American Journal of
Preventive Medicine

RESEARCH ARTICLE

# Elevated Dietary Inflammation Among Supplemental Nutrition Assistance Program Recipients Provides Targets for Precision Public Health Intervention

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**Introduction:** The Supplemental Nutrition Assistance Program was designed to prevent food insecurity among low-income Americans and has been linked to improvements in pregnancy health, long-term child development, and criminal recidivism. However, the pursuit of food security does not ensure nutritional sufficiency, and the program has not improved diet quality or cardiometabolic mortality (i.e., heart disease, stroke, diabetes). In this study, longitudinal cohort data are used to identify by Supplemental Nutrition Assistance Program status the proinflammatory characteristics that predispose to chronic disease.

**Methods:** Between 2015 and 2018, annual 24-hour dietary recalls were conducted with 409 residents from low-income, urban neighborhoods in Columbus and Cleveland, Ohio (statistical analysis started in 2019). The Dietary Inflammatory Index was calculated. It provides empirically validated estimates of the internal inflammation that each diet should produce; higher Dietary Inflammatory Index scores have been associated with elevated inflammatory biomarkers. Finally, associations between Supplemental Nutrition Assistance Program and Dietary Inflammatory Index were evaluated, and dietary components that differed by Supplemental Nutrition Assistance Program status were identified.

**Results:** Supplemental Nutrition Assistance Program recipients had higher Dietary Inflammatory Index scores (+0.40, 95% CI=0.09, 0.70) and a consistently lower intake of 4 anti-inflammatory nutrients (dietary fiber, $\beta$-carotene, magnesium, vitamin E) than nonrecipients. Vitamin D intake did not differ by Supplemental Nutrition Assistance Program status but was well below the Recommended Daily Allowance in this sample.

**Conclusions:** Supplemental Nutrition Assistance Program recipients had elevated Dietary Inflammatory Index scores, implying higher diet-driven inflammation. This was due, in part, to low intake of 4 anti-inflammatory food components, which were higher yet still nutritionally insufficient among nonrecipients. Findings highlight specific nutritional targets for improving public health through dietary change.
*Am J Prev Med 2021;61(2):192−200.* 

## INTRODUCTION

In January 2020, >37 million Americans received Supplemental Nutrition Assistance Program (SNAP) benefits,[1] with rates expected to increase dramatically owing to the coronavirus disease 2019 (COVID-19) pandemic. SNAP is a government assistance program designed to reduce food insecurity in low-income households. Although the net health effect of SNAP is hard to characterize, let alone quantify,[2,3] it is associated with some important positive outcomes

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0749-3797/$36.00
https://doi.org/10.1016/j.amepre.2021.02.007

related to pregnancy, child development,[4,5] and criminal recidivism.[6] However, SNAP is linked to negative outcomes such as unhealthy diets[7] and cardiometabolic diseases.[8] These findings highlight the need to promote both food security and nutrition quality through SNAP.

A *precision public health approach*, defined as "providing the right intervention to the right population at the right time,"[9] could allow for the development of targeted improvements to SNAP to lessen the nutritional gaps that increase the risk of chronic disease. This requires the use of nutritional measures that are known to affect disease risk and must therefore go beyond food group assessments such as the Healthy Eating Index.[10] The Healthy Eating Index provides an estimate of general diet quality by characterizing broad categories such as fruit and vegetable intake, but it lacks the physiologic underpinning to guide SNAP redesign. By contrast, the Dietary Inflammatory Index (DII) is a metric that aggregates information from multiple food components to rank diets in terms of capacity to alter inflammatory biomarkers (IL-1$\beta$, IL-4, IL-6, IL-10, tumor necrosis factor-$\alpha$, and C-reactive protein).[11] Diets with higher DII scores are associated with higher levels of these serum inflammatory mediators,[11−13] and thus this metric provides a physiologically based estimate of inflammation driven by an individual's diet. Importantly, the validity of this metric is corroborated by the existence of multiple published associations between elevated DII scores and inflammation-related noncommunicable diseases, including cardiovascular disease, colorectal cancer, prostate cancer, neurocognitive decline, and depression.[14] Furthermore, low-income minority communities are experiencing greater burdens of inflammation-related disease,[15−17] and there is strong motivation to determine the modifiable dietary causes of excess inflammation in these settings.

