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ASSOCIAÇÃO DA INSEGURANÇA ALIMENTAR COM VITAMINAS E CAROTENÓIDES PLASMÁTICOS EM ADULTOS PARTICIPANTES DO *NATIONAL HEALTH AND NUTRITION EXAMINATION SURVEY* (NHANES) 2017–2018

THAIS CUNHA REIS

UBERLÂNDIA
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Dissertação apresentada ao Programa de Pós-Graduação em Ciências da Saúde da Faculdade de Medicina da Universidade Federal de Uberlândia, como requisito parcial para a obtenção do título de Mestre em Ciências da Saúde.

Área de concentração: Ciências da Saúde.

Orientador: Profa. Dra. Catarina Machado Azeredo

Co-orientador: Dra. Flávia Moure Simões de Branco

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UNIVERSIDADE FEDERAL DE UBERLÂNDIA
Coordenação do Programa de Pós-Graduação em Ciências da Saúde - Acadêmico
Av. Pará, 1720, Bloco 2H, Sala 11 - Bairro Umuarama, Uberlândia-MG, CEP 38400-902
Telefone: (34) 3225-8628 - www.ppcsa.famed.ufu.br - ppcsa@famed.ufu.br

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Reuniu-se em sala virtual, pela plataforma Google Meet, a Banca Examinadora, designada pelo Colegiado do Programa de Pós-graduação em Ciências da Saúde, composta pelos Profs. Drs. Larissa Limirio (UNITRI), Cibele Aparecida Crispim (UFU) e Flávia Moure Simões de Branco (UFU) coorientadora em substituição a orientadora Catarina Machado Azeredo.

Iniciando os trabalhos a presidente da mesa, Dra. Flávia Moure Simões de Branco, apresentou a Comissão Examinadora e a candidata, agradeceu a presença dos membros da banca, e concedeu a Discente a palavra para a exposição do seu trabalho. A duração da apresentação da Discente e o tempo de arguição e resposta foram conforme as normas do Programa.

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DEDICATÓRIA

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"A ideia de que algumas vidas importam menos é a raiz de tudo o que há de errado com o mundo."
Paul Farmer

RESUMO

Introdução: Nos Estados Unidos, a Insegurança Alimentar (INSAN) predispõe as populações vulneráveis ao paradoxo da obesidade coexistente com a 'fome oculta'. Embora a literatura aponte a má qualidade da dieta como mediadora dessa relação, as evidências baseiam-se majoritariamente em inquéritos alimentares. Para contornar as limitações de autorrelato, o uso de biomarcadores séricos torna-se indispensável para quantificar o impacto dessa vulnerabilidade na qualidade da dieta. **Objetivos:** Avaliar a relação da insegurança alimentar sobre o perfil bioquímico de micronutrientes em adultos e idosos norte-americanos, considerando a modificação de efeito por sexo, faixa-etária e raça/etnia. **Material e métodos:** Estudo transversal utilizando dados do *National Health and Nutrition Examination Survey* (NHANES) 2017-2018, incluindo 3.092 adultos (≥20 anos). A Insegurança Alimentar foi avaliada pela escala *Household Food Security Survey Module*. Os níveis séricos das vitaminas A, C, D e E, bem como de carotenoides, foram avaliados. Modelos de regressão linear com pesos amostrais foram utilizados para examinar a associação entre a INSAN e esses biomarcadores. As variáveis de confusão para os modelos ajustados foram rigorosamente selecionadas a partir de um Grafo Acíclico Direcionado (DAG). As análises foram realizadas na amostra total e estratificadas por sexo, idade e raça/etnia. **Resultados:** Na amostra total, após ajustes, a Insegurança Alimentar manteve associação inversa significativa com os níveis de carotenoides totais, cis- e trans-betacaroteno. Nas análises estratificadas, a depleção de carotenoides manteve-se entre as mulheres e adultos jovens. Em contraste, homens apresentaram associação com a redução de vitamina E e licopeno, e os idosos com as vitaminas D e E. Quanto à raça/etnia, a associação perdeu significância entre minorias após os ajustes socioeconômicos, indicando que variáveis estruturais como renda e educação absorvem o impacto isolado da Insegurança Alimentar nestes grupos.**Conclusão:** A Insegurança Alimentar nos EUA transcendeu a restrição calórica e configurou um grave estado de fome oculta. A depleção de carotenoides evidenciou a restrição ao acesso a alimentos *in natura* (frutas e vegetais). O uso de biomarcadores séricos ressaltou como a vulnerabilidade social pode se refletir em diferenças nutricionais mensuráveis.

Palavras-chave: *Insegurança Alimentar, Estado Nutricional,Micronutrientes, Desigualdades em Saúde e Grupos Raciais.*

ABSTRACT

Introduction: In the United States, food insecurity (FI) predisposes vulnerable populations to the paradox of obesity coexisting with “hidden hunger.” Although the literature points to poor diet quality as a mediator of this relationship, the evidence is based primarily on dietary surveys. To overcome the limitations of self-reporting, the use of serum biomarkers is essential for quantifying the impact of this vulnerability on dietary quality. **Objective:** To evaluate the relationship between Food Insecurity and the serum biochemical profile of vitamins and carotenoids in U.S. adults and older adults, considering effect modification by sex, age group, and race/ethnicity. **Material and methods:** A cross-sectional study using data from the National Health and Nutrition Examination Survey (NHANES) 2017-2018, comprising 3,092 adults (≥20 years). Serum levels of vitamins A, C, D, and E, as well as carotenoids, were evaluated. Survey-weighted linear regression models were used to examine the association between FI and these biomarkers. Food Insecurity was assessed using the Household Food Security Survey Module. Confounding variables for the adjusted models were strictly selected using a Directed Acyclic Graph (DAG). Analyses were performed on the total sample and stratified by sex, age, and race/ethnicity. **Results:** In the total sample, after adjustments, Food Insecurity maintained a significant inverse association with levels of total carotenoids, cis-, and trans-beta-carotene. In stratified analyses, carotenoid depletion persisted among women and young adults. In contrast, men showed an association with reduced vitamin E and lycopene, and older adults with vitamins D and E. Regarding race/ethnicity, the association lost significance among minorities after socioeconomic adjustments, indicating that structural variables such as income and education absorb the isolated impact of Food Insecurity in these groups. **Conclusion:** Food Insecurity in the U.S. transcends caloric restriction and constitutes a severe state of hidden hunger. The depletion of carotenoids highlights the restricted access to fresh, unprocessed foods (fruits and vegetables). The use of serum biomarkers underscored how social vulnerability can be reflected in measurable nutritional differences.

Keywords: *Food Insecurity, Nutricional Status, Micronutrients, Health Inequities and Continental Population Group*

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LISTA DE ABREVIATURAS E SÍMBOLOS

BMI	*Body mass index*
CAPI	*Computer-Assisted Personal Interview*
CSA	*Comitê de Segurança Alimentar Mundial*
CDC	*Centers for Disease Control and Prevention*
DCNT	*Doenças Crônicas Não Transmissiveis*
FAO	*Food and Agriculture Organization*
FI	*Food Insecurity*
FNDDS	*Food and Nutrient Database for Dietary Studie*
FS	*Food Security*
HFSSM	*Household Food Security Survey Module*
INSAN	*Insegurança Alimentar e Nutricional*
NHANES	*National Health and Nutrition Examination Survey*
NCHS	*National Center for Health Statistics*
NHIS	*National Health Interview Survey*
PSU	*Unidades Primárias de Amostragem*
UDSA	*United States Department of Agriculture*
UPLC	*Ultra Performance Liquid Chromatography*
SAN	*Segurança Alimentar e Nutricional*

SUMÁRIO

1. Introdução

A Insegurança Alimentar e Nutricional (INSAN) é um fenômeno complexo, que classicamente é definido como “a disponibilidade limitada ou incerta de alimentos nutricionalmente adequados e seguros, ou a capacidade limitada ou incerta de adquirir alimentos adequados de formas socialmente aceitáveis” (ANDERSON, 1990). Essa condição apresenta uma violação do direito à alimentação adequada repercutindo negativamente nos desfechos de saúde e nos ciclos de desenvolvimento do indivíduo (LOPES; ABRANTES; AZEVEDO; MORAIS *et al.*, 2023). Em âmbito global, dados da Organização das Nações Unidas para Alimentação e Agricultura (FAO) de 2023 indicam que 2,3 bilhões de pessoas enfrentaram a insegurança alimentar moderada ou grave (WHO, 2023).

Essa realidade assume contornos distintos nos países desenvolvidos. Nos EUA, a insegurança alimentar associa-se paradoxalmente ao sobrepeso, configurando a chamada 'fome oculta': uma carência crônica de micronutrientes em meio ao excesso calórico. Devido a restrições orçamentárias, a substituição de alimentos nutritivos por opções de baixo custo e alta densidade energética gera deficiências vitamínicas que coexistem com a obesidade (LOWE, 2021). Corroborando com esse cenário, (LOPES; ABRANTES; AZEVEDO; MORAIS *et al.*, 2023) menores concentrações séricas de vitaminas A e E foram encontrados em adultos nessa condição.

As vitaminas A, C, D, E e os carotenoides desempenham papéis cruciais na regulação imunológica e na defesa antioxidante, atuando como fatores protetores contra o estresse oxidativo e doenças crônicas não transmissíveis, condições frequentemente prevalentes em populações vulneráveis (LIBERATO, 2023). Um estudo demostrou que os indivíduos em insegurança alimentar apresentam pior qualidade dietética, caracterizada pela baixa ingestão desses micronutrientes essenciais (HANSON; CONNOR, 2014).

Entretanto, o consumo alimentar isolado não reflete necessariamente a disponibilidade fisiológica desses nutrientes. A maioria das evidências disponíveis baseia-se exclusivamente em métodos de inquérito alimentar (como recordatórios de 24h) (COWAN; JUN; TOOZE; EICHER-MILLER *et al.*, 2019; TER BORG; VERLAAN; HEMSWORTH; MIJNARENDS *et al.*, 2015), que estão sujeitos a vieses de memória, subnotificação e metabolismo, além de não capturarem a real biodisponibilidade dos nutrientes (BOOTH; TUCKER; MCKEOWN; DAVIDSON *et al.*, 1997). Uma metanálise destaca a necessidade de associar a insegurança alimentar a deficiência de micronutrientes em adultos em geral, pois é o grupo que costuma ser o primeiro afetado pela INSAN no domicílio, por priorizarem a alimentação da prole. Isso pode, muitas vezes, prejudicar a capacidade produtiva individual , gerar perdas na economia e causar prejuízos na saúde da população geral (LOPES; ABRANTES; AZEVEDO; MORAIS *et al.*, 2023).

