchasing nutritious food can be cost-effective and generate health gains [10]. In earlier research, we found clinically significant improvements in cardio-metabolic risk factors among Hispanic/Latino adults by providing access to fresh vegetables using a produce prescription program [11].

The aim of this study was to test the hypothesis that, for a cohort of predominantly Hispanic/Latino adults, the provision of medical prescriptions for fresh vegetables can improve cardiometabolic outcomes, including changes in glucose profiles over time measured using continuous glucose monitoring (CGM). The study also examined the association between changes in CGM metrics and $HbA_{1c}$ levels.

## 2. Methods

The Farming for Life (NCT03940300) study was conducted in Santa Barbara, California, from 2019 to 2022 with approval by an Independent Review Board before the start of any participation (Advarra IRB Study 2018–01793, Protocol 00036476). Details of the protocol have been published previously [11]. Participants were enrolled through bilingual (English and Spanish) outreach materials, advertisements on social media, or existing programs and organizations focusing on the Hispanic/Latino community. Eligible participants had to be 18 years old or older at the first visit and self-report as diagnosed with T2D or as a high risk for developing T2D using the American Diabetes Association diabetes risk assessment tool [12]. Participants with prior use of insulin, pregnancy, or other severe conditions were excluded. Detailed protocol information can be found in the supplementary material (Table A).

Eligible and consented participants were asked to complete 12 visits over three months. Data collection by trained research staff was repeated in the baseline and conclusion visits. The primary objective was to assess changes in blood pressure (BP), weight, waist circumference (WC), glycemic control, and $HbA_{1c}$ levels (a measure of long-term blood glucose control) throughout the trial. Additional questionnaires (available in Spanish and English) were collected to assess the impact of vegetable prescriptions on food security, mood, sleep, and pain, as well as vegetable, tortilla, and soda consumption.

We obtained fresh vegetables from local farms (located within 70 miles of each distribution center) within 72 h of distribution from the fields and chose them according to seasonal availability. During visit 1, upon screening and enrollment, baseline clinical measurements and questionnaires were completed. Visits 2–11 consisted of the collection of prescribed produce. At each study visit, each participant received the recommended 21 servings for the week [13]. Participants collected the weekly prescriptions, signed by a medically qualified practitioner from Sansum Diabetes Research Institute. During visit 12, the same clinical measurements and questionnaires that were collected at baseline were repeated.

### 2.1. Continuous glucose monitoring (CGM)

In addition to the clinical measurements and questionnaires collected, a subset of participants agreed to wear CGMs. This subgroup

**Table 1**
Baseline age for participants with paired (pre- and post-intervention) clinical measurements.

| | Paired $HbA_{1c}$ (n = 247) | Paired weight and waist circumference (n = 234) | Paired average systolic blood pressure (n = 235) | Paired CGM with >10 days of data (n = 105) |
|---|---|---|---|---|
| Age (years) | mean ± SD | mean ± SD | mean ± SD | mean ± SD |
| **All participants** | **54·2 ± 11·9** | **54·3 ± 11·8** | **54·3 ± 11·8** | **54·4 ± 11·8** |
| Female | 53·9 ± 11·6 | 54·1 ± 11·5 | 54·1 ± 11·6 | 55·1 ± 11·1 |
| Male | 55·1 ± 12·8 | 55·0 ± 12·9 | 55·1 ± 12·8 | 52·6 ± 13·6 |

Note: n = number of participants, SD = standard deviation.

used FreeStyle Libre Pro CGM sensors (Abbott Diabetes Care) for two weeks pre-intervention and during the final two weeks of the intervention period. Of the initial group, 150 participants completed the baseline and conclusion CGM. Overall, 105 of those had sufficient data (≥10 days of CGM data over the 14 days monitoring period) to provide a reliable estimate of glucose metrics for three months [14,15] as well as $HbA_{1c}$ levels. We computed common summary metrics: average glucose; standard deviation (SD); coefficient of variation (CV); time in range (TIR) from 70 to 140 mg/dL, 70–180 mg/dL, and 140–180 mg/dL; time above range (TAR) for time surpassing 140 mg/dL and 180 mg/dL; time below range (TBR) for time spent in the range of 54–69 mg/dL or below 54 mg/dL.

### 2.2. Statistical analysis

All statistical tests were performed using Matlab 2021b (https://www.mathworks.com/). The Kolmogorov-Smirnov test was used to test for normality. We used a two-tailed Student's t-test to compare normally distributed paired data. For non-normally distributed paired measurements, we conducted a permutation test with $10^4$ resamples [16]. Confidence intervals were computed using bootstrapping with $2 \times 10^4$ samples. Statistical significance was expressed at the 5% level. Participants were stratified by baseline $HbA_{1c}$ into three categories: at risk ($HbA_{1c} < 5{\cdot}7\%$), pre-T2D ($HbA_{1c}$ 5·7%-6·4%), and T2D ($HbA_{1c} > 6{\cdot}4\%$) [17]. To analyze the correlation between CGM summary metrics and $HbA_{1c}$, we stratified the participants-based magnitude of change in $HbA_{1c}$ levels where $\Delta HbA_{1c} = Conclusion\ HbA_{1c} - Baseline\ HbA_{1c}$. A threshold of 0·4% change was considered clinically significant, with $\Delta HbA_{1c} \leq -0{\cdot}4\%$ considered an improvement, and $\Delta HbA_{1c} \geq 0{\cdot}4\%$ considered as a worsening of glycemia. Simple and multiple linear regression analyses were performed with Matlab's 'fitlm' to model the relationship between clinical measurements and CGM summary metrics with changes in $HbA_{1c}$.

## 3. Results

### 3.1. Description of the dataset and participant demographics

Overall, 303 participants (age 55·3 ± 12·6 years [mean ± SD], 71·3% female, 82·2% self-reporting as Hispanic/Latino, 36% with a known diagnosis of T2D) were enrolled. For participants with T2D, the average time from diagnosis to enrollment was 9·6 ± 8·1 years. Of the 303 participants, 247 completed the 12 visits (Tables 1 and 2, Fig. 1). Participants not completing reported different reasons, with the majority related to concerns about COVID-19. Detailed demographic information can be found in Tables 1 and 2 for paired (i.e., with both pre-and post-intervention data) clinical health measurements and CGM data.