In this study, longitudinal cohort data from low-income urban settings are used to evaluate whether SNAP recipients have higher DII scores and, if so, to identify the nutrients that are responsible for these differences. In contrast to traditional risk factor epidemiology, this precision public health approach[9] does not interrogate SNAP as a potential cause but rather seeks to characterize a subpopulation at risk and thereby promote the development of targeted interventions. The identification of anti-inflammatory nutrient deficiencies among SNAP recipients could provide precise targets for improving SNAP policy and reducing health inequities.

# METHODS

## Study Population

Participants were enrolled in a prospective cohort study designed to evaluate dietary patterns among residents living in 2 low-income urban neighborhoods that have limited access to stores selling fresh and healthy foods.[18] Data were collected at 3 timepoints: baseline (2015−2016), 12 months (2016−2017), and 24 months (2017−2018). The study neighborhoods represent 11 census tracts in Cleveland (7) and Columbus (4), Ohio, with a combined population of >18,000, of which more than two thirds are African American, and about 40% receive SNAP benefits.[19]

Eligibility criteria at enrollment included living in targeted neighborhoods (primarily low-income census tracts with low supermarket access), planning to live in the current neighborhood for ≥12 months, being aged ≥18 years, being an English speaker, and being responsible for ≥50% of household food shopping. These criteria were chosen because this study was an ancillary part of broader effort[18] and because there was a goal of enrolling individuals who represented typical shoppers for each household. Of the 1,395 initially screened residents, 655 (47%) were eligible, and 516 (79%) of these residents were enrolled in the study (Appendix Figure 1, available online). The most common reason for ineligibility was not living in the targeted neighborhoods. Participants provided either written or verbal informed consent, and the analysis was limited to 409 participants with data for ≥2 of the 3 years.

The study protocol was reviewed and approved by the Case Western Reserve University IRB. The data were collected through phone surveys and retail store observations as described in the Appendix (available online).

## Measures

Dietary recalls were assessed using the Nutrition Data System for Research (University of Minnesota, Minneapolis, MN), a rigorous research instrument for dietary assessment.[20] Daily intake estimates were based on the average of 2−3 dietary recalls conducted annually during the same seasonally matched 37-day window (Appendix, available online, shows the data collection details).[18] Intake levels for 31 dietary components, shown in Appendix Table 1 (available online), were obtained from the Nutrition Data System for Research and were used to calculate the DII.[11] This metric is designed to reflect the relative level of internal inflammation caused by dietary exposures.[11] Briefly, intakes of the 31 dietary components were multiplied by empirically derived coefficients to determine the relative level of physiologic inflammation that each will produce.[11] The process of obtaining coefficients has been previously described,[11] but in short, they represent the integration of information from almost 2,000 studies. Articles linking a given dietary component to elevated IL-1$\beta$, IL-4, IL-6, IL-10, tumor necrosis factor-$\alpha$, or C-reactive protein result in an increase in the DII coefficient for that dietary component.[11] The 31 inflammation effects, 1 for each dietary component, were then summed to generate a physiologically validated estimate of the net inflammation that the participant's reported diet should produce. Lower DII scores represent lower inflammation and lower risk of inflammation-associated chronic diseases.[14]

$$DII = \sum_{j=1}^{N} Dietary\ Component_j \times Inflammatory\ Coefficient_j \quad (1)$$

where $j$ indexes $N$ dietary components.

Self-reported SNAP status was assessed in each of the 3 years with the following question: *In the last 12 months, did you or anyone who lives in your house receive SNAP or Food Stamp benefits?* This allowed for the evaluation of (1) the associations between current SNAP use and DII and (2) the differences between consistent and occasional SNAP use. The data needed to determine SNAP eligibility were not available, so no comparisons could be made between recipients and eligible nonrecipients. This comparison would be important for an analysis that aimed to assess the causal effects of the program (i.e., a traditional risk factor epidemiology approach). However, this analysis did not have this aim. Instead, it sought to identify and characterize a subpopulation at risk (i.e., a precision public health approach).