Nesse contexto, o presente estudo se diferencia ao avaliar o *status* nutricional por meio de concentrações séricas, um biomarcador mais objetivo e fidedigno que reflete não apenas o consumo, mas a absorção e o metabolismo real dessas vitaminas. Adicionalmente, nossa abordagem inova ao estratificar a análise, permitindo identificar como as iniquidades sociais, raça, gênero e renda, se interseccionam com a insegurança alimentar para determinar a deficiência oculta de micronutrientes, preenchendo uma importante lacuna sobre a distribuição dessas carências em subgrupos populacionais específicos.

Dessa forma, é imprescindível a avaliação da associação das vitaminas plasmáticas e carotenoides com a Insegurança Alimentar em adultos e idosos americanos, verificando se essa relação é dependente da idade, sexo e raça.

2. Revisão da literatura

2.1 Insegurança alimentar e Nutricional (definição, mensuração e cenário nos Estados Unidos)

O conceito de Segurança Alimentar e Nutricional (SAN) é multidimensional. De acordo com a Organização das Nações Unidas para a Alimentação e a Agricultura (FAO) é “quando todas as pessoas, em todos os momentos, têm acesso físico e econômico a alimentos suficientes, seguros e nutritivos para satisfazer suas necessidades alimentares e preferências para uma vida ativa e saudável”(FAO, 2012). A Insegurança Alimentar e Nutricional (INSAN) ocorre quando esse acesso é incerto, limitado ou inexistente, comprometendo a qualidade ou a quantidade da dieta (HANSON; CONNOR, 2014; LOPES; ABRANTES; AZEVEDO; MORAIS *et al.*, 2023).

Nos Estados Unidos a Segurança alimentar pode ser classificada em alta segurança alimentar (sem indícios de problemas de acesso a alimentos), segurança alimentar marginal (ansiedade quanto a suficiência alimentar), baixa segurança alimentar (indivíduos reduzem a qualidade da dieta, mas não a ingestão de alimentos) e muito baixa segurança alimentar (múltiplos indícios de padrões alimentares alterados e redução da ingestão de alimentos)(COLEMAN-JENSEN; RABBITT; GREGORY; SINGH, 2017). A principal ferramenta para essa mensuração é a *Household Food Security Survey Module* (HFSSM). Trata-se de um instrumento validado composto por 18 perguntas (sendo 8 específicas para lares com crianças) que avalia a condição domiciliar com base em experiências autodeclaradas de restrição financeira e percepção de fome.(BICKEL; NORD; PRICE; HAMILTON *et al.*, 2000). Essa escala é utilizada amplamente em inquéritos populacionais como *National Health and Nutrition Examination Survey* (NHANES) e *National Health Interview Survey* (NHIS) (Figura 1).

Figura 1- Perguntas (em inglês) Utilizadas Para Avaliar a Segurança Alimentar dos Domicílios no Suplemento de Segurança Alimentar

1. "We worried whether our food would run out before we got money to buy more." Was that often, sometimes, or never true for you in the last 12 months?
2. "The food that we bought just didn't last and we didn't have money to get more." Was that often, sometimes, or never true for you in the last 12 months?
3. "We couldn't afford to eat balanced meals." Was that often, sometimes, or never true for you in the last 12 months?
4. In the last 12 months, did you or other adults in the household ever cut the size of your meals or skip meals because there wasn't enough money for food? (Yes/No)
5. (If yes to question 4) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?
6. In the last 12 months, did you ever eat less than you felt you should because there wasn't enough money for food? (Yes/No)
7. In the last 12 months, were you ever hungry, but didn't eat, because there wasn't enough money for food? (Yes/No)
8. In the last 12 months, did you lose weight because there wasn't enough money for food? (Yes/No)
9. In the last 12 months did you or other adults in your household ever not eat for a whole day because there wasn't enough money for food? (Yes/No)
10. (If yes to question 9) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?

(Questions 11-18 were asked only if the household included children age 0-17)

11. "We relied on only a few kinds of low-cost food to feed our children because we were running out of money to buy food." Was that often, sometimes, or never true for you in the last 12 months?
12. "We couldn't feed our children a balanced meal, because we couldn't afford that." Was that often, sometimes, or never true for you in the last 12 months?
13. "The children were not eating enough because we just couldn't afford enough food." Was that often, sometimes, or never true for you in the last 12 months?
14. In the last 12 months, did you ever cut the size of any of the children's meals because there wasn't enough money for food? (Yes/No)
15. In the last 12 months, were the children ever hungry but you just couldn't afford more food? (Yes/No)
16. In the last 12 months, did any of the children ever skip a meal because there wasn't enough money for food? (Yes/No)
17. (If yes to question 16) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?
18. In the last 12 months did any of the children ever not eat for a whole day because there wasn't enough money for food? (Yes/No)

Em termos epidemiológicos a Insegurança Alimentar continua sendo um problema de saúde pública. Nos Estados Unidos 10,2% da população foi afetada em 2021 (LEE; BARRETT; HODDINOTT, 2024). Para idosos o cenário é mais preocupante, 5,5 milhões de idosos vivem nessas condições e com projeções de aumento para mais de 7 milhões até 2050 (ZILIAK; GUNDERSEN, 2021).

Na população geral a insegurança alimentar se apresenta de forma desproporcional, sendo as populações historicamente marginalizadas, especificamente minorias étnicas e domicilios chefiados por mulheres, os grupos que mais enfrentam barreiras estruturais que limitam o acesso aos alimentos seguros e saudáveis (FEDINA; ASHWELL; BRIGHT; BACKES *et al.*, 2022; HALES; COLEMAN-JENSEN, 2024; JOHNSON; SHARKEY; LACKEY; ADAIR *et al.*, 2018).

As consequências da Insegurança Alimentar transcedem a situação de fome imediata, podendo ser considerado um determinante social que afeta negativamente a saúde física e emocional. A literatura evidencia a relação da Insegurança Alimentar com alguns desfechos clínicos adversos em saúde, como diabetes, hipertensão, obesidade e doenças psiquicas (GIANFREDI; NUCCI; SOYSAL; MAGGI *et al.*, 2025; RAHI; AL MASHHARAWI; HARB; EL KHOURY-MALHAME *et al.*, 2025).

2.2 O paradoxo da Insegurança Alimentar e obesidade

As mudanças abrangentes na ingestão de nutrientes estão atreladas ao fardo duplo gerado pela transição nutricional e a Insegurança Alimentar. Juntos, esses fatores agem no decorrer da vida para elevar a carga da má nutrição, resultando em inúmeros prejuízos à saúde (EGELAND; JOHNSON-DOWN; CAO; SHEIKH *et al.*, 2011). Nesse cenário, observou-se que os indivíduos com insegurança alimentar apresentaram maior probabilidade de obesidade e adiposidade central.

Consequentemente o consumo de uma dieta rica em energia, mas pobre em nutrientes, pode levar a deficiências múltiplas deficiências de micronutrientes como as vitaminas, caracterizando o que chamamos de fome oculta(LOWE, 2021). Ou seja, uma pessoa pode ter acesso as calorias suficientes, mas não possuir todos do nutrientes adequados para a manutenção da saúde e produtividade (BURCHI; FANZO; FRISON, 2011).

Dados de 2021 revelam que as dietas saudáveis são inacessíveis para cerca de 2,8 bilhões de pessoas no mundo. Essa falta de acesso acontece porque os alimentos mais nutritivos (frutas, verduras e carnes) são mais caros, enquanto que os alimentos ricos em amido, óleo e gorduras são mais baratos (MASTERS; WALLINGFORD; HERFORTH; BAI, 2025). Por influência disso, essas pessoas com baixa renda, não encontram outra alternativa senão consumir dietas de baxa qualidade nutricional, indicando que o alto custo de alimentos saudáveis atua como barreira estrutural a saúde.

2.3 Micronutrientes e as consequências da deficiência

Os micronutrientes possuem inúmeros benefícios para a saúde como regulação do crescimento e diferenciação das células e tecidos, funções antioxidantes e manutenção de ossos e tecidos (AWUCHI; IGWE; AMAGWULA; ECHETA, 2020). Um estudo, mostrou que adultos em situação de Insegurança Alimentar consomem menos frutas e verduras, e consequentemente ingerem quantidades menores de vitaminas (A, B6) e minerais (cálcio, magnésio, zinco)(HANSON; CONNOR, 2014).

Esse consumo insuficiente a longo prazo, pode resultar em deficiência de vitaminas que mesmo não gerando doenças graves, como cegueira noturna (nictalopia) e ceratomalácia (vitamina A), escorbuto (vitamina C), raquitismo (vitamina D) e má condução dos impulsos elétricos ao longo dos nervos (vitamina E) podem levar ao comprometimento da resposta imune e aumento do estresse oxidativo, fatores de risco para o desenvolvimento de Doenças Crônicas Não Transmissíveis (DCNT) (AWUCHI; IGWE; AMAGWULA; ECHETA, 2020).

A insegurança alimentar foi associada a deficiencia de algumas vitaminas como: A, B12, D e E, em diferentes grupos populacionais. Todavia, há uma carência de trabalhos em adultos explorando tal associação com micronutrientes(LOPES; ABRANTES; AZEVEDO; MORAIS *et al.*, 2023).

2.4 Iniquidades em saúde e IA

A insegurança alimentar se apresenta de forma heterogênea na população, sendo modulada por determinantes sociais. Os estudos mostram que a renda estabelece um gradiente inverso com a Insegurança Alimentar, de modo que as famílias de maior renda apresentam menor prevalência de Insegurança Alimentar em relação as famílias de menor renda. Sendo renda domiciliar um indicador consistente e de forte risco para Insegurança Alimentar (LOOPSTRA, 2018).