Most participants were not born in the U.S. (77·5%), the majority (>90%) of whom reported Mexico as their country of origin. The median score for acculturation was 1.5 (IQR: 1·25 to 3·75), indicating a low level of acculturation [19]. Only 195 (64·4%) participants had health insurance.

### 3.2. Clinical measurements

A comparison of baseline vs. conclusion health measurements for participants with paired data is shown in Table 3. Mean weight difference decreased by −1·1 ([95% CI: 1·6, −0·6] lbs., $p < 0{\cdot}001$). This was significant in women ($p < 0{\cdot}001$), but not men. Similarly, waist circumference was reduced by −0·4 ([95% CI: 1·2, −0·2] cm, $p = 0{\cdot}01$), with significance for females ($p = 0{\cdot}03$). Systolic blood pressure for participants with baseline systolic BP > 120 mmHg decreased by −4·2 ([95% CI: 6·8, −1·8] mmHg, $p < 0{\cdot}001$). Changes in $HbA_{1c}$ levels overall with a mean decrease of −0·1 ([95% CI: 0·2 to −0·0]%, $p = 0{\cdot}03$) were significant. Changes were significant

**Table 2**
Demographic measurements for participants with paired (pre- and post-intervention) clinical measurements.

| | Paired $HbA_{1c}$ | Paired weight and waist circumference | Paired average systolic blood pressure | Paired CGM with >10 days of data |
|---|---|---|---|---|
| | **n (Percentage)** | **n (Percentage)** | **n (Percentage)** | **n (Percentage)** |
| **Total** | **247** | **234** | **235** | **105** |
| **Gender** | | | | |
| Female | 187 (75·7%) | 179 (76·5%) | 179 (76·2%) | 77 (73·3%) |
| Male | 60 (24·3%) | 55 (23·5%) | 56 (23·8) | 28 (26·7%) |
| **Race/Ethnicity** | | | | |
| Hispanic/Latino | 208 (84·2%) | 200 (85·5%) | 201 (85·5%) | 96 (91·4%) |
| Non-Hispanic White | 33 (13·4%) | 28 (11·9%) | 28 (11·9%) | 9 (8·6%) |
| Non-Hispanic Black | 3 (1·2%) | 3 (1·3%) | 3 (1·3%) | 0 |
| Asian | 3 (1·2%) | 3 (1·3%) | 3 (1·3%) | 0 |
| **Diabetes status based on baseline $HbA_{1c}$** | | | | |
| At risk ($HbA_{1c} < 5{\cdot}7\%$) | 79 (31·9%) | 73 (31·2%) | 75 (31·9%) | 38 (36·2%) |
| Pre-T2D ($5{\cdot}7\% \leq HbA_{1c} \leq 6{\cdot}4\%$) | 90 (36·4%) | 87 (37·2%) | 88 (37·4%) | 35 (33·3%) |
| T2D ($HbA_{1c} > 6{\cdot}4\%$) | 78 (31·6%) | 74 (31·6%) | 72 (30·6%) | 32 (30·5%) |

Note: n = number of participants.

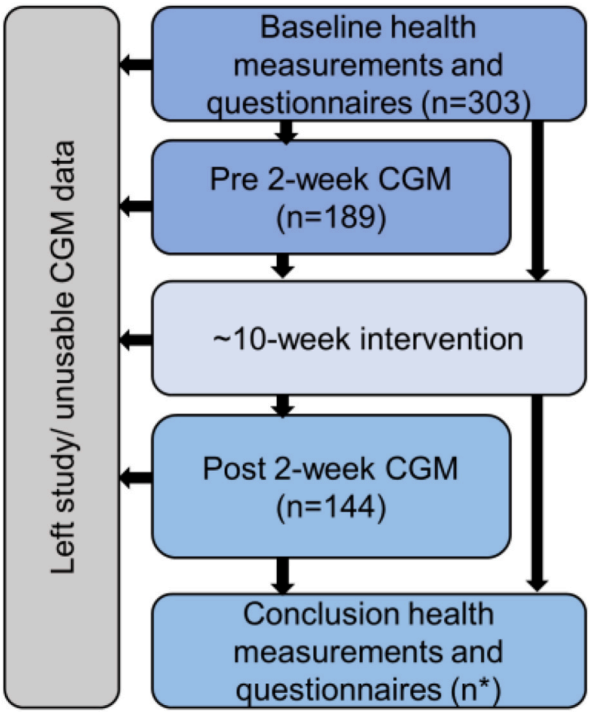


**Fig. 1.** Study design. Where n is the number of participants at each stage. For the conclusion health measurements, n* is the number of participants with paired data, which differs for each variable (Table 3).

**Table 3**
Comparison of variables collected at the first visit (baseline) vs the last visit (conclusion) for participants with paired clinical measurements.