Covariates of 3 primary types were considered: food shopping environment, dietary beliefs, and demographics (details are presented in the Appendix, available online). The variables were chosen because there was a priori reason to believe that they could have an independent effect on diet quality and thus dietary-driven inflammation.

### Statistical Analysis

Descriptive statistics were obtained across 3 categories of SNAP status: consistent recipients (3 of 3 years), occasional recipients (1 or 2 of 3 years), and nonrecipients (0 of 3 years). Differences in the distribution of categorical and continuous variables across SNAP status were tested using chi-square and Kruskal−Wallis tests, respectively. Covariates that demonstrated associations ($p<0.05$) with exposure (SNAP status) were considered as potential confounders in the subsequent analyses.

Multivariable-adjusted mixed-effect regression models with a random intercept for participants were used to estimate the association between current SNAP status and DII. This approach was chosen because standard regression models are not appropriate in this context because they overestimate precision and increase the risk of Type 1 error (false positives) by failing to account for clustering.[21,22] Mixed effect regression models allowed for the inclusion of all observations while accounting for the underlying correlation structure (3 measurements per person).[23] This approach also allowed for the assessment of current SNAP use among occasional SNAP recipients. In this subset of occasional SNAP recipients, the SNAP−DII associations are less prone to confounding from stable but unmeasured personal characteristics that could independently increase the risk of both chronic poor diet and long-term SNAP use.

To examine the nutrients that might be drivers of the DII differences between the current SNAP recipients and the current nonrecipients, Wilcoxon−Mann−Whitney tests were conducted in the baseline data (Year 1). For nutrients that differed by SNAP status at $p<0.05$, these differences were then tested in Years 2 and 3. This strategy was chosen because requiring both multiple-testing correction and replication on follow-up unnecessarily generates inflated Type 2 error rates (false negatives).[24] Models were built using R, version 3.6.3, and the descriptive epidemiology analyses were conducted in SAS, version 9.4.

## RESULTS

At baseline, the study comprised 409 participants, 76% were female, 67% were Black, and 83% had annual incomes <$30,000 (Table 1).[10,25] The median age was 53 years. There were 204 consistent SNAP recipients, 99 occasional SNAP recipients, and 106 nonrecipients. Several covariates differed significantly by SNAP status, including age, race, education level, income, having a car for shopping, healthy food availability scores, effort to eat fresh and healthy foods, worry about having enough money to buy nutritious meals, and DII scores.

In the mixed effect models (Table 2), age, race, education level, income, having a car for shopping, and making a conscious effort to eat a fresh and healthy diet were significantly associated with DII scores. All of these variables except income, and having a car remained significantly associated with DII in the multivariable-adjusted model. Increasing age, White race, higher education level, and making a greater effort to eat a fresh and healthy diet were significantly associated with lower DII scores (Table 2). Current SNAP use was associated with a DII score increase of 0.50 (95% CI=0.26, 0.74), and this association remained significant in the multivariable-adjusted model (0.40, 95% CI=0.09, 0.70). When sex was added to the multivariable-adjusted model, the SNAP−DII association was essentially unchanged: 0.39 (95% CI=0.08, 0.69). The association did not differ significantly by sex ($p$=0.23 for a sex x SNAP interaction term added to the model), but when stratified by sex, the SNAP−DII association was more prominent among the male participants (0.86, 95% CI=0.28, 1.44 vs 0.23, 95% CI= −0.13, 0.59). The relationship between SNAP and DII was not evident among the 99 participants with occasional use (0.11, 95% CI= −0.32, 0.55). In the occasional SNAP use subset, individuals were compared with themselves when their SNAP status changed. However, the observed relationship between SNAP and DII was stronger among the 310 participants with stable SNAP status (0.61, 95% CI=0.17, 1.04). In this subset, consistent recipients were compared with consistent nonrecipients, and there were no within-person comparisons.