Adicionalmente, para além da barreira finaceira, o gênero e a estrutura familiar influenciam na Insegurança Alimentar. De modo que para as mulheres, principalmente quando responsáveis exclusivamente pelo sustento, são mais vulneráveis a Insegurança Alimentar quando comparadas aos homens (JUNG; DE BAIRROS; PATTUSSI; PAULI *et al.*, 2017).

Evidências apontam a existência de uma divisão racial estrutural: a raça prediz a insegurança alimentar com mais força do que o status de imigração. Mesmo nivelando-se o status socioeconômico, negros e hispânicos apresentam maior risco de insegurança alimentar do que brancos, independentemente de serem nativos ou estrangeiros (MYERS; PAINTER, 2017). Em 2021, a insegurança alimentar atingiu 19,8% dos domícilios chefiados por pessoas pretas e não hispânicas e a prevalencia para famílias hispâncias foi de 16,2%, enquanto que em lares brancos foi 7% (COLEMAN-JENSEN; RABBITT; GREGORY; SINGH, 2022).

2.5 National Health and Nutrition Examination Survey (NHANES)

O *National Health and Nutrition Examination Survey* (NHANES), conduzido pelo NCHS/CDC, é um programa contínuo que avalia a saúde e nutrição da população civil não institucionalizada dos Estados Unidos através de entrevistas e exames físicos (médicos, laboratoriais e antropométricos). Para garantir a representatividade nacional, o estudo não utiliza amostragem aleatória simples, mas sim um desenho probabilístico complexo em múltiplos estágios:

Estágio 1 (Unidades Primárias - PSUs): Seleção de condados ou grupos de condados com probabilidade proporcional ao tamanho da população.

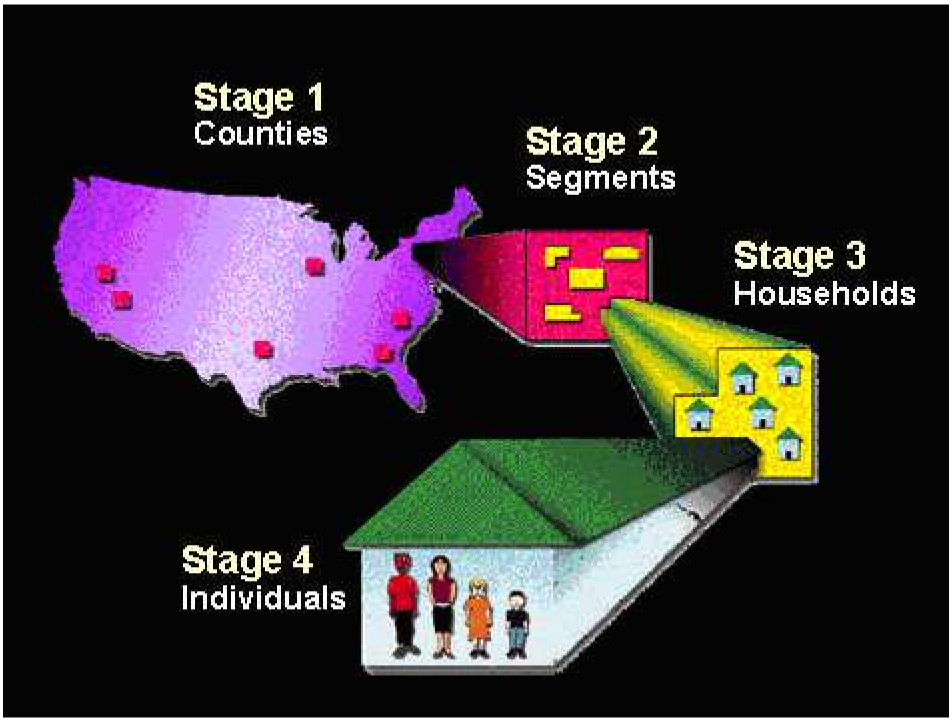
Estágio 2 (Segmentos): Divisão das PSUs em segmentos geográficos menores (como quarteirões), também selecionados proporcionalmente.

Estágio 3 (Domicílios): Listagem e sorteio aleatório de domicílios dentro dos segmentos selecionados.

Estágio 4 (Indivíduos): Seleção dos participantes dentro dos domicílios, com sobreamostragem intencional de grupos específicos (como certas faixas etárias ou minorias étnicas) para garantir precisão estatística.

Devido a esse desenho complexo e às probabilidades desiguais de seleção, é imprescindível o uso de pesos amostrais (*sample weights*) nas análises estatísticas. Esses pesos corrigem as distorções da sobreamostragem, permitindo que os dados de cerca de 10.000 participantes anuais produzam estimativas imparciais e fidedignas para toda a população americana.

Figura 2- Quatro etapas do procedimento de amostragem do *NHANES*



3. Objetivo geral

Avaliar a relação da insegurança alimentar sobre o perfil bioquímico de micronutrientes em adultos e idosos norte-americanos, considerando condicionantes demográficos.

3.1 Objetivos específicos

- Caracterizar o perfil sociodemográfico, de estilo de vida e antropométrico da população estudada, comparando indivíduos em situação de segurança e insegurança alimentar.
- Investigar a relação entre os níveis de insegurança alimentar e as concentrações séricas de vitaminas e carotenoides na amostra total.
- Verificar se a associação entre insegurança alimentar e os biomarcadores nutricionais é modificada por variáveis biológicas e sociais, especificamente sexo, faixa etária e raça/etnia.

4. Original Article

Food insecurity is independently associated with lower serum carotenoid levels in U.S. adults: NHANES 2017–2018

Thaís C. Reis[1], Flávia M. S. de Branco[1], Catarina M. Azeredo[1]

[1]School of Medicine. Federal University of Uberlandia (UFU). Uberlandia. Minas Gerais. Brazil.

Abstract

Background: In the United States, food insecurity (FI) predisposes vulnerable populations to the paradox of obesity coexisting with "hidden hunger." Although the literature points to poor diet quality as a mediator of this relationship, the evidence is based primarily on dietary surveys. To overcome the limitations of self-reporting, the use of serum biomarkers is essential for quantifying the impact of this vulnerability on dietary quality. **Objective:** To evaluate the relationship between FI and the serum biochemical profile of vitamins and carotenoids in U.S. adults and older adults, overall and stratified by sex, age group, and race/ethnicity. **Methods:** A cross-sectional study using data from the National Health and Nutrition Examination Survey (NHANES) 2017-2018, comprising 3,092 adults (≥20 years). FI was assessed using the Household Food Security Survey Module. Serum levels of vitamins A, C, D, and E, as well as carotenoids, were evaluated. Survey-weighted linear regression models were used to examine the association between FI and these biomarkers. Adjusted models included age, sex, race/ethnicity, education, per capita income, and marital status, selected using a Directed Acyclic Graph (DAG). Analyses were performed on the total sample and stratified by sex, age, and race/ethnicity. **Results:** In the total sample, after adjustment, FI remained significantly and inversely associated with total carotenoids, cis-beta-carotene, and trans-beta-carotene. In stratified analyses, lower carotenoid levels persisted among women and young adults. Among men, FI was associated with lower vitamin E, lycopene, and trans-lycopene levels, whereas among older adults, FI was associated with lower vitamins D and E levels. **Conclusion:** FI was associated with lower serum carotenoid levels among U.S. adults, suggesting poorer diet quality and possible restricted access to micronutrient-rich foods. These findings support the role of serum carotenoids as biomarkers of nutritional vulnerability in food-insecure populations and highlight the need for policies that improve access to healthy foods.

Key-words: *Food Insecurity, Nutricional Status, Micronutrients, Health Inequities.*

Background

Food insecurity (FI) is classically defined as the "limited or uncertain availability of nutritionally adequate and safe food"[1]. Beyond immediate hunger, FI acts as a critical social determinant affecting 2.3 billion people globally[2]. Its consequences transcend caloric restriction, negatively impacting physical and mental health through chronic stress and poor diet quality, linking social vulnerability to adverse clinical outcomes like diabetes and hypertension [3].FI is closely related to poorer diet quality, as individuals with limited economic access to food may rely more frequently on low-cost, energy-dense foods like ultra-processed food and consume fewer nutrient-rich foods, such as fruits and vegetables. This dietary pattern may result in inadequate micronutrient intake even when total energy intake is sufficient, contributing to the phenomenon known as "hidden hunger"[4]. Therefore, FI may compromise nutritional status not necessarily through caloric restriction, but through reduced dietary diversity and lower micronutrient density.

However, assessing this specific nutritional status remains a challenge. Most existing evidence relies on self-reported dietary surveys (e.g., 24-hour recalls), which are prone to memory and underreporting biases and fail to capture physiological bioavailability [5,6,7]. In this context, serum biomarkers may provide a more objective measure of nutritional status, and carotenoids are particularly useful because they have been validated as biomarkers of fruit and vegetable intake[8,9]. While a few studies have utilized biochemical indicators to evaluate the impact of FI, they frequently focus on specific populations, such as children and women [10], or rely on older data cycles[11]. Consequently, comprehensive evidence on the association between FI and a multi-marker panel of serum micronutrients in the general adult population remains limited. To address this gap, the present study utilizes the most recently available complete dataset (NHANES 2017-2018) for this comprehensive biomarker panel. Furthermore, focusing on adults is crucial, as they are typically the first to sacrifice dietary quality to protect children in the household, compromising their own productive capacity[12].

Therefore, this study aimed to examine the association between food insecurity and a broad panel of serum micronutrient biomarkers, including vitamins A, C, D, and E and carotenoids, among U.S. adults participating in NHANES 2017–2018. We also investigated whether these associations differed across sex, age group, and race/ethnicity, providing a more detailed understanding of nutritional vulnerability in food-insecure populations.

Methodology

Participants

This is a cross-sectional study using data from the National Health and Nutrition Examination Survey (NHANES). Although NHANES includes participants of all ages, the present study was restricted to adults aged ≥20 years. The study sample included data from the 2017-2018 biennium, comprising adults and older adults (aged 20 to 85 years). Individuals with missing data on FI classification, vitamin A, C, D, E, and carotenoid levels, diet, pregnant women, lactating women, and anthropometry were excluded. In the end, 5,589 individuals were evaluated (Figure 3). Written consent, as well as approval from the NCHS Research Ethics Review Committee (Protocol #2011-17 for the 2017 NHANES cycle and Protocol #2018-01 for the 2018 cycle), were obtained from all NHANES participants.