| | Baseline Median (IQR) | Conclusion Median (IQR) | Mean change (95% CI) | *P*-Value |
|---|---|---|---|---|
| **$HbA_{1c}$ (%) (n = 247)** | 5·9 (5·6, 6·7) | 5·9 (5·5, 6·6) | −0·1 (−0·2 to −0·0) | **0·03** |
| Female (n = 187) | 5·9 (5·6, 6·5) | 5·9 (5·5, 6·5) | 0·0 (−0·1 to 0·1) | 0·89 |
| Male (n = 60) | 6 (5·5, 7·7) | 5·9 (5·5, 7) | −0·4 (−0·8 to −0·0) | < **0·001** |
| At risk (n = 79) | 5·5 (5·3, 5·6) | 5·4 (5·3, 5·6) | 0·03 (−0·0 to 0·1) | 0·17 |
| Pre-T2D (n = 90) | 5·9 (5·8, 6·1) | 5·9 (5·8, 6·2) | −0·02 (−0·1 to 0·0) | 0·45 |
| T2D (n = 78) | 7·5 (6·8, 8·7) | 7·3 (6·7, 8·2) | −0·3 (−0·6 to −0·1) | **0·01** |
| Baseline $HbA_{1c} \geq 7\%$ (n = 55) | 8·1 (7·5, 9·0) | 7·6 (7·1, 8·8) | −0·45 (−0·9 to −0·1) | **0·01** |
| **Weight (lbs) (n = 234)** | 169·8 (148·8, 198·4) | 164·2 (148, 196·4) | −1·1 (−1·6 to −0·6) | < **0·001** |
| Female (n = 179) | 167 (145·5, 190·5) | 164·8 (144·6, 191·3) | −1·2 (−1·8 to −0·6) | < **0·001** |
| Male (n = 55) | 180·4 (163·1, 214·5) | 180 (161·8, 211·5) | −0·8 (−1·9 to 0·3) | 0·16 |
| **Waist circumference (cm) (n = 233)**[a] | 100 (92, 107·6) | 98 (91,108) | −0·4 (−1·2 to −0·2) | **0·01** |
| Female (n = 179) | 100 (91·6, 107·5) | 98 (91,107·4) | −0·7 (−1·3 to −0·1) | **0·03** |
| Male (n = 54) | 98·3 (93,110) | 97·8 (91,109) | −0·9 (−1·2 to 0·0) | 0·08 |
| **Systolic BP (mmHg) Baseline > 120 (n = 127)**[b] | 133·5 (124·1, 140) | 129·5 (120·5, 139·5) | −4·2 (−6·8 to −1·8) | < **0·001** |
| Female (n = 95) | 135 (126, 142·4) | 130·1 (119·8, 140·3) | −4·5 (−7·7 to −1·4) | < **0·01** |
| Male (n = 32) | 130·5 (122·6, 135·5) | 125·3 (120·8, 132·3) | −3·4 (−7·8 to 0·1) | 0·12 |

Note: n = number of participants, IQR = interquartile range, CI = confidence interval.
[a] One participant was removed from WC measurements due to outlier data.
[b] Threshold for elevated blood pressure [18].

specifically for males ($p < 0{\cdot}001$) and for participants with T2D ($p = 0{\cdot}01$). We also analyzed participants with baseline $HbA_{1c} \geq 7\%$. This subgroup had a higher $\Delta HbA_{1c}$ (−0·5 [95% CI: 0·9 to −0·1]) than the T2D subgroup (−0·3 [95% CI: 0·6 to −0·1]).

### *3.3. Questionnaires*

For the participants enrolled at baseline, participants with low or very low food security (score ≥3 on the U.S. Adult Food Security Scale [20]) accounted for 31% of the sample. Upon conclusion, this fell to 15·4%. During the exit interview, participants were asked to rank their vegetable consumption before and after the intervention on a scale of 1–4, where 1 was defined as "more than once a day", 2 was defined as "4–6 times/week", 3 as "1–3 times/week", and 4 as "not at all". We obtained 231 responses with a median score before

the intervention of 3 (IQR: 2 to 3) that decreased to 1 (IQR: 1 to 2). The percentage of food discarded was also reported on a scale from 1 to 4, with 1 being from 0% to 25%, 2 from 26% to 50%, etc. The median percentage discarded was 1 (IQR: 1 to 1) indicating that participants discarded food on limited occasions (0–25% of the produce was discarded).

Sleep (Fig. 2a), mood (Fig. 2b), and pain (Fig. 2c), scores all significantly improved from baseline to conclusion.

Depression (Fig. 3a), anxiety (Fig. 3b), and stress (Fig. 3c) scores, evaluated with the DASS-21 questionnaire [21], all showed significant improvements (i.e. reductions) from baseline to conclusion. The median depression raw score improved from 3 (IQR: 1 to 9) to 1 (IQR: 0 to 4·3). Anxiety raw score improved from 3 (IQR: 1 to 7·5) to 2 (IQR: 0 to 5). Stress raw scores improved from 6.5 (IQR: 3, 11) to 3 (IQR: 1,9). For clinical interpretation, we adjusted the scoring using a scale from zero to four according to the DASS-21 guidelines, where 0 corresponds to normal, 1 to mild, 2 to moderate, 3 to severe, and 4 to extremely severe (Figure A, supplementary materials). There was a decrease in the mean of the adjusted scores of −0·4 (95% CI: 0·7 to −0·2) for depression, −0·4 (95% CI: 0·7 to −0·1) for anxiety, and −0·3 (95% CI: 0·5 to −0·1) for stress.

### 3.4. Continuous glucose monitoring data

Baseline and conclusion comparisons of CGM from participants with available $HbA_{1c}$ levels (n = 105) with over ten days of data were made. We used permutation testing for changes in the mean of baseline vs conclusion measurements and reported p-values in Table 4. To assess if CGM summary metrics changed in correspondence with changes in $HbA_{1c}$ levels, we stratified the cohort into "Improved", "No Change", and "Worsened," considering $\Delta HbA_{1c} \geq 0.4\%$ a significant change. Overall, there was no significant change in CGM summary metrics for all participants except for time in range (TIR) from 140 to 180 mg/dL (Table 4, Supplementary Figure B). Improvement in $HbA_{1c}$ levels was not reflected in the CGM metrics. In comparison, for participants with worsening $HbA_{1c}$, there was a significant change in average glucose, SD, TIR (70–140 and 70–180 mmHg), and TAR (140 and 180 mmHg).

Correspondence between changes in $HbA_{1c}$ and changes in average glucose levels can be seen in Fig. 4. Two participants showed worsening $HbA_{1c}$ levels with improved average glucose (quadrant IV, Fig. 4), while nine participants improved in $HbA_{1c}$ but worsened in average glucose (quadrant II, Fig. 4). There was no correlation between $\Delta HbA_{1c}$ and ΔAverage Glucose for participants with improving $HbA_{1c}$ (r = 0·2, p = 0·34), but there was a positive correlation for participants with worsening $HbA_{1c}$ (r = 0·8, p = 0·001) (Supplementary Figure C).