When each of the study years was analyzed separately, 4 dietary components were consistently and significantly lower among current SNAP recipients: total dietary fiber, $\beta$-carotene, magnesium, and vitamin E (Table 3).[26] Intake of total dietary fiber, magnesium, vitamin E, and vitamin D was far below their Dietary Reference Intakes among both SNAP recipients and nonrecipients (Table 3).[26]

## DISCUSSION

In this longitudinal cohort data from low-income urban neighborhoods, SNAP recipients had higher DII scores, a metric that is associated with increased risk of several chronic diseases. Mixed models were used to identify

**Table 1.** Baseline Characteristics of the Study Population by SNAP Status

| Variables | All participants[a] (N=409) | Consistent SNAP recipients (*n*=204) | Occasional SNAP recipients (*n*=99) | Nonrecipients (*n*=106) | *p*-value[b] |
|---|---|---|---|---|---|
| Demographic characteristics | | | | | |
| Sex (female), *n* (%) | 311 (76.0) | 163 (79.9) | 69 (69.7) | 79 (74.5) | 0.136 |
| Age, median (IQR) | 53 (43–60) | 52 (41–58) | 51 (41–59) | 56 (46–63) | **0.005**[c] |
| Race, *n* (%) | | | | | **<0.001** |
| Black | 274 (67.0) | 149 (73.0) | 79 (79.8) | 46 (43.4) | |
| White | 106 (25.9) | 17 (8.3) | 6 (6.1) | 6 (5.7) | |
| Other | 29 (7.1) | 38 (18.6) | 14 (14.1) | 54 (50.9) | |
| Education, *n* (%) | | | | | **<0.001** |
| High school or less | 251 (61.5) | 147 (72.4) | 56 (56.6) | 48 (45.3) | |
| Some college | 107 (26.2) | 49 (24.1) | 35 (35.4) | 23 (21.7) | |
| College graduate or more | 50 (12.3) | 7 (3.5) | 8 (8.1) | 35 (33.0) | |
| Income, *n* (%) | | | | | **<0.001** |
| ≤$10,000 | 143 (35.4) | 99 (48.8) | 35 (36.1) | 9 (8.7) | |
| $10,001–$20,000 | 132 (32.7) | 73 (36.0) | 31 (32.0) | 28 (26.9) | |
| $20,001–$30,000 | 65 (16.1) | 23 (11.3) | 19 (19.6) | 23 (22.1) | |
| ≥$30,001 | 64 (15.8) | 8 (3.9) | 12 (12.4) | 44 (42.3) | |
| Shopping and food environment | | | | | |
| Use a personal car for food shopping, *n* (%) | 223 (54.5) | 86 (42.2) | 50 (50.5) | 87 (82.1) | **<0.001** |
| Most or all food shopping done in the neighborhood, *n* (%) | 232 (56.7) | 118 (57.8) | 62 (62.6) | 52 (49.1) | 0.132 |
| Healthy food availability score, median (IQR), range: 0–15 | 7.6 (6.0–9.3) | 7.5 (6.0–9.1) | 7.2 (5.4–8.8) | 7.7 (6.9–10.0) | **0.012**[c] |
| Dietary beliefs and behaviors | | | | | |
| Make a conscious effort to try and eat a fresh and healthy diet quite often or most of the time, *n* (%) | 265 (64.8) | 119 (58.3) | 63 (63.6) | 83 (78.3) | **0.002** |
| Usually or always worried about having enough money to buy nutritious meals, *n* (%) | 98 (24.0) | 54 (26.5) | 29 (29.3) | 15 (14.2) | **0.020** |
| Healthy eating identity,[d] median (IQR), range: 1–4 | 3.00 (2.33–3.67) | 3.00 (2.33–3.67) | 3.00 (2.50–3.67) | 3.00 (2.75–3.67) | 0.058[c] |
| Total daily energy intake in kcal, median (IQR) | 1,722 (1,311–2,233) | 1,665 (1,327–2,071) | 1,878 (1,347–2,443) | 1,646 (1,270–2,137) | 0.089[c] |
| Diet-driven inflammation | | | | | |
| DII, median (IQR) | −0.05 (−2.12–2.17) | 0.64 (−1.71–2.42) | −0.05 (−2.00–1.98) | −1.11 (−2.69–1.36) | **0.005**[c] |