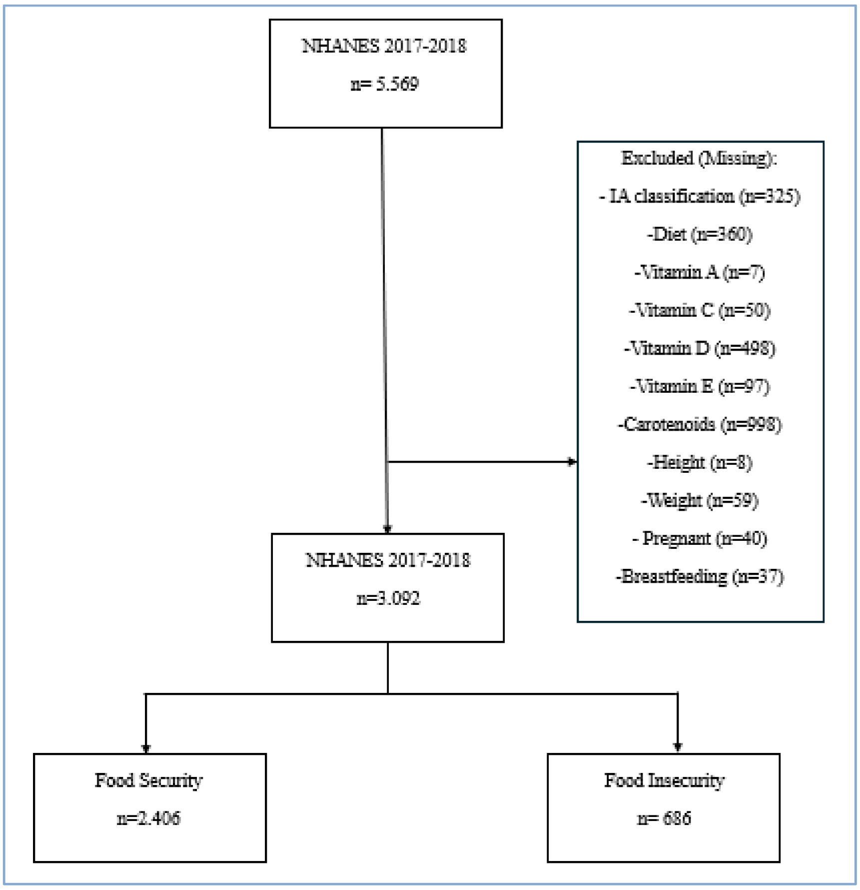


Figure 3- Flow diagram of participant selection from the NHANES 2017-2018.

Sociodemographic data

In the NHANES database, demographic data were provided individually, by family, and by household. The sample questionnaires were collected at home by trained interviewers using the Computer-Assisted Personal Interview (CAPI) system. The sample design for the 2017-2018 biennium included a subsample of Asian Americans. The variables analyzed were household income, gender, anthropometric measurements, consumption, medical conditions, race/hispanic origin, education, and marital status.

Food Intake

Food consumption was assessed using two 24-hour dietary recalls for each volunteer. The first 24-hour dietary recall interview was conducted in person, while the second was conducted by telephone between 3 and 10 days later. For individuals who completed both 24-hour dietary recalls, the average nutrient intake was calculated; for those who completed only the first 24-hour dietary recall (but not the second), data from that single day were used. NHANES dietary data were collected using the Automated Multiple Pass Method, which conducts the interview in 5 steps (quick list, forgotten foods, time and occasion, detailed cycle, and final probe). The USDA's 2011-2012 Food and Nutrient Database for Dietary Studies (FNDDS) was used to process food intake. The nutrient values in the 2011-2012 FNDDS were based on the USDA National Nutrient Database for Standard Reference, Version 26, produced by the USDA Nutrient Data Lab.

Food Insecurity

In the NHANES databases, food security was measured using the US Household Food Security Survey Module. The interview on participants' food security status was conducted in person and included questions relating to the previous 12 months. The questions covered all family members, not just NHANES participants. For adults, a total of 10 questions were asked to determine the level of food insecurity. Based on the responses, individuals were classified into 4 categories: 1 = Full food security, when there are no affirmative responses; 2 = Marginal food security, when there are 1 to 2 affirmative responses; 3 = Low food security, when there were 3 to 5 affirmative responses; and 4 = Very low adult food security, when there were 6 to 10 affirmative responses. Thus, in this study, it was decided to classify the level of food security into two categories to increase the power of statistical analysis. Individuals classified in categories 1 (Full food security) and 2 (Marginal food security) were considered to be food secure, and individuals classified in categories 3 (Low food security) and 4 (Very low adult food security) were considered to have some degree of food insecurity.

Serum Vitamin Levels

Biochemical data for vitamins A, C, D, E, and carotenoids were obtained from serum samples collected in the NHANES 2017-2018 cycle. Following standard NHANES protocols, blood samples were processed, stored frozen (≤ -70°C), and protected from light until analysis. Serum retinol, retinyl esters, alpha- and gamma-tocopherol, and specific carotenoids were analyzed using high-performance liquid chromatography (HPLC) with photodiode array detection. Serum ascorbic acid (vitamin C) was measured via isocratic ultra-high-performance liquid chromatography (UPLC) with electrochemical detection. To assess vitamin D status, serum 25-hydroxyvitamin D [25(OH)D] was measured using standardized ultra-high-performance liquid chromatography-tandem mass spectrometry (UHPLC-MS/MS). Comprehensive methodological and quality control details are available in the respective NHANES laboratory manuals (NHANES, 2018).

Statistical analysis

Participants were characterized for the total sample and according to food security status (food secure vs. food insecure). Sociodemographic characteristics, dietary intake, anthropometric variables, serum vitamin and carotenoid levels, lifestyle factors, and medical conditions were described. Continuous variables were presented as means and standard errors, while categorical variables were presented as percentages and 95% confidence intervals. Differences between groups were evaluated using p for trend.

Survey-weighted linear regression models were used to examine the association between food insecurity and serum levels of vitamins A, C, D, E, and carotenoids in the total sample and according to sex (male and female), age group (<60 and ≥60 years), and race/ethnicity (Mexican American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, and Multiracial/Other Race). Crude analyses were presented as Model 1, and adjusted analyses as Model 2. For the adjusted analyses, the selection of covariates was guided by a Directed Acyclic Graph (DAG) constructed using the DAGitty web application (Figure 4). Food insecurity was considered the primary exposure and serum micronutrient biomarkers the primary outcomes. Based on causal assumptions, age, sex, race/ethnicity, education, per capita income, and marital status were identified as the minimal sufficient adjustment set. Variables such as dietary intake, supplement use, and alcohol consumption were considered potential mediators, while BMI was identified as a collider; therefore, these variables were not included in the adjusted models to avoid overadjustment and collider bias.

All analyses accounted for the complex NHANES sampling design and were performed using Stata 17 software (StataCorp, College Station, TX, USA). Statistical significance was defined as $p < 0.05$.

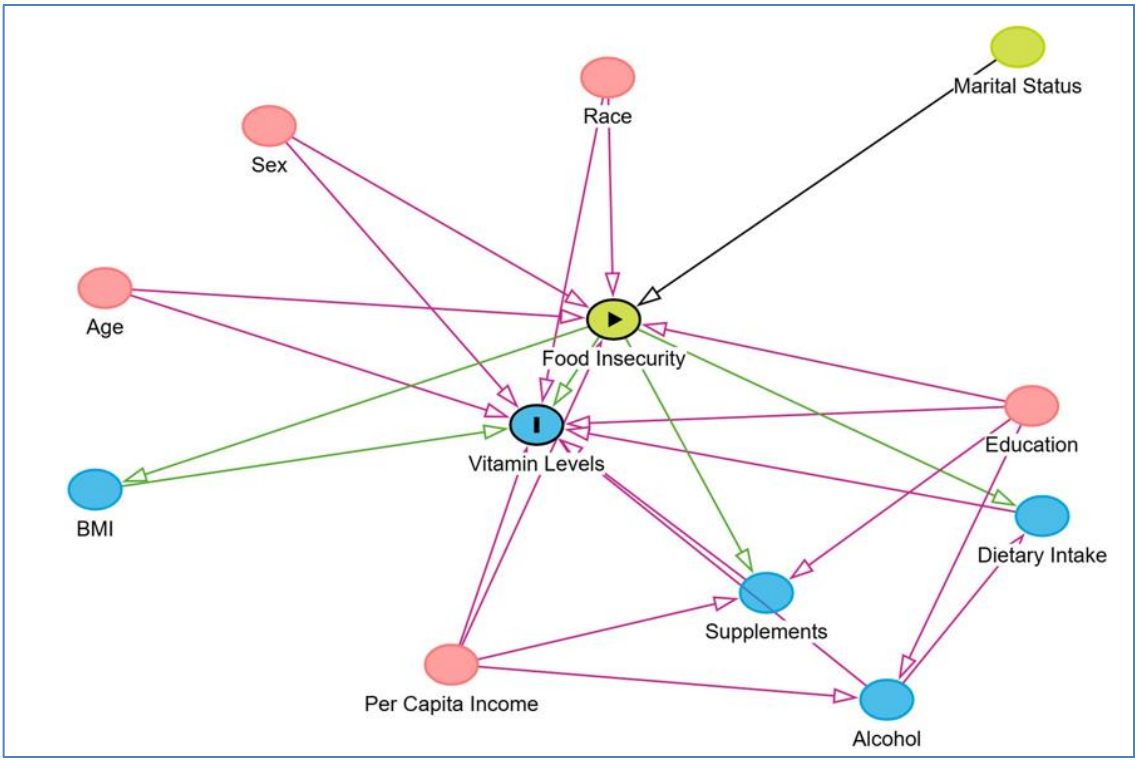


Figure 4- Directed Acyclic Graph (DAG) illustrating the causal assumptions between food insecurity, serum vitamin levels, and covariates.