To investigate the relationship between changes in HbA1c and alterations in other variables, a multiple linear regression analysis focusing only on participants with a clinically significant shiftin$HbA_{1c}$ (i.e., $|\Delta HbA_{1c}| \geq 0{\cdot}4\%$ n = 30) was examined. The relationship between $\Delta HbA_{1c,}$ clinical measurements (Δweight, Δblood pressure, Δwaist circumference, age, gender, baseline $HbA_{1c}$), and changes in CGM summary metrics was performed (Supplementary table D). There was no association between alterations in CGM-derived metrics of ΔTBR, ΔCV, and ΔSD and $\Delta HbA_{1c}$ (r < 0·4). In contrast, ΔTIR and ΔTAR were correlated to $\Delta HbA_{1c}$ (ΔTIR 70–140 mg/dl [r = −0·45, p = 0·01]; ΔTIR 70–180 mg/dl [r = −0·5, p < 0·01]; ΔTAR 140 [r = 0·46, p < 0·01]; ΔTAR 180 [r = 0·51, p < 0·01]), as well as the change in average glucose (ΔAverage glucose). Only ΔAverage glucose was included in the model to minimize multicollinearity issues since it had the highest correlation with $\Delta HbA_{1c}$ (r = 0·59, p < 0·001). Weight, age, baseline $HbA_{1c}$, and waist circumference were not correlated to $\Delta HbA_{1c}$ they were excluded as well (r < 0·4). Gender was also included since it appeared to be associated with the changes in $HbA_{1c}$ (Supplementary figure D). The final multiple linear regression model included changes in systolic blood pressure, gender (0 – male, 1 – female), and ΔAverage glucose as covariates. The model was used to determine the association between changes in HbA1c and changes in the covariates. Using this model, the adjusted R-squared value was significant (R^2 = 0·62, p < 0·0001). This model performs better than the single regression using only changes in average glucose (R^2 = 0·35, p < 0·001).

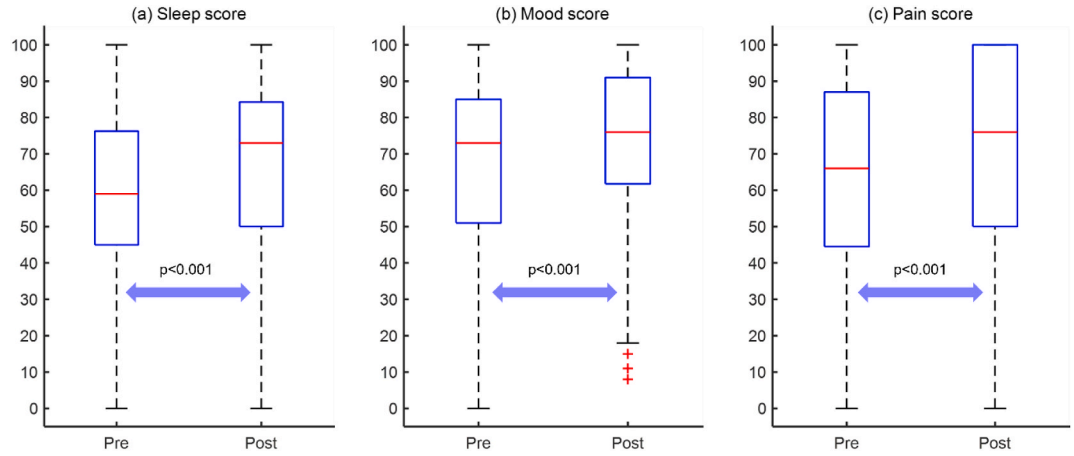


**Fig. 2. Self-reported sleep, mood, and pain scores (n = 237) pre vs post intervention.** Using 100 mm visual analog scales ranging from 0 (for worst sleep/mood/pain) to 100 (for best sleep/mood or no pain).

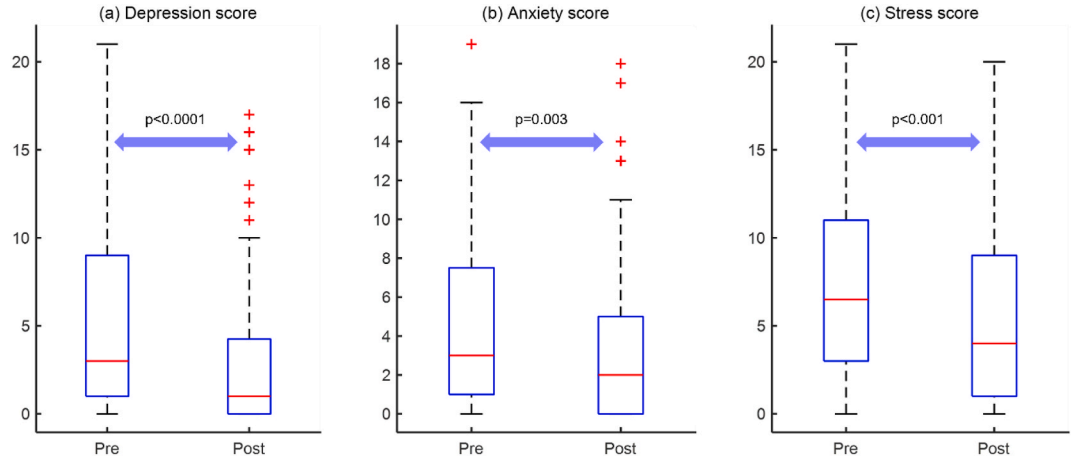


**Fig. 3. Depression, anxiety, and stress scores using DASS-21 (n = 117) pre vs post intervention.** Scale differs for each disorder [21]. For depression (a): Normal (0–4), Mild (5–6), Moderate (7-10), Severe (11–13), and Extremely severe (≥14). For anxiety (b): Normal (0–3), Mild (4–5), Moderate (6–7), Severe (8–9), and Extremely severe (≥10). For stress (c): Normal (0–7), Mild (8–9), Moderate (10–12), Severe (13–16), and Extremely severe (≥17). Note: "+" indicates outliers.