*Note:* Boldface indicates statistical significance ($p<0.05$).
[a]Data from the first year of data collection (2015).
[b]Test for the difference by SNAP status; chi-square test (unless otherwise noted) comparing consistent, occasional, and nonrecipients of SNAP.
[c]Kruskal–Wallis test comparing consistent, occasional, and nonrecipients of SNAP.
[d]This Likert scale score is high if the person identifies as a healthy eater.[25] Its calculation is described in the Appendix (available online), but please note that it is distinct from the Healthy Eating Index.[10]
DII, Dietary Inflammatory Index; kcal, kilocalorie; SNAP, Supplemental Nutrition Assistance Program.

this association and to determine that it was less evident among occasional SNAP recipients. Intake of 4 anti-inflammatory nutrients was significantly lower among SNAP recipients in all the 3 years of the study (i.e., total dietary fiber, $\beta$-carotene, magnesium, and vitamin E). Three of these nutrients have Dietary Reference Intake standards[26] (i.e., total dietary fiber, magnesium, vitamin E), and the intakes among the sample population were far below these recommendations, even among the nonrecipients of SNAP. Finally, although vitamin D intake did not differ by SNAP status, intake among both SNAP recipients and nonrecipients was well below the Recommended Daily Allowance.

Receiving SNAP has been associated with poor Healthy Eating Index scores.[10] Although this metric reflects general standards of healthy diets, it is not a physiologically based measure directly linked to health outcomes. By contrast, DII is linked to disease risk.[14]

**Table 2.** Associations With DII From the Mixed Model Analyses

| Variables | Estimate $\beta$ (95% CI)[a] | Adjusted estimate $\beta$ (95% CI)[b] |
|---|---|---|
| Exposure of interest | | |
| Current SNAP use (received SNAP this year)[c] | **0.50 (0.26, 0.74)** | **0.40 (0.09, 0.70)** |
| Covariates | | |
| Age, years | **−0.020 (−0.031, −0.009)** | **−0.016 (−0.027, −0.005)** |
| Race[d] | | |
| White | **−0.92 (−1.25, −0.58)** | **−0.58 (−0.92, −0.24)** |
| Other | −0.07 (−0.65, 0.50) | 0.00 (−0.56, 0.56) |
| Education[e] | **−0.42 (−0.60, −0.23)** | **−0.34 (−0.55, −0.13)** |
| Income[f] | **−0.19 (−0.30, −0.08)** | −0.05 (−0.19, 0.10) |
| Personal car to use for shopping | **−0.41 (−0.68, −0.14)** | −0.16 (−0.44, 0.11) |
| Make a conscious effort to eat a fresh and healthy diet[g] | **−0.69 (−0.91, −0.47)** | **−0.24 (−0.36, −0.12)** |
| Healthy food availability score | −0.03 (−0.08, 0.01) | NA[h] |
| Worry about having enough money to buy nutritious meals[g] | −0.001 (−0.004, 0.002) | NA[h] |

*Note:* Boldface indicates statistical significance ($p<0.05$). One participant had a reported total daily energy intake of 24,000 kcal (>20 IQRs above the median). This participant remained in the analytic data set, but the 1 year of data were excluded from the mixed models. A random intercept was used for each of the 409 participants to account for clustering in the data set (3 values per person, 1 for each year), and the fixed effects are presented.
[a]All models included an independent term for total daily energy intake to estimate the associations with energy-adjusted DII.
[b]The adjusted model included independent terms for total daily energy intake and all the covariates with betas displayed.
[c]The reference is not receiving SNAP, and the $\beta$ estimates the change in DII associated with utilizing SNAP.
[d]ref=Black race.
[e]Three level ordinal scale: 1=High school or less, 2=Some college, 3=College graduate or more.
[f]Four level ordinal scale: 1=<\$10,000, 2=\$10,001–\$20,000, 3=\$20,001–\$30,000, 4= ≥\$30,001.
[g]Likert scale: 1–5, higher=more often.
[h]These variables were not associated with outcome and were not included in the adjusted model.
DII, Dietary Inflammatory Index; kcal, kilocalorie; NA, not applicable; SNAP, Supplemental Nutrition Assistance Program.