Results

Characteristics of individuals

The characteristics of the total sample and according to the FI classification are shown in Table 1. When comparing the groups, a distinct sociodemographic profile was observed. Individuals in Food Security (FS) had a significantly higher mean age, a higher proportion of non-Hispanic whites, married individuals, and a higher prevalence of high educational attainment and income. In contrast, the Food Insecurity (FI) group was composed mainly of younger individuals, racial/ethnic minorities (such as Mexican Americans and non-Hispanic blacks), single or divorced individuals, and people with lower levels of education and income.

In terms of lifestyle, the group with FS showed higher frequencies of non-smokers and those who practiced physical activity. Regarding anthropometric data (weight and BMI), there was no statistical difference between the groups; both had average BMIs compatible with obesity.

In the biochemical nutritional assessment, individuals with FS had higher serum concentrations of vitamins A, C, D, and E, as well as the entire carotenoid profile (alpha-carotene, beta-carotene, lycopene, and lutein/zeaxanthin). Although total energy intake did not differ between groups, diet quality varied: The reported intake of vitamin A, carotenoids, and lipid fractions (mono- and polyunsaturated fats) was higher in the food-secure group, corroborating the serum findings. Finally, the use of supplements (general and specific for vitamins C, D, and lycopene) was also significantly more frequent among food-secure individuals.

Association of AI with serum levels of vitamins and carotenoids

Table 2 shows data from the linear regression between FI classification and serum levels of vitamins and carotenoids in the total sample. In the unadjusted analyses, there was a significant negative association between FI and vitamins A (retinol), C, D, E, total carotenoids, lycopene, cis-beta-carotene, alpha-carotene, trans-beta-carotene, lutein-zeaxanthin, and trans-lycopene. However, after adjustments, only total carotenoids, cis-beta-carotene, and trans-beta-carotene remained inversely associated for the total sample.

Association of FI with serum levels of vitamins and carotenoids according to gender

Table 3 shows the linear regression analysis between Food Insecurity Classification and serum levels of vitamins and carotenoids, stratified by gender. In Model 1, for women, there was a negative association between Food Insecurity and vitamins A (retinol), C, D, E, total carotenoids, cis-beta-carotene, trans-beta-carotene, and lutein-zeaxanthin, and for men, there was a negative association between FI and vitamins D and E, carotenoids, lycopene, cis-beta-carotene, and trans-lycopene. However, in the adjusted model, an inverse association was observed only for cis- and trans-beta-carotene in women; among men, this association was verified for vitamin E, lycopene, and trans-lycopene.

Association of FI with serum levels of vitamins and carotenoids according to age

Table 4 shows the linear regression between the Food Insecurity Classification and serum levels of vitamins and carotenoids, stratified by age. In model 1 (without adjustments) for adults (<60 years), a negative association was found between FI and carotenoids, lycopene, cis-beta-carotene, alpha-carotene, trans-beta-carotene, lutein, zeaxanthin, and trans-lycopene. For the elderly (>60 years), there was a negative association between FI and vitamins A (retinol), C, D, E, total carotenoids, and trans-beta-carotene. When model 2 was applied to adults, the negative association remained only for total carotenoids, cis-beta-carotene, and trans-beta-carotene. For the elderly, the negative association remained only for vitamins D and E.

Association of FI with serum levels of vitamins and carotenoids according to race/ethnicity

Table 5 shows the linear regression between Food Insecurity Classification and serum levels of vitamins and carotenoids, stratified by race/ethnicity. In model 1 (without adjustments), for non-Hispanic whites, there was a negative association between FI and vitamins D, C, E, total carotenoids, lycopene, alpha-cryptoxanthin, cis-beta-carotene, alpha-carotene, trans-beta-carotene, lutein-zeaxanthin, and trans-lycopene. For non-Hispanic blacks, there was a negative association between FI and vitamin D, cis-beta-carotene, and trans-beta-carotene. And for multiracial/other races, there was a negative association between AI and vitamin A (retinol) and C, total carotenoids, alpha-cryptoxanthin, cis-beta-carotene, alpha-carotene, trans-beta-carotene, and lutein-zeaxanthin. For other races/ethnicities, there was no significant association. In model 2 (with adjustments), a negative association remained for non-Hispanic whites with carotenoids, cis-beta-carotene, trans-beta-carotene, and lutein-zeaxanthin. And for multiracial/other races with cis-beta-carotene, alpha-carotene, trans-beta-carotene, and lutein-zeaxanthin. For other races/ethnicities, there was no significant association.

Discussion

The results of this study demonstrate that food insecurity is associated with an unfavorable biochemical profile of micronutrients, particularly reduced serum levels of carotenoids. Although initial associations were observed for various vitamins, after adjusting for sociodemographic and lifestyle factors, the association remained consistent mainly for carotenoids, especially cis- and trans-beta-carotene. This finding suggests that food insecurity is more strongly related to diet quality, particularly lower consumption of fruits and vegetables, than to vitamin intake. Furthermore, stratified analyses showed that this association is not homogeneous across the population: in women, it persisted for carotenoids, while in men, associations were also observed with vitamin E and compounds such as lycopene and trans-lycopene. Additional differences were identified by age group and race/ethnicity, indicating that social and demographic factors significantly modulate the relationship between food insecurity and the nutritional biochemical profile.

Methodologically, the use of serum carotenoid concentrations strengthens this study by providing an objective marker of diet quality, beyond self-reported dietary intake. Blood carotenoids, particularly alpha-carotene, beta-carotene, and lutein, are considered valid biomarkers of fruit and vegetable intake and are less affected by recall and reporting biases than dietary surveys[8,9] . Therefore, the inverse association observed between food insecurity and serum carotenoids may reflect lower access to or consumption of micronutrient-rich foods, especially fruits and vegetables. This interpretation is consistent with evidence that lower-cost diets tend to be more energy-dense and less nutrient-dense, with grain- and sugar-based foods being cheaper per calorie than fruits and vegetables[13]. Over time, this pattern may contribute to poorer micronutrient status and increased vulnerability to chronic diseases among food-insecure populations [14].

Grain- and sugar-based foods are cheaper per calorie than vegetables and fruits. These price differences may help explain why low-cost foods—which are high in energy density and low in nutritional value—are associated with lower levels of education and income[15].

The stratified analysis revealed that food insecurity (FI) does not affect the entire population uniformly. Associations with nutritional biomarkers showed distinct patterns according to sex, age group, and race/ethnicity, suggesting that nutritional vulnerability is shaped by biological, behavioral, and sociostructural contexts. Regarding sex differences, women with FI showed significant inverse associations with cis-beta-carotene and trans-beta-carotene, whereas men with FI showed lower levels of vitamin E, lycopene, and trans-lycopene. Although this study did not analyze family composition, previous evidence suggests that women, particularly mothers, may adopt coping strategies based on self-sacrifice, such as reducing portion sizes or skipping meals to prioritize feeding the family[16,17]. In contrast, men may present different dietary vulnerability patterns, with studies reporting higher intake of prepared foods, meat, and processed meats, and lower intake of fruits and vegetables compared with women[18,19].

When analyzing life stages, the differences are also significant and may be related to physiological and lifestyle factors. In young adults, FI was associated with a decline in total carotenoids, which appears to reflect an acute restriction in access to fresh produce. In this group, the time constraints of the economically active population are compounded by the high cost of fruits and vegetables[13], pushing this population toward high consumption of fast food[20]. In contrast, in the elderly sample, FI was negatively associated with vitamins D and E, consistent with previous studies[7]. Unlike younger people lower serum vitamin levels in older adults can result from various factors, such as reduced intestinal absorption, difficulty chewing, or mobility issues that may affect their ability to shop for food[21] making them more susceptible to serious health outcomes[22].

Finally, the analysis by race/ethnicity reinforces the fact that inequalities in dietary quality are intrinsic to structural contexts of disadvantage. Although there are no biological justifications for differences in nutrient metabolism among ethnic groups, we observed that, for racial minorities, the association between FI and biomarker depletion lost statistical significance after socioeconomic adjustments. This phenomenon does not indicate an absence of risk, but suggests that variables such as income and education are such profound determinants of access to healthcare in these groups that they end up absorbing the isolated impact of FI[23]. In contrast, for non-Hispanic whites, the association persisted, suggesting that, in this group with a history of lower vulnerability, entering into a state of food insecurity acts as an acute shock capable of rapidly worsening dietary quality. This racial disparity can be understood through the lens of structural and systemic racism. Historical discriminatory practices in the United States, such as redlining (which restricted investment and access to loans in neighborhoods inhabited by racial minorities), have geographically shaped what are known as food deserts[24]. This spatial racial segregation severely restricts access to fresh, high-quality food, regardless of individual effort[25]. Studie show that even when whites and Blacks have similar incomes and levels of education, Black families are more likely to experience food insecurity[26], since racial discrimination acts as an independent barrier to public health[27].

Therefore, the disparities in serum micronutrient levels examined in this study not only reflect the link to food insecurity but also serve as biomarkers of social inequality and the lingering effects of systemic racism on access to safe and healthy food.

Limitations and strengths of the study

This study has some limitations that should be considered. First, due to the cross-sectional design, causality cannot be inferred. Second, sociodemographic vulnerabilities overlap and interact, meaning that some observed associations may reflect broader structural inequalities. In addition, food insecurity is a multidimensional concept involving not only access to food, but also availability, stability, and utilization. As this study focused primarily on the access dimension, future studies incorporating all dimensions of food security may provide a more comprehensive understanding of nutritional vulnerability. The strengths of this study lie primarily in the use of serum concentrations as an objective measure of nutritional status, a methodological approach that overcomes the limitations of recall bias and underreporting inherent in traditional dietary survey methods. The strategic selection of carotenoids and vitamins as biomarkers allowed for the capture of the actual bioavailability of nutrients from fresh foods such as fruits and vegetables, biologically validating the phenomenon of hidden hunger and demonstrating that nutritional depletion coexists with overweight. Finally, the use of a population-based sample, characterized by a complex and representative design of the U.S. population, reinforces the statistical robustness and reliability of the results.