**Table 4**
CGM summary metrics p-values for paired permutation test of mean difference (conclusion-baseline) where $|\Delta HbA_{1c}| \geq 0{\cdot}4\%$ is considered a significant change.

| | All (n = 105) | $HbA_{1C}$ Improved (n = 18) | No change $HbA_{1C}$ (n = 75) | $HbA_{1C}$ Worsened (n = 12) |
|---|---|---|---|---|
| **$HbA_{1c}$** | 0·34 | .. | .. | .. |
| **Average Glucose** | 0·57 | 0·53 | 0·98 | **0·01** |
| **SD** | 0·42 | 0·76 | 1.00 | **0·01** |
| **CV%** | 0·51 | 0·41 | 0·99 | 0·98 |
| **TIR 70,140 mg/dL** | 0·83 | 0·19 | 0·61 | **0·02** |
| **TIR 70–180 mg/dL** | 0·22 | 0·78 | 0·42 | **0·05** |
| **TIR 140–180 mg/dL** | **0·04** | 0·05 | 0·43 | 0·89 |
| **TAR 140 mg/dL** | 0·76 | 0·17 | 0·68 | **0·01** |
| **TAR 180 mg/dL** | 0·33 | 0·66 | 0·13 | **0·01** |
| **TBR 54–69 mg/dL** | 0·59 | 0·27 | 0·99 | 0·94 |
| **TBR 54 mg/dL** | 0·53 | 0·27 | 0·60 | 0·75 |

Note: n = number of participants, SD = standard deviation, CV = coefficient of variation, TIR = time in range, TAR = time above range, TBR = time below range.

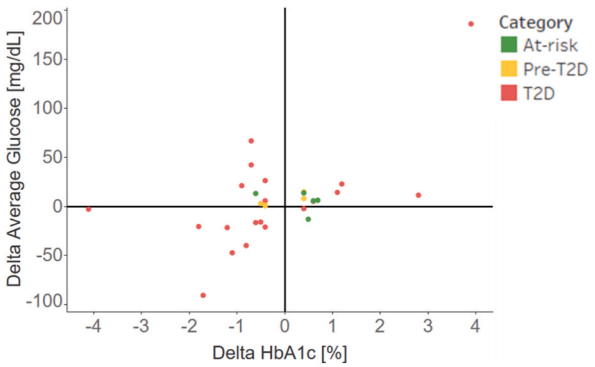


**Fig. 4. $\Delta HbA_{1c}$ vs ΔAverage glucose for participants with $|\Delta HbA_{1c}| \geq 0{\cdot}4\%$** (n = 30).

## 4. Discussion

In the U.S., lack of access to foods known to be beneficial to health is an important contributor to the disproportionate burden of T2D and other serious non-communicable diseases faced by Hispanic/Latino families [22,23]. To overcome this, food prescription

interventions are gaining popularity [24]. The Farming for Life program aimed to evaluate the impact of improving access to fresh vegetable produce for predominantly Hispanic/Latino adults with or at risk of T2D and low levels of acculturation. After three months of participation in the produce prescription program, there were modest improvements in cardio-metabolic risk factors, including weight, waist circumference, and systolic blood pressure for participants with above-target baseline values. Similarly, for participants with established T2D, $HbA_{1c}$ levels also fell by an average of 0·4%, most notably among male participants. In addition to improving biological outcomes, participation in Farming for Life was also associated with benefits in mood, sleep, self-reported pain scores, as well as reduced depression, stress, and anxiety. There was also a reduction in the number of participants with low or very low food security. Comparably, previous studies have found significant improvement in $HbA_{1c}$ levels when providing access to fresh vegetables, but in these studies, improved access to fresh produce was accompanied by education on nutrition [24,25].

This observational cohort study suggests that improving access to fresh vegetables without supplementary education can still positively impact glycemic control, cardiometabolic health, and quality of life. The level of nutrition knowledge was not assessed. It is known that lower nutritional knowledge is associated with a lower intake of vegetables and fruits [26] and that individuals may be unaware that their vegetable consumption is below recommended levels [27]. For adults with established T2D, promoting healthy eating habits without improving access can be challenging as dietary recommendations often require individuals to alter deeply entrenched perceptions about food [28]. There are also several established barriers to accessing fresh produce including time burden, taste preferences, inadequate cooking skills, and motivation [29]. Prior research has also shown that ethnicity is a factor in food preferences resulting in consumption differences [30]. Participants in this program were predominantly of Mexican-American heritage, and there is evidence that Hispanics/Latinos' abilities to consume food known to be beneficial to health, compared with other racial/ethnic groups, are impacted negatively by barriers related to access, food insecurity, and low socioeconomic status. Acculturation among Hispanic/Latinos may also be linked to poor dietary choices such as a lack of sufficient intake of fruits and vegetables [31]. For Hispanic/Latino immigrants to the U.S., the less acculturated consume more fruit, vegetables, rice, and beans, and fewer foods harmful to health including less sugar and sugar-sweetened beverages [31].

In this study, in addition to $HbA_{1c}$ levels, continuous glucose monitoring (CGM) was used to examine changes in glycemia over time for a subgroup of participants in Farming for Life. It is established that CGM has demonstrable benefits for people living with diabetes using insulin. However, only a few studies have examined CGM in non-insulin-treated T2D or for individuals without diabetes. In addition, most published studies have not differentiated between individuals with normal glucose tolerance and those with pre-diabetes. In recent cross-sectional analyses of baseline CGM profiles in a smaller number of participants in the Farming for Life program, there appeared to be a progression of dysglycemia comparing Hispanic/Latino adults at risk of T2D or with pre-T2D with those with non-insulin-treated T2D [32]. The metrics used in the comparison included standard measures (average glucose, glucose variability, and time in range of 70–180 mg/dL) as well as newer metrics including time spent between 140 and 180 mg/dL during the day. In that study, the time between 70 and 140 mg/dL during the day was also significantly correlated with $HbA_{1c}$ levels after adjusting for age, sex, BMI, and waist circumference. There is also evidence that using real-world post-breakfast glucose excursions might also provide novel insights into differences in glycemia when comparing these same groups (i.e., at risk, pre-T2D, and T2D) [33].

