frontiers | Research Topics

Learning from global food and nutrition insecurity

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Published in
Frontiers in Public Health
Frontiers in Nutrition

ISSN 1664-8714
ISBN 978-2-8325-5636-8
DOI 10.3389/978-2-8325-5636-8

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Learning from global food and nutrition insecurity

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Citation

Perez-Escamilla, R., Laar, A., Vorkoper, S., eds. (2024). *Learning from global food and nutrition insecurity*. Lausanne: Frontiers Media SA.

doi: 10.3389/978-2-8325-5636-8

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frontiers | Frontiers in Public Health

TYPE Editorial
PUBLISHED 18 October 2024
DOI 10.3389/fpubh.2024.1478523

OPEN ACCESS

EDITED AND REVIEWED BY
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RECEIVED 09 August 2024
ACCEPTED 26 September 2024
PUBLISHED 18 October 2024

CITATION
Laar A, Vorkoper S and Pérez-Escamilla R (2024) Editorial: Learning from global food and nutrition insecurity.
Front. Public Health 12:1478523.
doi: 10.3389/fpubh.2024.1478523

Editorial: Learning from global food and nutrition insecurity

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KEYWORDS

global food insecurity, across borders, challenges, opportunities, constructs, measurement, frameworks

Editorial on the Research Topic
Learning from global food and nutrition insecurity

As the physical, economic, and epistemic access to healthy, nutritious, and safe food becomes increasingly unreliable particularly among the world's low-income groups, research on food and nutrition insecurity and dissemination of the results remains critically important both within local contexts and on the global stage. As governments worldwide become increasingly interested in developing and implementing novel and effective policy approaches to address food insecurity, it is key for researchers to help improve the stakeholders' understanding of the root causes and consequences of food and nutrition insecurity, including the inequitable distribution of the triple burden of malnutrition (1). Among others, this can be done through collaborative multidisciplinary research, evaluation and dissemination endeavors. Over the past decades, the relevant fields in this space have gained a better understanding of the epidemiology of food and nutrition insecurity within and across countries as well as its causes and consequences, although much less is known about structural policy solutions (1–3). Where evidence and knowledge exist, they tends to stay siloed and have not been extensively shared across countries and regions. This gap has led to calls for the establishment of food and nutrition and water security research networks and knowledge sharing platforms across the globe (4).

Despite the global awareness about the crucial importance of food and nutrition security for human health (1) among civil society organizations, international health agencies, and scholars, there has been little dissemination of successfully implemented and evaluated evidence-based food and nutrition security policies between countries with very few exceptions (5–7). Sharing research strategies and proven methods among researchers, policymakers, consumers and other food systems actors worldwide can help identify promising initiatives for local adaptation and implementation. For instance, by sharing experiences with evidence-informed strategies shown to be effective when properly adapted to the needs of different contexts, the world may reach a turning point to prevent and mitigate the acute and chronic food insecurity crises that have spread all over the globe. Such experiences may be shared among experts via scientific publications, expert-expert, or expert-lay people via stakeholder engagements, and government-to-people via policies.

In response to this need for broader sharing and collaboration across borders, this Research Topic emphasizes opportunities for mutual learning among researchers around the world on promising food and nutrition insecurity research. It is grounded in the Fogarty International Center's webinar series on "*Lessons learned from global food and nutrition insecurity*" conducted in the Fall of 2022. The three-part webinar series

highlighted robust food and nutrition security conceptual frameworks, measurement, and indicators; innovative policy-relevant research examining the intersections of food and nutrition insecurity with other social determinants of health including water insecurity; and how these relate to poor physical and mental health outcomes worldwide. The importance of using household food insecurity experience scales for conducting research and program monitoring and evaluation was strongly highlighted as a success story of what happens when countries share their research and experiences with each other. In this instance, an initiative that started in the US rapidly disseminated globally to support regions around the world with similar efforts (5, 8).

Through this food and nutrition insecurity Research Topic, we aimed to (i) map out the food and nutrition security globally agreed upon definitions, frameworks, measurement tools, and indicators, (ii) describe the foodscapes and landscapes of global food insecurity, (iii) identify promising opportunities for implementation of effective policies and programs across different settings; and (iv) spotlight pivotal food insecurity research gaps that need to be addressed through global networks of researchers. Such sharing is needed if food insecurity and malnutrition in all its forms are to be sustainably addressed by 2030 as outlined in the United Nations Sustainability Goals.