Conclusion

In conclusion, food insecurity was associated with lower serum carotenoid levels (total carotenoids, cis-beta-carotene, and trans-beta-carotene) among U.S. adults, suggesting poorer diet quality and possible reduced access to micronutrient-rich foods. These findings are consistent with the concept of hidden hunger, in which nutritional vulnerability may occur even in the absence of differences in energy intake or BMI. The use of serum biomarkers highlights how social vulnerability can be reflected in measurable nutritional differences. Public health strategies should prioritize access to healthy foods, including fruits and vegetables, and address the structural disparities that perpetuate dietary inequalities.

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APÊNDICE A- CARACTERISTICAS SOCIODEMOGRAFIACAS DA AMOSTRA

Table 1. Sociodemographic, anthropometric, dietary intake, serum levels of vitamins and carotenoids characteristics according to the food insecurity classification, 2017-2018.

Variables	Total sample (n=3092)	Food Security (n=2406)	Food Insecurity (n=686)	p-trend
Age, Years	49.16 ± 17.11	50.07 ± 16.71	44.67 ± 17.79	**<0.001**
Sex, %				0.233
Men	49.5 (47.1; 51.9)	50.0 (47.1; 52.9)	47.0 (43.1; 50.9)	
Women	50.5 (48.1; 52.9)	50.0 (47.1; 52.9)	53.0 (49.1; 56.9)	
Race/ Hispanic origin %				**0.001**
Mexican American	8.0 (5.1; 12.1)	6.4 (4.2; 9.6)	15.6(8.7; 26.4)	
Other Hispanic	6.5(4.8; 8.7)	5.3(4.0; 6.9)	12.5(7.9; 19.4)	
Non-Hispanic White	65.8 (58.6; 72.2)	69.2(61.4; 76.0)	48.7(38.7; 58.7)	
Non-Hispanic Black	10.4 (7.5; 14.4)	9.7(6.8; 13.6)	14.1 (9,4; 20.7)	
Other Race - Including Multi-Racial	9.3 (6.7; 12.8)	9.4(6.3; 13.8)	9.0(6.3; 12.9)	
Marital status, %				**<0.001**
Married/ living as married	63.6 (60.3; 66.7)	66.2 (62.8; 69.5)	50.8 (45.4; 56.1)	
Single/divorced/widowed/never married	36.4 (33.2; 39.6)	33.7 (30.5; 37.2)	49.2 (43.9; 54.5)	
Missing	-	0.1	-	
Per capita income				**<0.001**
$0-19.999	13.0 (10.5; 16.0)	8.1 (6.3; 10.4)	37.3 (30.1; 45.1)	
$20.000-54.999	33.0 (29.0; 37.4)	31.3 (27.3; 35.7)	41.6 (33.1; 50.5)	
$55.000-74.999	10.9 (8.7; 13.4)	11.5 (9.1;14.3)	7.7 (5.1; 11.5)	
Over $75.000	40.7 (35.6; 46.0)	46.8 (41.4; 52.4)	10.3 (4.5; 21.8)	
Missing	2.4 (1.7; 3.3)	2.2 (1.5; 3.4)	3.1 (1.7; 5.7)	
Educational level				**<0.001**
High school graduate or under	39.1 (34.2; 44.2)	34.6 (30.1; 39.4)	61.2 (53.2; 68.8)	
Some college or above	60.9 (55.8; 65.7)	65.3 (60.5; 69.9)	38.7 (31.2; 46.8)	
Missing	-	0.1	-	
Health conditions and habits				
Hypertension, %				0.440
Yes	33.1 (29.8; 36.5)	32.6 (29.3; 36.0)	35.6 (27.3; 44.8)	
No	66.8 (63.4; 70.0)	67.3 (63,9; 70.6)	64.1 (55.0; 72.3)	
Missing	0.1	0.1	0.3	
Diabetes, %				0.396
Pre Diabetes	2.7 (1.9; 3.7)	2.6 (1.8; 3.9)	2.7(1.3; 5.5)	
Yes	12.4 (10.8; 14.1)	12.1 (10.5; 13.9)	14.0 (9.7; 19.7)	
No	84.9 (83.4; 86.2)	85.2 (83.8; 86.4)	83.3 (77.9; 87.5)	
Missing	*	0.1	*	
Smoking %				**<0.001**
Yes	16.8 (13.8; 20.3)	13.1(10.4; 16.3)	35.0 (28.6; 41.8)	
No	83.2 (79.7; 86.2)	86.9 (83.7; 89.5)	65.0(58.2; 71.4)	
Missing				
Physical activity				**0.007**
Yes	54.3 (50.6; 58.0)	52.8(49.0;56.5)	61.8(55.5; 67.7)	
No	45.7(42.0;49.4)	47.2(43.4;51.0)	38.2(32.2; 44.5)	
Anthropometrics				
Weight, kg	84.4± 22.23	84.31 ± 21.36	84.82 ± 26.31	0.771
Height, m	1.68 ±0.10	1.68 ± 0.10	1.67 ± 0.11	**0.023**
Body mass index, kg/m^2	29.76 ± 7.13	29.63 ± 6.72	30.41 ± 9.14	0.204
Vitamin levels				
Vitamin E (umol/L)	29.42 ± 10.92	29.89 ± 10.83	27.07 ± 10.37	**<0.001**
Vitamin C (umol/L)	51.51 ± 28.48	52.47 ± 27.65	46.77 ± 31.47	**0.001**
Vitamin D 25OHD2+25OHD3 (nmol/L)	74.14 ± 30.51	75.71 ±29.7	66.35 ± 32.51	**<0.001**
Vitamin A, retinol (umol/L)	1.89 ± 0.56	1.92 ± 0.53	1.78 ± 0.64	**0.002**
Total carotenoids (µmol/L)	2.19 ± 1.11	2.24 ± 1.08	1.95 ± 1.18	**<0.001**
Alpha-carotene (umol/L)	0.1 ± 0.15	0.1 ± 0.15	0.07 ± 0.13	**0.003**
Alpha-cryptoxanthin (µmol/L)	0.05 ± 0.03	0.05 ±0.03	0.04 ± 0.03	0.160
Lycopene (µmol/L)	0.75 ± 0.35	0.76 ± 0.33	0.71 ± 0.41	**0.002**
Cisbetacaroteno (µmol/L)	0.02 ± 0.02	0.02 ± 0.02	0.01 ± 0.02	**<0.001**
Beta-cryptoxanthin (µmol/L)	0.16 ± 0.17	0.16 ±0.17	0.16 ± 0.21	0.764
Lutein + Zeaxanthin (µmol/L)	0.34 ± 0.23	0.35 ± 0.23	0.29 ± 0.25	**0.002**
Trans beta-carotene (µmol/L)	0.37 ± 0.44	0.39 ± 0.44	0.26 ± 0.38	**<0.001**
Translycopene (µmol/L)	0.41 ± 0.19	0.41 ± 0.19	0.39 ± 0.23	**0.005**
Dietary intake				
Energy, kcal	2096 ± 862	2099 ± 795	2083 ± 1195	0.753
Carbohydrate, g	239.52±108.96	237.37±100.43	250.20 ± 150.35	0.132
Protein, g	81.80 ± 37.03	82.67 ± 34.67	77.49 ± 48.38	0.092
Protein, g/kg	1.01 ± 0.49	1.02 ± 0.44	0.98 ± 0.74	0.577
Lipids, g	85.91 ± 41.91	87.00± 39.7	80.53 ± 52.30	**0.013**
Saturated fat, g	28.00 ± 15.04	28.34 ± 14.41	26.33 ± 17.91	0.040
Monounsaturated fat, g	29.57 ± 15.58	29.95 ± 14.60	27.64 ± 20.31	**0.019**

Polyunsaturated fat, g	20.00 ± 11.17	20.31 ± 10.68	18.48 ± 13.39	**0.006**
Fiber, g	16.64 ± 9.64	16.89 ± 9.14	15.39 ± 12.00	0.075
Vitamin E, as α-tocopherol (mg)	9.22 ± 6.04	9.38 ± 5.69	8.43 ± 7.69	0.047
Vitamin C (mg)	75.14 ± 69.85	76.61 ± 67.42	67.90 ± 80.53	0.092
Vitamin D (mcg)	4.26 ± 4.51	4.33 ± 4.47	3.92 ± 4.48	0.183
Vitamin A, RAE (mcg)	637.52±468.42	657.30±455.79	539.70±506.90	**0.001**
Total carotenoids (mcg)	9606 ±10743	9959 ±10675	7860 ±10278	0.009
Alpha-carotene (mcg)	380 ± 836	410 ± 845	230 ± 687	**<0.001**
Lycopene (mcg)	4968 ± 7852	5009 ±7662	4767 ± 8611	0.721
Beta-carotene (mcg)	2430 ± 3401	2604 ± 3402	1567 ± 2971	**<0.001**
Beta-cryptoxanthin (mcg)	85 ± 210	84 ± 176	93 ± 359	0.611
Lutein + Zeaxanthin (mcg)	1742 ± 3994	1851 ± 4133	1202 ± 2354	**0.003**
Alcohol, g	9 ± 21	9 ± 19	10 ± 30	0.526
Supplement use %				
Any dietary supplement	57.4 (52.6; 61.9)	58.8 (54.3; 63.1)	50.2 (43.4; 57.0)	**0.003**
Vitamin D (mcg)	41.2 (37.0; 45.5)	43.5 (39.1; 47.9)	29.9 (24.6; 35.9)	**0.001**
Vitamin C (mg)	35.8 (31.9; 39.9)	37.4 (33.4; 41.6)	27.8 (22.6; 33.6)	**0.003**
Lycopene (mcg)	11.3 (9.2; 13.8)	12.1(10.0; 14.5)	7.4 (4.6; 11.8)	**0.022**
Lutein + Zeaxanthin (mcg)	12.6 (10.2; 15.6)	13.4 (10.9; 16.3)	9.1 (5.6; 14.7)	0.097

Data are described as mean ± standard error or percentage (confidence interval).

APÊNDICE B – ASSOCIATION BETWEEN FOOD INSECURITY CLASSIFICATION AND SERUM LEVELS OF VITAMINS AND CAROTENOIDS IN THE TOTAL SAMPLE

Table 2 - Association between Food Insecurity classification and serum levels of vitamins and carotenoids in the total sample.