This is the first study, to the authors' knowledge, that examined SNAP and DII, and it can offer targeted insights about nutrients that exacerbate inflammation-mediated disease in low-income urban settings. This is important because chronic inflammatory pathologies are highly prevalent among SNAP recipients[8] and low-income urban settings in general.[27] Although these models were not designed to evaluate SNAP as a cause of inflammation, they indicate that SNAP and DII were not significantly associated among occasional SNAP recipients. In this analysis, each participant served as their own control, and thus this finding is consistent with the interpretation that the program itself is not driving dietary changes that promote inflammation. Instead, it indicates opportunities for improving health (and hence the program) among people requiring longer use of SNAP.

By identifying population-specific nutrient gaps that are known to cause inflammation, population-level interventions can be developed to address these deficits and reduce disease. For example, foods that are high in total dietary fiber, $\beta$-carotene, magnesium, and vitamin E, such as almonds, black beans, spinach, and sweet potatoes,[28] could be incentivized to address the observed deficiencies. Importantly, this approach could be implemented within existing structures such as the Gus Schumacher Nutrition Incentive Program,[29] and its network of grantees could be leveraged to conduct trials targeting specific nutrients for improvement.[30] Stocking standards for food stores accepting SNAP[31] and Medicaid-based food prescriptions[32] for SNAP recipients may also be viable policy options. Because 66% of Medicaid recipients and 12% of Medicare recipients are also on SNAP,[30] any dietary improvement through SNAP policy may result in less government spending on health care. Emerging evidence indicates that even nonspecific incentives to increase fruit and vegetable intake through SNAP could reduce healthcare safety net spending.[30] A DII-informed approach may generate even greater health and fiscal benefits through targeted incentives.

Finally, these findings raise hypotheses for reducing disparities in inflammatory and immune pathologies. Low-income populations are experiencing disproportional burdens of COVID-19,[33,34] and although there are many factors contributing to this pattern, nutritional status may play a large role in determining immunocompetency in the setting of viral infection.[35] Furthermore, emerging evidence indicates that severe COVID-19 involves inflammatory disruptions,[36] and low-income minority communities are experiencing greater burdens of both inflammation-associated chronic disease and COVID-19.[15,16,37] Study findings indicate that people receiving SNAP may be at