Previous studies have examined correlations between $HbA_{1c}$ and CGM metrics [32,33]. In this analysis, comparing baseline with conclusion CGM profiles, there were no significant differences (except for a change in the time in range between 140 and 180 mg/dL, which improved over time). We did find, however, that when stratifying the participants by $HbA_{1c}$ changes over three months, in the group with worsening levels (i.e., an increase in $HbA_{1c}$ by at least 0·4%), there was a significant deterioration in average glucose, standard deviation of glucose, time in range between 70 and 140 and 70 and 180 mg/dL, and time above 140 and 180 mg/dL. However, there was no substantial change in glycemic variability or time spent in the hypoglycemic range. This was not seen in the sub-groups with unchanged or improved $HbA_{1c}$ levels. Only 36% of the participants with a significant change in $HbA_{1c}$ levels showed corresponding changes in CGM summary metrics. Moreover, we found that gender potentially has an influence, as the relationship between changes in $HbA_{1c}$ and CGM was only seen in predominantly female Hispanic/Latino adults. The relationship between CGM data and $HbA_{1c}$ levels is complex [34]. In addition to factors influencing the number and life span of red blood cells, variations in the rate of glycation can also affect achieved $HbA_{1c}$ levels [34]. For example, inter-individual variability may result due to variations in the apparent glycation ratio (AGR) [35]. At present, it is unclear whether AGR changes over time or whether there is differential sensitivity of the AGR to the magnitude and direction of glucose fluctuations.

This study has some important limitations. A major limitation of the study is the absence of a control group. Participants were recruited by using outreach materials in English and Spanish with help from bilingual community health workers and therefore were not a random sample. Females formed nearly 80% of the cohort, so generalizability to males needs to be investigated. Further, this study did not collect data related to food choices and physical activity levels. Previous studies have demonstrated links between the timing of food intake and insulin sensitivity [36]. Similarly, the timing of physical activity appears to influence achieved $HbA_{1c}$ levels in Hispanic/Latino adults with or at risk of T2D [37]. We also have no specific data on participant storage, preparation, or consumption of the vegetables. We cannot know if nutrition education could have altered our findings. The use of self-reported data without methods to prove its validity (for example, whether the information was entered incorrectly or misremembered) is also a limitation. Finally, participants did not have access to their real-time glucose levels, so we could not compare the results to analyze if unblinded CGM was beneficial in modifying behavior and food choices. Previous literature suggests that 14 days of CGM data (when used at least 70% or ~10 days) correlate with three months of CGM of data [14]. However, summary CGM metrics might not correlate with clinically significant improvement of $HbA_{1c}$ levels. Our data suggests that more guidelines for the interpretation of CGM metrics and correlation with $HbA_{1c}$ levels are needed for patients at risk or with T2D.

In conclusion, prescriptions of fresh produce to Hispanic/Latino adults with or at risk of developing T2D were associated with improvements in health measurements relevant to cardiometabolic risk factors. The findings from this study provide evidence of the

potential value of produce prescription programs as an intervention to reduce food insecurity and improve the quality of food choices to impact the disproportionate burden of T2D faced by the population experiencing health disparities.

## Contributors

DK: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.
ES, AS, SB, AP: Analyzed and interpreted the data; Wrote the paper.
NG, WB: Conceived and designed the experiments; Performed the experiments; Wrote the paper.CC, AL: Performed the experiments; Wrote the paper.

## Data sharing statement

Data is available upon reasonable request. The investigators agree to share de-identified data that underlie the results reported in this article three months after publication and up to five years after. Proposals should be directed to kerr@diabetestechnology.org. To gain access, data requestors will need to sign a data access agreement.

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## Ethics approval

Independent Review Board (Advarra IRB).

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: David Kerr reports equipment, drugs, or supplies was provided by Abbott Diabetes Care Inc.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e18440.

## References

[1] R. Micha, J.L. Peñalvo, F. Cudhea, F. Imamura, C.D. Rehm, D. Mozaffarian, Association between dietary factors and mortality from heart disease, stroke, and type 2 diabetes in the United States, JAMA 317 (2017) 912–924, https://doi.org/10.1001/JAMA.2017.0947.
[2] Center for Disease Control and Prevention, State Indicator Report on Fruits and Vegetables, 2018, Atlanta, GA, 2018. https://www.cdc.gov/nutrition/data-statistics/. (Accessed 5 October 2022).
[3] C.A. Gregory, A. Coleman-Jensen, Food Insecurity, Chronic Disease, and Health Among Working-Age Adults, 2017. www.ers.usda.gov/publications. (Accessed 5 October 2022).
[4] A. Coleman-Jensen, M.P. Rabbitt, C.A. Gregory, A. Singh, Household Food Security in the United States in 2021, 2022. https://www.ers.usda.gov/publications/. (Accessed 29 September 2022).
[5] H.K. Seligman, A.F. Bolger, D. Guzman, A. López, K. Bibbins-Domingo, Exhaustion of food budgets at month's end and hospital admissions for hypoglycemia, Health Aff. 33 (2014) 116–123, https://doi.org/10.1377/HLTHAFF.2013.0096.
[6] H.K. Seligman, A.B. Bindman, E. Vittinghoff, A.M. Kanaya, M.B. Kushel, Food insecurity is associated with diabetes mellitus: results from the national health examination and nutrition examination survey (NHANES) 1999–2002, J. Gen. Intern. Med. 22 (2007) 1018–1023, https://doi.org/10.1007/S11606-007-0192-6.
[7] Center for Disease Control and Prevention, Prevalence of diagnosed diabetes, national diabetes statistics report. https://www.cdc.gov/diabetes/data/statistics-report/diagnosed-diabetes.html, 2022. (Accessed 5 October 2022).
[8] Y.J. Cheng, A.M. Kanaya, M.R.G. Araneta, S.H. Saydah, H.S. Kahn, E.W. Gregg, W.Y. Fujimoto, G. Imperatore, Prevalence of diabetes by race and ethnicity in the United States, 2011-2016, JAMA 322 (2019) 2389–2398, https://doi.org/10.1001/JAMA.2019.19365.
[9] Center on Budget and Policy Priorities, SNAP Helps Millions of Latinos, 2018. https://www.cbpp.org/research/food-assistance/snap-helps-millions-of-latinos. (Accessed 12 October 2022).