	Model 1		Model 2	
	β (95% CI)	P-value	β (95% CI)	P-value
Total sample				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-9.36 (-13.45; -5.26)	**<0.001**	-3.53(-10.04; 2.98)	0.265
Vitamin C (umol/L)	-5.70 (-8.70; -2.70)	**0.001**	-0.65 (-4.11; 2.82)	0.696
Vitamin E (umol/L)	-2.82 (-3.79; -1.86)	**<0.001**	-0.80 (-1.63; 0.03)	0.058
Retinol (umol/L)	-0.13 (-0.21; -.056)	**0.002**	-0.02 (-0.11; 0.07)	0.580
Carotenoids (μmol/L)	-0.29 (-0.38; -0.20)	**<0.001**	-0.099 (-0.192; -0.007)	**0.037**
Lycopene (μmol/L)	-0.05 (-0.08; -0.02)	**0.002**	-0.025 (-0.059; 0.009)	0.140
Alfa- cryptoxanthin (μmol/L)	-0.0018 (-0.0043; 0.0008)	0.160	-0.0008(-0.0032; 0.0016)	0.501
Beta- cryptoxanthin (μmol/L)	-0.004 (-0.029; 0.022)	0.764	0.007(-0.016; 0.030)	0.549
Cisbetacaroteno (μmol/L)	-0.006 (-0.008; -0.004)	**<0.001**	-0.002 (-0.0040; -0.00042)	**0.019**
Alpha-carotene (umol/L)	-0.026 (-0.041; -0.010)	**0.003**	-0.005(-0.018; 0.007)	0.385
Trans-beta-carotene (μmol/L)	-0.126 (-0.158; -0.093)	**<0.001**	-0.046 (-0.078; -0.013)	**0.009**
Lutein + Zeaxanthin (μmol/L)	-0.056 (-0.088; -0.024)	**0.002**	-0.015 (-0.046; 0.015)	0.297
Translycopene (μmol/L)	-0.023 (-0.038; -0.008)	**0.005**	-0.012 (-0.029; 0.006)	0.179

APÊNDICE C- ASSOCIATION BETWEEN FOOD INSECURITY CLASSIFICATION AND THE SERUM LEVELS OF VITAMINS AND CAROTENOIDS, STRATIFIED BY SEX

Table 3 – Association between Food Insecurity classification and the serum levels of vitamins and carotenoids, stratified by sex.

	Model 1		Model 2	
	β (95% CI)	P-value	β (95% CI)	P-value
Women				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-10.32 (-15.90; -4.75)	**0.001**	-3.19 (-12.04; 5.65)	0.453
Vitamin C (umol/L)	-9.32 (-13.55; -5.10)	**<0.001**	-2.89 (-7.44; 1.65)	0.195
Vitamin E (umol/L)	-2.35 (-3.56; -1.15)	**0.001**	0.24 (-1.51; 1.99)	0.772
Retinol (umol/L)	-0.119 (-0.187; -0.050)	**0.002**	-0.004(-0.105; 0.096)	0.926
Carotenoids (µmol/L)	-0.32 (-0.45; -0.19)	**<0.001**	-.073(-0.23; 0.08)	0.337
Lycopene (µmol/L)	-0.02 (-0.06; 0.02)	0.271	0.02 (-0.04; 0.08)	0.456
Alfa- cryptoxanthin (µmol/L)	-0.004 (-0.007; -.0006)	0.024	-0.002 (-0.007;0.002)	0.301
Beta- cryptoxanthin (µmol/L)	-0.016 (-0.045; 0.012)	0.246	-0.003 (-0.030;0.024)	0.833
Cisbetacaroteno (µmol/L)	-0.008 (-0.011; -0.006)	**<0.001**	-0.004 (-0.006;-0.001)	**0.003**
Alpha-carotene (umol/L)	-0.021 (-0.040; -0.001)	0.039	-0.002 (-0.021; 0.017)	0.822
Trans-beta-carotene (µmol/L)	-0.16 (-0.20; -0.11)	**<0.001**	-0.06 (-0.10; -0.02)	**0.003**
Lutein + Zeaxanthin (µmol/L)	-0.081 (-0.111; -0.052)	**<0.001**	-0.034(-0.070; 0.002)	0.063
Translycopene (µmol/L)	-0.008 (-0.031; 0.014)	0.446	0.014(-0.018; 0.046)	0.358
Men)				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-8.75 (-13.23; -4.27)	**0.001**	-4.00 (-8.92; 0.92)	0.103
Vitamin C (umol/L)	-2.23 (-6.87; 2.42)	0.323	1.70 (-3.16; 6.57)	0.467
Vitamin E (umol/L)	-3.44 (-5.44; -1.44)	**0.002**	-1.88 (-3.43; -0.32)	**0.022**
Retinol (umol/L)	-0.13 (-0.25; -0.02)	0.027	-0.05 (-0.14; 0.05)	0.329
Carotenoids (µmol/L)	-0.26 (-0.43; -0.10)	**0.004**	-0.14(-0.31; 0.02)	0.082
Lycopene (µmol/L)	-0.07 (-0.12; -0.02)	**0.007**	-0.08(-0.13; -0.02)	**0.007**
Alfa- cryptoxanthin (µmol/L)	0.0005 (-0.0039; 0.0048)	0.822	-0.0006 (-0.0032; 0.0044)	0.725
Beta- cryptoxanthin (µmol/L)	0.009 (-0.020; 0.040)	0.511	0.016 (-0.015; 0.047)	0.279
Cisbetacaroteno (µmol/L)	-0.004 (-0.005; -0.002)	**0.001**	-0.001 (-0.003; 0.001)	0.447
Alpha-carotene (umol/L)	-0.032 (-0.054; -0.011)	**0.006**	-0.011 (-0.026; 0.004)	0.142
Trans-beta-carotene (µmol/L)	-0.097 (-0.138; -0.057)	**<0.001**	-0.030 (-0.080; 0.020)	0.221
Lutein + Zeaxanthin (µmol/L)	-0.029 (-0.077; 0.019)	0.214	0.004 (-0.039; 0.047)	0.830
Translycopene (µmol/L)	-0.04 (-0.07; -0.01)	**0.010**	-0.04 (-0.07; -0.01)	**0.009**

APÊNDICE D- ASSOCIATION BETWEEN FOOD INSECURITY CLASSIFICATION AND THE SERUM LEVELS OF VITAMINS AND CAROTENOIDS, STRATIFIED BY AGE GROUP

Table 4 – Association between Food Insecurity classification and the serum levels of vitamins and carotenoids, stratified by age group.

	Model 1		Model 2	
	β (95% CI)	P-value	β (95% CI)	P-value
Total sample				
Young adults (< 60 anos)				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-4.42 (-9.61;0.77)	0.090	-1.46 (-7.46; 4.54)	0.611
Vitamin C (umol/L)	-2.70 (-6.27; 0.87)	0.128	1.50 (-2.08; 5.08)	0.386
Vitamin E (umol/L)	-1.21 (-2.24; -0.19)	0.023	-0.53 (-1.44; 0.38)	0.235
Retinol (umol/L)	-0.086 (-0.182; 0.009)	0.075	-0.021 (-0.140; 0.099)	0.718
Carotenoids (μmol/L)	-0.32 (-0.44; -0.20)	**<0.001**	-0.13 (-0.24; -0.02)	**0.021**
Lycopene (μmol/L)	-0.07 (-0.11; -0.02)	**0.007**	-0.04 (-0.10; 0.01)	0.092
Alfa- cryptoxanthin (μmol/L)	-0.00290 (-0.00584; 0.00005)	0.053	-0.00105 (-0.00323; 0.00112)	0.316
Beta- cryptoxanthin (μmol/L)	-0.005 (-0.029; 0.018)	0.629	0.004 (-0.018; 0.026)	0.686
Cisbetacaroteno (μmol/L)	-0.005 (-0.008; -0.003)	**<0.001**	-0.002 (-0.004; -0.001)	**0.009**
Alpha-carotene (umol/L)	-0.030 (-0.051; -0.008)	**0.010**	-0.008 (-0.024; 0.008)	0.300
Trans-beta-carotene (μmol/L)	-0.12 (-0.16; -0.07)	**<0.001**	-0.05 (-0.08;- 0.01)	**0.008**
Lutein + Zeaxanthin (μmol/L)	-0.06 (-0.09; -0.02)	**0.005**	-0.01 (-0.04; 0.02)	0.402
Translycopene (μmol/L)	-0.03 (-0.05; -0.01)	**0.010**	-0.02 (-0.05; 0.01)	0.134
Older adults (≥ 60 anos)				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-13.88 (-19.22; -8.54)	**<0.001**	-9.49 (-17.18; -1.80)	**0.019**
Vitamin C (umol/L)	-10.68 (-19.09; -2.28)	**0.016**	-5.66 (-14.88; 3.57)	0.211
Vitamin E (umol/L)	-4.90 (-6.61; -3.19)	**<0.001**	-2.83 (-5.16; -0.50)	**0.021**
Retinol (umol/L)	-0.16 (-0.28; -0.05)	**0.007**	-0.05 (-0.17; 0.07)	0.388
Carotenoids (μmol/L)	-0.29 (-0.51; -0.07)	**0.013**	-0.13 (-0.39; 0.13)	0.299
Lycopene (μmol/L)	-0.067 (-0.136; 0.002)	0.057	-0.038 (-0.100; 0.024)	0.212
Alfa- cryptoxanthin (μmol/L)	-0.003 (-0.008; 0.003)	0.348	-0.002 (-0.008; 0.004)	0.501
Beta- cryptoxanthin (μmol/L)	-0.0096 (-0.0518; 0.0325)	0.633	0.0002 (-0.0478; 0.0482)	0.994
Cisbetacaroteno (μmol/L)	-0.0045 (-0.0092; 0.0001)	0.054	-0.0014 (-0.0064; 0.0035)	0.552
Alpha-carotene (umol/L)	-0.0137 (-0.0454; 0.0180)	0.373	0.0002 (-0.0368; 0.0372)	0.992
Trans-beta-carotene (μmol/L)	-0.111 (-0.205; -0.017)	**0.024**	-0.043 (-0.147; 0.062)	0.395
Lutein + Zeaxanthin (μmol/L)	-0.04 (-0.09; 0.02)	0.163	-0.03 (-0.09; 0.04)	0.416
Translycopene (μmol/L)	-0.0418 (-0.0837; 0.0002)	0.051	-0.0219 (-0.0612; 0.0174)	0.253

APÊNDICE E- ASSOCIATION BETWEEN FOOD INSECURITY CLASSIFICATION AND THE SERUM LEVELS OF VITAMINS AND CAROTENOIDS, STRATIFIED BY RACE/ETHNICITY

Table 5 – Association between Food Insecurity classification and the serum levels of vitamins and carotenoids, stratified by race/ethnicity.