Pérez-Escamilla sets the stage by elaborating on the food and nutrition security definitions, constructs, frameworks, and measurements of food and nutrition security, as well as applications of lessons learned at the global level. Developing and using globally agreed upon evidence-informed definitions, frameworks and measurement approaches are key given that food security is a powerful social determinant of health that is crucial for human health and planetary health (1). In this article, he makes the case for countries to benefit from the rich global experience of applying experience-based household food insecurity scales to improve our understanding across the globe of the distribution and root and more immediate causes of food and nutrition insecurity as well as its consequences for human and planetary health and for evaluating the impact of interventions designed to address it. As he points out, food security has traditionally been framed by four key dimensions, which together ensure that all people have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life—in the context of food "availability; access; utilization; and stability" (1). Recently, discussions have expanded to include the dimensions of "agency," and "sustainability," acknowledging their critical role in achieving food security (9, 10, 19). Including agency as a dimension of food security reflects a holistic understanding that achieving food security is not only about meeting physical needs but also about ensuring that people have the knowledge, capabilities, and freedoms to secure their dietary needs in a way that is sustainable and equitable.

Two studies focused on breastfeeding, which is a key element of the "first food systems" during the first 1,000+ days of life (11). They examined the economic benefits of breastfeeding (Smith et al.), and global lessons for strengthening breastfeeding as a key pillar of food security (Tomori). The Mothers' Milk Tool was developed to increase the visibility of the economic value that women's unpaid care work through breastfeeding infants and young children contributes to society. Smith et al. describe the development and key features of the tool, and report results for selected countries ($n = 14$) high-, middle- and low-income countries. Globally, breastfeeding women produce around 35.6 billion liters of milk annually, but 38.2% is currently "lost." The concept of "breastmilk loss" refers to the quantity of breastmilk that is not utilized for breastfeeding despite the capacity and potential availability to do so. Such losses, Smith et al. note, are usually due to cultural and structural barriers to breastfeeding. The Mother's Milk tool is valuable to food and health policymakers, advocates, researchers, and individual mothers by attributing a monetary value to breastmilk production. It shows what is at risk economically for nations and the world if women's capacity for breastfeeding is not protected, promoted, and supported by effective national policies, programs, and investments. Tomori presents the global lessons for strengthening breastfeeding as a key pillar of food security. This paper highlights the central importance of breastfeeding for food security across diverse global settings by examining three case studies from Honduras, Pakistan, and the USA. Lessons drawn from these case studies (including low prioritizing of breastfeeding and suboptimal incorporation of infant and young child feeding protocols into disaster preparedness into the policy agenda, as well as ensuring that first food security is considered in energy policy) reinforce the importance of multisectoral collaboration to scale up investment in creating equitable, enabling environments for breastfeeding. An integrated approach to policy change is necessary to recognize and strengthen breastfeeding as a pivotal part of ensuring food security across the globe (Tomori).

Two other studies address food insecurity among adolescents. Sridhar et al. responds to the many global calls not to leave the adolescents behind in the global fight against food insecurity and malnutrition. Adolescents make up roughly a quarter of the population in Zambia; however, most food and nutrition security-related programming is targeted at children under 5 years old. Their work shows that the prevalence of malnutrition in adolescents and older children living in a Zambian district was comparable to those under five calling for interventions that address both age groups. In a separate study, Osei Bonsu et al. used data from the global in-school students survey to examine the relationship between food insecurity and sleep disturbance among almost 200,000 school going adolescents They concluded that reducing food insecurity could be an effective policy strategy for enhancing adolescent sleep quality and thus overall quality of life. A youth-focused study by Mokari-Yamchi et al. utilized data from the US National Health and Nutrition Examination Survey 2017–2018 to examine the prevalence of household food insecurity in connection with specific sociodemographic factors and its association with obesity. Their analysis revealed that youth from food insecure households were more likely to be obese (adjusted odds ratio [aOR]: 1.59, 95% confidence interval [CI]: 1.19–2.13) and to have abdominal obesity (aOR: 1.56, 95% CI: 1.19–2.03). In contrast, factors such as having a head of household with a college degree and a household income exceeding 350% of the poverty line were associated with a reduced risk of experiencing household food insecurity.