**Table 3.** Dietary Components That Differ Between SNAP Recipients and Nonrecipients at Baseline

| Dietary components of the DII | Dietary reference intakes[a] | SNAP recipients n=272, Median (IQR) | Nonrecipients n=136, Median (IQR) | p-value[b] for the difference by SNAP status |
|---|---|---|---|---|
| Anti-inflammatory | | | | |
| Fiber (g)[c] | 25[d] | 11.9 (8.8–6.4) | 16.1 (10.7–21.8) | **<0.0001** |
| β-Carotene (μg)[c] | — | 921 (350–2,420) | 2,180 (655–5,270) | **<0.0001** |
| Green/black tea (g) | — | NA | 6.0 (6.0–6.0) | NA |
| Magnesium (mg)[d] | 320 | 210 (156–262) | 248 (176–310) | **0.0006** |
| Ginger (g) | — | 0.7 (0.4–1.0) | 0.3 (0.3–1.3) | 0.3045 |
| Vitamin D (μg) | 15 | 3.5 (2.3–5.8) | 3.2 (2.1–5.6) | 0.3350 |
| Omega-3 PUFA (g)[e] | — | 1.4 (0.9–2.0) | 1.6 (1.0–2.3) | **0.0497** |
| Vitamin C (mg)[f] | 75 | 53 (32–97) | 84 (37–125) | **0.0008** |
| Vitamin E (mg)[c] | 15 | 5.9 (4.3–8.6) | 7.7 (5.0–10.0) | **0.0031** |
| Vitamin A (RE) | 700 | 455 (284–720) | 526 (319–827) | 0.1201 |
| Vitamin B6 (mg) | 1.3 | 1.5 (1.1–1.9) | 1.5 (1.1–2.0) | 0.7021 |
| Total PUFA (g) | — | 15.1 (10.7–22.7) | 15.8 (11.4–24.2) | 0.5246 |
| Zn (mg) | 8 | 9.0 (6.7–11.7) | 8.5 (5.9–11.1) | 0.2812 |
| Onion (g) | — | 17.2 (8.7–30.5) | 18.9 (10.5–31.5) | 0.2108 |
| Alcohol (g)[f] | — | 0.00 (0.00–0.09) | 0.03 (0.00–0.32) | **0.0143** |
| Niacin (mg) | 14 | 34.0 (24.9–43.1) | 33.5 (24.4–43.2) | 0.6265 |
| Se (μg) | 55 | 103 (80–133) | 99 (72–135) | 0.3140 |
| Folic acid (μg) | 400 | 386 (282–541) | 412 (305–576) | 0.3328 |
| Caffeine (g)[c] | — | 5.4 (1.0–12.5) | 7.7 (1.9–18.0) | **0.0171** |
| Thyme (mg) | — | 0.21 (0.12–0.34) | 0.21 (0.17–0.36) | 0.6707 |
| Thiamin (mg) | 1.1 | 1.4 (1.1–1.9) | 1.4 (1.0–2.0) | 0.8853 |
| Riboflavin (mg) | 1.1 | 1.5 (1.2–2.1) | 1.6 (1.2–2.1) | 0.5104 |
| MUFA (g) | — | 24.5 (17.3–32.1) | 24.9 (16.6–34.6) | 0.8249 |
| Proinflammatory | | | | |
| Protein (g) | 46 | 70 (54–88) | 69 (51–93) | 0.4477 |
| Fe (mg) | 18 | 11.0 (8.6–14.9) | 11.9 (8.4–15.6) | 0.4288 |
| Carbohydrate (g) | 130 | 199 (154–250) | 200 (142–281) | 0.7767 |
| Vitamin B12 (μg)[e] | 2.4 | 3.5 (2.4–5.2) | 3.1 (2.1–4.8) | **0.0292** |
| Cholesterol (mg)[f] | — | 300 (195–434) | 218 (137–359) | **0.0001** |
| Trans fat (g) | — | 2.0 (1.2–3.1) | 1.8 (1.2–3.0) | 0.4582 |
| Total fat (g) | — | 70 (52–91) | 69 (50–95) | 0.9499 |
| Saturated fat (g) | — | 23.9 (16.6–30.5) | 23.3 (14.6–29.9) | 0.3928 |

*Note:* Boldface indicates statistical significance ($p<0.05$). From the first year of the study (2015–2016), nutrients are listed from smallest to largest inflammatory potential.
[a]For a female aged 31–50 years (Recommended Daily Allowance unless otherwise noted).
[b]*p*-Values from Wilcoxon–Mann–Whitney test comparing SNAP and non-SNAP recipients.
[c]Differences replicate in both follow-up years.
[d]Adequate intake value—no Recommended Daily Allowance was available.[26]
[e]Differences do not replicate in either follow-up years.
[f]Differences replicate in at least 1 of the follow-up years.
DII, Dietary Inflammatory Index; Fe, iron; MUFA, monounsaturated fatty acid; NA, not applicable; PUFA, polyunsaturated fatty acid; RE, retinol equivalent; Se, selenium; SNAP, Supplemental Nutrition Assistance Program; Zn, zinc.

increased risk of being in a proinflammatory state owing to diet, thereby potentially making their response to COVID-19 more severe. In addition, each of the nutrient deficiencies identified in this study, including vitamin D, which was insufficient among the full study population, is independently linked to the prevention of inflammation-driven chronic disease and the support of immune responses to viral infections.[35,38–46] Thus, chronic disease and COVID-19 disparities seen in low-income minority communities[15,16,37] may both be driven, in part, by modifiable nutritional deficiencies. This offers further support for leveraging SNAP policy to boost nutritional defense mechanisms.