	Model 1		Model 2	
	β (95% CI)	P-value	β (95% CI)	P-value
Total sample				
Mexican American				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-5.97 (-13.26; 1.31)	0.097	-1.17 (-8.81; 6.47)	0.737
Vitamin C (umol/L)	-1.79 (-6.91; 3.33)	0.449	0.70 (-3.81; 5.21)	0.733
Vitamin E (umol/L)	-2.19 (-5.03; 0.65)	0.115	-0.52 (-3.10; 2.06)	0.660
Retinol (umol/L)	-0.06 (-0.22; 0.09)	0.395	0.04 (-0.12; 0.20)	0.583
Carotenoids (µmol/L)	-0.11 (-0.42; 0.21)	0.458	-0.02 (-0.32; 0.28)	0.887
Lycopene (µmol/L)	-0.07 (-0.18; 0.04)	0.170	-0.03 (-0.10; 0.04)	0.374
Alfa- cryptoxanthin (µmol/L)	-0.001 (-0.010; 0.009)	0.848	-0.002 (-0.015; 0.012)	0.755
Beta- cryptoxanthin (µmol/L)	0.02 (-0.04; 0.09)	0.423	0.01 (-0.08; 0.10)	0.790
Cisbetacaroteno (µmol/L)	-0.00040 (-0.00551; 0.00470)	0.862	0.00002 (-0.00505; 0.00510)	0.992
Alpha-carotene (umol/L)	-0.002 (-0.033;0.029)	0.871	0.002 (-0.030; 0.034)	0.882
Trans-beta-carotene (µmol/L)	-0.003 (-0.101; 0.095)	0.947	0.005 (-0.099; 0.109)	0.917
Lutein + Zeaxanthin (µmol/L)	-0.012 (-0.078; 0.054)	0.695	0.006 (-0.059; 0.071)	0.843
Translycopene (µmol/L)	-0.04 (-0.10; 0.02)	0.202	-0.01 (-0.05; 0.02)	0.459
Others Hispanics				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-1.43 (-7.83; 4.96)	0.637	2.20 (-5.84; 10.24)	0.565
Vitamin C (umol/L)	-4.40 (-11.93; 3.12)	0.228	-3.00 (-10.77; 4.77)	0.419
Vitamin E (umol/L)	-0.26 (-2.88; 2.35)	0.830	-0.27 (-3.28; 3.28)	0.873
Retinol (umol/L)	-0.09 (-0.24; 0.06)	0.209	-0.05 (-0.25; 0.15)	0.627
Carotenoids (µmol/L)	-0.02 (-0.64; 0.61)	0.954	0.12 (-0.45; 0.70)	0.645
Lycopene (µmol/L)	-0.02 (-0.21; 0.17)	0.835	-0.02 (-0.22; 0.18)	0.838
Alfa- cryptoxanthin (µmol/L)	-0.002 (-0.014; 0.009)	0.673	0.001 (-0.012; 0.014)	0.877
Beta- cryptoxanthin (µmol/L)	-0.03 (-0.10; 0.04)	0.423	-0.01 (-0.08; 0,05)	0.654
Cisbetacaroteno (µmol/L)	0.0003 (-0.0075; 0.0081)	0.933	0.0029 (-0.0054; 0.0112)	0.464
Alpha-carotene (umol/L)	0.03 (-0.03; 0.09)	0.311	0.04 (-0.02; 0.10)	0.218
Trans-beta-carotene (µmol/L)	0.01 (-0.17; 0.19)	0.894	0.07 (-0.11; 0.26)	0.403
Lutein + Zeaxanthin (µmol/L)	-0.004 (-0.105; 0.097)	0.928	0.047 (-0.028; 0.122)	0.201
Translycopene (µmol/L)	-0.006 (-0.099; 0.087)	0.893	-0.002 (-0.103; 0.098)	0.962
Non-hispanic white				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-6.70 (-10.83; -2.57)	**0.004**	-2.53 (-9.95; 4.89)	0.478
Vitamin C (umol/L)	-7.27 (-13.17; -1.36)	**0.019**	-0.27 (-7.51; 6.98)	0.938
Vitamin E (umol/L)	-3.58 (-5.10; -2.05)	**<0.001**	-1.07 (-3.11; 0.97)	0.280
Retinol (umol/L)	-0.09 (-0.22; 0.03)	0.130	0.02 (-0.14; 0.19)	0.769

Carotenoids (µmol/L)	-0.50 (-0.63; -0.36)	**<0.001**	-0.27 (-0.41; -0.13)	**0.001**
Lycopene (µmol/L)	-0.08 (-0.14; -0.01)	**0.020**	-0.05 (-0.13; 0.02)	0.133
Alfa- cryptoxanthin (µmol/L)	-0.008 (-0.012; -0.004)	**0.001**	-0.005 (-.009; 0.001)	0.026
Beta- cryptoxanthin (µmol/L)	-0.03 (-0.05; -0.02)	**0.001**	-0.01 (-0.03; 0.001)	0.176
Cisbetacaroteno (µmol/L)	-0.008 (-0.010; -0.006)	**<0.001**	-0.004 (-0.006; -0.002)	**<0.001**
Alpha-carotene (umol/L)	-0.042 (-0.065; -0.019)	**0.002**	-0.015 (-0.032; 0.002)	0.083
Trans-beta-carotene (µmol/L)	-0.19 (-0.23; -0.15)	**<0.001**	-0.09 (-0.13; -0.06)	**<0.001**
Lutein + Zeaxanthin (µmol/L)	-0.09 (-0.14; -0.05)	**<0.001**	-0.05 (-0.09; -0.01)	**0.015**
Translycopene (µmol/L)	-0.04 (-0.08; -0.01)	**0.021**	-0.03 (-0.07; 0.01)	0.107
Non-hispanic Black				
Vitamin D 25OHD2+25OHD3 (nmol/L)	-6.70 (-12.01; -1.40)	**0.017**	-3.27 (-8.93; 2.40)	0.238
Vitamin C (umol/L)	0.47 (-5.00; 5.95)	0.856	1.28 (-4.47; 7.03)	0.642
Vitamin E (umol/L)	-0.92 (-2.82; 0.97)	0.317	0.13 (-1.12; 1.37)	0.830
Retinol (umol/L)	-0.10 (-0.24; 0.04)	0.149	-0.03 (-0.17; 0.10)	0.628
Carotenoids (µmol/L)	-0.18 (-0.39; 0.03)	0.095	-0.03 (-0.22; 0.17)	0.755
Lycopene (µmol/L)	-0.02 (-0.10; 0.06)	0.589	0.01 (-0.07; 0.09)	0.824
Alfa- cryptoxanthin (µmol/L)	-0.004 (-0.010; 0.003)	0.247	-0.001 (-0.006; 0.004)	0.630
Beta- cryptoxanthin (µmol/L)	-0.013 (-0.031;0.006)	0.167	-0.007 (-0.024; 0.010)	0.390
Cisbetacaroteno (µmol/L)	-0.0037 (-0.0068; -0.0007)	**0.020**	-0.0015 (-0.0053; 0.0023)	0.416
Alpha-carotene (umol/L)	-0.038 (-0.078; 0.002)	0.063	-0.023 (-0.065; 0.018)	0.246
Trans-beta-carotene (µmol/L)	-0.07 (-0.12; -0.02)	**0.012**	-0.03 (-0.10; 0.04)	0.414
Lutein + Zeaxanthin (µmol/L)	-0.026 (-0.068; 0.016)	0.211	0.006 (-0.021; 0.034)	0.613
Translycopene (µmol/L)	-0.0006 (-0.0445; 0.0433)	0.976	0.0161 (-0.0260; 0.0583)	0.427
Multirracial / Other race				
Vitamin D 25OHD2+25OHD3 (nmol/L)	1.01 (-10.44; 12.47)	0.853	4.61 (-4.91; 14.13)	0.319
Vitamin C (umol/L)	-10.11 (-17.19; -3.04)	**0.008**	-5.03 (-11.65; 1.59)	0.127
Vitamin E (umol/L)	-3.27 (-7.09; 0.55)	0.088	-1.97 (-6.46; 2.51)	0.363
Retinol (umol/L)	-0.145 (-0.286; -0.004)	**0.045**	-0.091 (-0.268; 0.085)	0.286
Carotenoids (µmol/L)	-0.49 (-0.83; -0.15)	**0.008**	-0.27 (-0.63; 0.09)	0.134
Lycopene (µmol/L)	0.03 (-0.11; 0.17)	0.662	0.01 (-0.14; 0.15)	0.904
Alfa- cryptoxanthin (µmol/L)	-0.009 (-0.015;0.003)	**0.005**	-0.002 (-0.008; 0.003)	0.362
Beta- cryptoxanthin (µmol/L)	-0.06 (-0.15; 0.03)	0.160	-0.01 (-0.11; 0.08)	0.763
Cisbetacaroteno (µmol/L)	-0.014 (-0.018; -0.010)	**<0.001**	-0.009 (-0.015; -0.002)	**0.010**
Alpha-carotene (umol/L)	-0.061 (-0.077; -0.046)	**<0.001**	-0.036 (-0.068; 0.004)	**0.030**
Trans-beta-carotene (µmol/L)	-0.28 (-0.37; -0.20)	**<0.001**	-0.17 (-0.28; -0.06)	**0.004**
Lutein + Zeaxanthin (µmol/L)	-0.13 (-0.20; -0.07)	**<0.001**	-0.08 (-0.13; -0.02)	**0.011**
Translycopene (µmol/L)	0.04 (-0.03; 0.12)	0.249	0.03 (-0.05; 0.11)	0.408