Focusing on two sub-Saharan Africa countries—Ethiopia and Tanzania—two studies examined different dimensions of food security including food availability in Ethiopia (Wubetie et al.), agency in rural Tanzania (Madzorera et al.). Wubetie et al. examined the levels of household food insecurity in Ethiopia considering geographic, environmental, and socioeconomic variables and compared this to measurements of food insecurity in Ethiopia using the United Nations World Food Program's Food Consumption Score. They conclude that the -recommended cut off points in WFP consumption score underestimated the prevalence of household food insecurity, which has both policy and programmatic implications. Madzorera et al. evaluated the associations of women's participation and decision-making in key agricultural and household activities with women's diet quality. They found that women's input and decision-making in agriculture were associated with improved diet quality in rural Tanzania.

Martinez-Brockman et al. examined the risk factors for household food insecurity using data from the Eastern Caribbean Health Outcomes Research Network Cohort (ECHORN). They showed that demographic, psychosocial, behavioral, and environmental risk factors were associated with household food insecurity among adults 40 years of age or older in the ECHORN cohort. In contrast to previous studies, the researchers did not find that women in the cohort had a higher risk of household food insecurity compared to men, although a different set of risk factors affected men and their vulnerability to household food insecurity. This underscores the complexity and multidimensionality of how different factors affect household food insecurity across different contexts.

Gaitán-Rossi et al. examined the persistence of household food insecurity in the context of the COVID-19 pandemic in Mexico using machine learning to identify predictors of persistent moderate or severe household food insecurity. They found that the most consistent and influential predictors of household food insecurity were household food insecurity at the beginning of the study period, lower socioeconomic status, not being able to adopt financial coping strategies, and not receiving government support. The authors suggest that governments should consider these factors for identifying households that may be less responsive to food insecurity policies when prioritizing government support.

Two papers in this Research Topic looked at the implications of external shocks on food insecurity. Bangham et al. examined the effect of adverse economic events (including job loss, changes in family structure, and poor health) on hunger severity among food pantry clients in Boston, USA. Their data show that unexpected or increased medical expenses, job loss, pay reduction, and the death of a family member were associated with moderate to severe hunger. They concluded that anticipating the impact of adverse economic events on food insecurity can inform preparedness for public health programs and policies for people in need of additional resources, which is essential for their wellbeing in times of increased economic instability. Using a case study approach, Dietz and Fanzo explored the bidirectional relationship of the U.S. agrifood sector to climate change. For instance, cattle production for beef consumption generates methane and nitrous oxide, both of which are potent greenhouse gases. These gases contribute to global warming which in turn increases the frequency and strength of adverse catastrophic events, which compromise the food supply. Increased greenhouse gases also affect crop yields and the micronutrient content of crops, which adversely affect the prevalence of food and nutrition insecurity, particularly in low- and middle-income countries. Such complexities impact the ability to develop sustainable food systems and call for meaningful and sufficient engagements of key food systems actors, emphasizing the critical need to build the political will for change. Both articles clearly illustrate the need for local solutions to collectively address a global existential problem and the engagement of the community through knowledge sharing platforms and robust action-oriented evidence-informed networks.

Finally, two studies examined "produce prescription" programs that are part of the US "Food is Medicine" initiative. Broadly, food as medicine interventions address food insecurity among patients and at the same time deploy nutrition-based interventions many of them targeting chronic diseases (12–14). Among others, these programs improve food security by increasing access to fresh fruit and vegetable consumption, by giving money to their clients earmarked for purchasing fresh produce in local supermarkets and other food retailers. Owens et al. evaluated a hospital-based food and nutrition programming. The program was delivered by a level 1 trauma health care system in Atlanta, Georgia, USA in partnership with community-based organizations. They found that the Food as Medicine program provides a novel model for building health equity through food within healthcare organizations. They concluded that the intervention was feasible but required further improvements for further successful scale up or transferability toward improving food security and human wellbeing for patients nationwide. Clients' experiences and satisfaction with "produce prescription" programs targeting low-income people in California were examined in a rich qualitative study by Rhodes et al.. While evidence shows that produce prescription programs can improve food security, fruit, and vegetable consumption, and ultimately health outcomes, clients' satisfaction with the programs is critical. Clients' experiences and satisfaction with "produce prescription" programs targeting low-income people in California were examined in a rich qualitative study by Rhodes et al.. While evidence shows that produce prescription programs can improve food security, fruit, and vegetable consumption, and ultimately health outcomes, clients' satisfaction with the programs is critical. Rhodes et al. reported that clients were quite satisfied with the program but at the same time offered recommendations on how to ensure that the programs services are delivered with dignity and respect to all clients. Their findings inform efforts to make "produce prescription" programs more person-centered and respectful, which in turn may increase program demand, engagement, and impact. As other countries conduct or consider initiating similar prescription programs, the evidence provided in this article could help inform the program co-design and implementation approaches.