[10] Y. Lee, D. Mozaffarian, S. Sy, Y. Huang, J. Liu, P.E. Wilde, S. Abrahams-Gessel, T.D.S. Veiga Jardim, T.A. Gaziano, R. Micha, Cost-effectiveness of financial incentives for improving diet and health through Medicare and Medicaid: a microsimulation study, PLoS Med. 16 (2019), https://doi.org/10.1371/journal.pmed.1002761.

[11] D. Kerr, S. Barua, N. Glantz, C. Conneely, M. Kujan, W. Bevier, A. Larez, A. Sabharwal, Farming for life: impact of medical prescriptions for fresh vegetables on cardiometabolic health for adults with or at risk of type 2 diabetes in a predominantly Mexican-American population, BMJ Nutr Prev Health 3 (2020) 239–246, https://doi.org/10.1136/BMJNPH-2020-000133.

[12] H. Bang, A.M. Edwards, A.S. Bomback, C.M. Ballantyne, D. Brillon, M.A. Callahan, S.M. Teutsch, A.I. Mushlin, L.M. Kern, A patient self-assessment diabetes screening score: development, validation, and comparison to other diabetes risk assessment scores, Ann. Intern. Med. 151 (2009) 775–783, https://doi.org/10.1059/0003-4819-151-11-200912010-00005.

[13] U.S. Department, Of Agriculture, 2015-2020 Dietary Guidelines for Americans, 2015. http://health.gov/dietaryguidelines/2015/guidelines/. (Accessed 5 October 2022).

[14] T.D. Riddlesworth, R.W. Beck, R.L. Gal, C.G. Connor, R.M. Bergenstal, S. Lee, S.M. Willi, Optimal sampling duration for continuous glucose monitoring to determine long-term glycemic control, Diabetes Technol. Therapeut. 20 (2018) 314–316, https://doi.org/10.1089/DIA.2017.0455.

[15] I.B. Hirsch, T. Battelino, A.L. Peters, J.J. Chamberlain, G. Aleppo, R.M. Bergenstal, Role of Continuous Glucose Monitoring in Diabetes Treatment, 2018, https://doi.org/10.2337/db20181. Arlington. (Accessed 22 September 2022).

[16] J.P. Curley, T.M. Milewski, Permutation testing, in: PSY317L & PSY120R Guidebook (2021). https://bookdown.org/content/50286a34-7e39-4500-8dd2-62bf686c1710/. (Accessed 14 September 2022).

[17] American Diabetes Association, 2, Classification and diagnosis of diabetes: standards of medical Care in diabetes—2021, Diabetes Care 44 (2021), https://doi.org/10.2337/DC21-S002. S15–S33.

[18] American College of Cardiology, Guideline for the Prevention, Detection, Evaluation, and Management of High Blood Pressure in Adults, 2017, 2017, https://doi.org/10.1016/j.jacc.2017.07.745.

[19] S.D. Mills, V.L. Malcarne, R.S. Fox, G.R. Sadler, Psychometric evaluation of the brief acculturation scale for hispanics, Hisp. J. Behav. Sci. 36 (2014) 164–174, https://doi.org/10.1177/0739986314526697.

[20] USDA, U.S, Household Food Security Survey Module, 2012. https://www.ers.usda.gov/media/8271/hh2012.pdf. (Accessed 22 September 2022).

[21] J.D. Henry, J.R. Crawford, The short-form version of the Depression Anxiety Stress Scales (DASS-21): construct validity and normative data in a large non-clinical sample, Br. J. Clin. Psychol. 44 (2005) 227–239, https://doi.org/10.1348/014466505X29657.

[22] M.P. Rabbitt, M.D. Smith, A. Coleman-Jensen, Food Security Among Hispanic Adults in the United States, 2011-2014, 2016. www.ers.usda.gov/publications/eib-economic-information-bulletin/eib-153. (Accessed 5 October 2022).