This is the first study, to the authors' knowledge, that assessed SNAP with a physiologically based nutritional metric (DII). In addition, this analysis demonstrated that the association between SNAP receipt and elevated DII was not explained by confounding from age, race, education level, income, use of personal car for shopping, or self-assessed effort to eat healthily. In other words, the association with SNAP remained significant in the multivariable-adjusted model. Importantly, specific dietary components were identified that could be targeted for interventions among SNAP recipients. Finally, 3 non-nutrient factors were associated with DII scores in the fully adjusted model: education level, effort to eat a healthy diet, and race. The first 2 of these are modifiable, and although the socially defined category of race is not modifiable, the experience of race may be modulated.[47] Further work is needed, but these factors present immediate opportunities to test tailored interventions for SNAP recipients both at community and individual levels, such as stocking standards for food stores in communities with high SNAP participation, SNAP-based incentives for specific anti-inflammatory foods, SNAP status screening and anti-inflammatory food prescriptions in clinical settings, as well as education and training opportunities for low-income communities.

### Limitations

Data on the amount of SNAP money participants were receiving were not available, and it is possible that these patterns may vary by the amount of SNAP support received. The data needed to determine SNAP eligibility also were not available, so recipients could not be compared with eligible nonrecipients. However, any potential bias due to financial capacity was lessened by adjusting for personal income. In this study population, the total daily median energy intake was 1,722 kilocalories, and it is possible that participants under-reported their intakes. However, this study utilized the best available dietary assessment (repeated 24-hour recall), and this potential under-reporting would only affect the conclusions if it differed by SNAP status. Energy intake did not differ by SNAP status, and there was no evidence of differential under-reporting. Overall, it must be emphasized that these weaknesses would temper any causal conclusions about SNAP. However, this study refrained from addressing SNAP as causal. It was analyzed only as a dichotomous marker of the subpopulation of interest, and thus these limitations do not weaken the conclusions. The analyses revealed the evidence that 4 nutrient deficits that associate with inflammation were consistently prominent among SNAP recipients.

The predominance of female participants in the study population (76%) may accurately reflect the sex ratio among food shoppers in these neighborhoods, and thus, this is not a weakness per se, but it is a consideration for bias assessment, generalization, and future research. Sex and SNAP status were not associated in the study population, and when sex was added to the multivariable-adjusted model, the SNAP−DII association was essentially unchanged. Although the SNAP−DII association does not differ significantly by sex, there is a priori evidence that the relationship between SNAP and diet may differ between male and female individuals.[48,49] When stratifying by sex, the SNAP−DII association was more evident among the male participants in this study population. Larger studies may be able to corroborate and illuminate this putative difference between male and female individuals.

## CONCLUSIONS

The SNAP recipients in the studied low-income urban neighborhoods had elevated DII scores, a validated estimate of diet-driven inflammation. This was due, in part, to low intakes of 4 anti-inflammatory nutrients that were higher but still insufficient among nonrecipients of SNAP. Because this estimate of diet-driven inflammation (the DII) is associated with chronic diseases and because these nutrient deficiencies can impair immune function, these findings may help to explain disparities in chronic disease and COVID-19. These deficiencies represent potential targets for improving health through public policy.

## ACKNOWLEDGMENTS

The authors would like to thank the members of the data collection team for making this work possible (including Milen Embaye, Alicia Thomas, Wanda Rhynes, Hannah Zaim, and Ashley Banks). SMW and DAF contributed equally to this work.

Some of the funders were provided updates, but none of the funders had a role in study design; collection, analysis, or interpretation of data; writing the report; or the decision to submit the report for publication.

This research was supported by grants from the National Institute of Diabetes and Digestive and Kidney Diseases (R01DK108184), Foundation for Food and Agriculture Research (560290), Michael & Susan Dell Foundation (no grant number), the National Dairy Council (2923), and the National Center for Advancing Translational Sciences (UL1TR002548).

Author contributions are as follows: DAF's group collected the data. THC and DKN conducted the analyses with help and feedback from AR, SMW, and DAF. THC wrote most of the initial draft with help from DKN and AR. DAF and SMW were the senior authors, and they provided substantial guidance and input. All authors contributed intellectual and writing input in the iterative improvement of this work. All authors approve of this version for submission.

Portions of this work have been discussed in presentations and included in a poster for a national conference/workshop.

No financial disclosures were reported by the authors of this paper.

## SUPPLEMENTAL MATERIAL

Supplemental materials associated with this article can be found in the online version at https://doi.org/10.1016/j.amepre.2021.02.007.

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