[23] A. Afshin, P. John Sur, K.A. Fay, L. Cornaby, G. Ferrara, J.S. Salama, E.C. Mullany, K. Hassen Abate, C. Abbafati, Z. Abebe, M. Afarideh, A. Aggarwal, S. Agrawal, T. Akinyemiju, F. Alahdab, U. Bacha, V.F. Bachman, H. Badali, A. Badawi, I.M. Bensenor, E. Bernabe, S.K. Kassa Biadgilign, S.H. Biryukov, L.E. Cahill, J. J. Carrero, K.M. Cercy, L. Dandona, R. Dandona, A. Kim Dang, M. Girma Degefa, M. El Sayed Zaki, A. Esteghamati, S. Esteghamati, J. Fanzo, C. Sofia Sã, M. S. Farvid, F. Farzadfar, V.L. Feigin, J.C. Fernandes, L. Sorio Flor, N.A. Foigt, M.H. Forouzanfar, M. Ganji, J.M. Geleijnse, R.F. Gillum, A.C. Goulart, G. Grosso, I. Guessous, S. Hamidi, G.J. Hankey, S. Harikrishnan, H. Yimam Hassen, S.I. Hay, C. Linh Hoang, M. Horino, F. Islami, M.D. Jackson, S.L. James, L. Johansson, J. B. Jonas, A. Kasaeian, Y. Saleh Khader, I.A. Khalil, Y.-H. Khang, R.W. Kimokoti, Y. Kokubo, G. Anil Kumar, T. Lallukka, A.D. Lopez, S. Lorkowski, P.A. Lotufo, R. Lozano, R. Malekzadeh, W. Mã, T. Meier, Y.A. Melaku, W. Mendoza, G.B. Mensink, R. Micha, T.R. Miller, M. Mirarefin, V. Mohan, A.H. Mokdad, D. Mozaffarian, G. Nagel, M. Naghavi, C. Tat Nguyen, M.R. Nixon, K.L. Ong, D.M. Pereira, H. Poustchi, M. Qorbani, R. Kumar Rai, C. Razo-GarcÃ, C.D. Rehm, J. A. Rivera, S. RodrÃ, G. Roshandel, G.A. Roth, J. Sanabria, T.G. Sã, B. Sartorius, J. Schmidhuber, A. Elisabeth Schutte, S.G. Sepanlou, M.-J. Shin, R.J. Sorensen, M. Springmann, L. Szponar, A.L. Thorne-Lyman, A.G. Thrift, M. Touvier, B. Xuan Tran, S. Tyrovolas, K. Nnanna Ukwaja, I. Ullah, M. Vaezghasemi, T. Juhani Vasankar, S. Emil Vollset, T. Vos, G. Thu Vu, L. Gia Vu, E. Weiderpass, A. Werdecker, T. Wijeratne, W.C. Willett, J.H. Wu, G. Xu, N. Yonemoto, C. Yu, C.J. L Murray, D. Collaborators, Health effects of dietary risks in 195 countries, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017, The Lancet 393 (2019) 1958–1972, https://doi.org/10.1016/S0140-6736(19)30041-8.

[24] S. Downer, S.A. Berkowitz, T.S. Harlan, D.L. Olstad, D. Mozaffarian, Food is medicine: actions to integrate food and nutrition into healthcare, BMJ 369 (2020), https://doi.org/10.1136/bmj.m2482.

[25] R. Bryce, C. Guajardo, D. Ilarraza, N. Milgrom, D. Pike, K. Savoie, F. Valbuena, L.R. Miller-Matero, Participation in a farmers' market fruit and vegetable prescription program at a federally qualified health center improves hemoglobin A1C in low income uncontrolled diabetics, Prev Med Rep 7 (2017) 176–179, https://doi.org/10.1016/J.PMEDR.2017.06.006.

[26] I. Spronk, C. Kullen, C. Burdon, H. O'Connor, Relationship between nutrition knowledge and dietary intake, Br. J. Nutr. 111 (2014) 1713–1726, https://doi.org/10.1017/S0007114514000087.

[27] K. Hager, D. Mozaffarian, The promise and uncertainty of fruit and vegetable prescriptions in health Care, J. Nutr. 150 (2020) 2846–2848, https://doi.org/10.1093/JN/NXAA283.

[28] S. Vijan, N.S. Stuart, J.T. Fitzgerald, D.L. Ronis, R.A. Hayward, S. Slater, T.P. Hofer, Barriers to following dietary recommendations in Type 2 diabetes, Diabet. Med. 22 (2005) 32–38, https://doi.org/10.1111/J.1464-5491.2004.01342.X.

[29] L. McMorrow, A. Ludbrook, J.I. Macdiarmid, D. Olajide, Perceived barriers towards healthy eating and their association with fruit and vegetable consumption, Journal of Public Health (United Kingdom) 39 (2017) 330–338, https://doi.org/10.1093/PUBMED/FDW038.

[30] C.M. Devine, J. Sobal, C.A. Bisogni, M. Connors, Food choices in three ethnic groups: interactions of ideals, identities, and roles, J. Nutr. Educ. 31 (1999) 86–93, https://doi.org/10.1016/S0022-3182(99)70400-0.

[31] G.X. Ayala, B. Baquero, S. Klinger, A systematic review of the relationship between acculturation and diet among Latinos in the United States: implications for future research, J. Am. Diet Assoc. 108 (2008) 1330–1344, https://doi.org/10.1016/J.JADA.2008.05.009.

[32] S. Barua, A. Sabharwal, N. Glantz, C. Conneely, A. Larez, W. Bevier, D. Kerr, Dysglycemia in adults at risk for or living with non-insulin treated type 2 diabetes: insights from continuous glucose monitoring, EClinicalMedicine 35 (2021), https://doi.org/10.1016/J.ECLINM.2021.100853.

[33] S. Barua, A. Sabharwal, N. Glantz, C. Conneely, A. Larez, W. Bevier, D. Kerr, The northeast glucose drift: stratification of post-breakfast dysglycemia among predominantly Hispanic/Latino adults at-risk or with type 2 diabetes, EClinicalMedicine 43 (2022), 101241, https://doi.org/10.1016/j.

[34] R.W. Beck, R.M. Bergenstal, P. Cheng, C. Kollman, A.L. Carlson, M.L. Johnson, D. Rodbard, The relationships between time in range, hyperglycemia metrics, and HbA1c, J. Diabetes Sci. Technol. 13 (2019) 614, https://doi.org/10.1177/1932296818822496.

[35] Y. Xu, R.M. Bergenstal, T.C. Dunn, Y. Ram, R.A. Ajjan, Interindividual variability in average glucose-glycated haemoglobin relationship in type 1 diabetes and implications for clinical practice, Diabetes Obes. Metabol. 24 (2022) 1779–1787, https://doi.org/10.1111/DOM.14763.

[36] M.P. St-Onge, T. Pizinger, K. Kovtun, A. RoyChoudhury, Sleep and meal timing influence food intake and its hormonal regulation in healthy adults with overweight/obesity, Eur. J. Clin. Nutr. 72 (2018) 76–82, https://doi.org/10.1038/s41430-018-0312-x, 1. 72 (2018).

[37] D. Kerr, M. Abbasi, W. Bevier, N. Glantz, A. Larez, A. Sabharwal, Patterns of timing and intensity of physical activity and HbA1c levels in hispanic/latino adults with or at risk of type 2 diabetes, J. Diabetes Sci. Technol. 0 (2022), https://doi.org/10.1177/19322968221105531.