The series of articles in this Research Topic represent some of the global nutrition and food insecurity research happening across

the lifespan and explores innovative research interventions and methodologies on food insecurity that is of critical importance both domestically and abroad highlighting opportunities for mutual learning. As an example, the paper by Smith et al. (15) was recently cited in the Bulletin of the World Health Organization in an article detailing why evidence-based breastfeeding protection, promotion, and support should be officially incorporated by governments all over the world as a carbon offset intervention to mitigate climate change. It is our hope that this Research Topic can inform efforts to find better ways to improve food and nutrition security governance (5), policies, and programs around the world, particularly in areas where people are disproportionately affected by food insecurity as this condition has wide-ranging short- and long-term physical and mental health consequences.

To conclude, it is apropos to note the need to address the ongoing debates surrounding definitions and frameworks of global food and nutrition insecurity, which are often shaped by the perspectives of the Global North. These definitions can reflect cultural values that may not resonate with or apply to the diverse realities of those living in the Global South. Additionally, the dynamics of global trade play a significant role in shaping food insecurity. Power relations inherent in trade agreements and policies often exacerbate vulnerabilities for low-income groups, both in the Global South and within marginalized communities in the Global North.

Moving forward therefore, it is essential to fully incorporate the viewpoints of those affected by food insecurity, particularly people in the Global South and low-income populations in the Global North. This balanced approach will enhance our understanding of food insecurity and inform the development of equitable, well-coordinated policies across social, economic, agricultural, and healthcare sectors (16–19). Addressing the power imbalances in global trade is vital, as these imbalances significantly impact social determinants of health inequities, including food insecurity, within unhealthy and unsustainable food systems (1).

Author contributions

AL: Conceptualization, Writing – original draft, Writing – review & editing. SV: Conceptualization, Resources, Writing – original draft, Writing – review & editing. RP-E: Conceptualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work derives from the Fogarty International Center's webinar series on "Lessons Learned from Global Food and Nutrition Insecurity" conducted in the Fall of 2022.

Conflict of interest

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frontiers | Frontiers in Public Health

TYPE Methods
PUBLISHED 30 March 2023
DOI 10.3389/fpubh.2023.1152659

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Public Health and Nutrition, a section of the journal Frontiers in Public Health

RECEIVED 28 January 2023
ACCEPTED 06 March 2023
PUBLISHED 30 March 2023

CITATION
Smith JP, Iellamo A, Nguyen TT and Mathisen R (2023) The volume and monetary value of human milk produced by the world's breastfeeding mothers: Results from a new tool. *Front. Public Health* 11:1152659. doi: 10.3389/fpubh.2023.1152659

The volume and monetary value of human milk produced by the world's breastfeeding mothers: Results from a new tool

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The Mothers' Milk Tool was developed to make more visible the economic value contributed to society by women's unpaid care work through breastfeeding infants and young children. This manuscript describes the development and display key features of the tool, and reports results for selected countries. For the development, we used five steps: (1) defining the tool by reviewing existing tools and scholarly literature to identify uses, approaches, design features, and required data characteristics for a suitable product; (2) specifying the best open-access data available for measurement and easy updating; (3) analyzing development options; (4) testing predictive models to fill identified breastfeeding data gaps; and (5) validating the tool with prospective users and against previous research. We developed an Excel-based tool that allows working offline, displaying preloaded data, imputing data, and inputting users' data. It calculates annual quantities of milk produced by breastfeeding women for children aged 0–35.9 months, and the quantities lost compared to a defined biologically feasible level. It supports calculations for an individual mother, for countries, and global level. Breastfeeding women globally produce around 35.6 billion liters of milk annually, but 38.2% is currently "lost" due to cultural barriers and structural impediments to breastfeeding. The tool can also attribute a monetary value to the production. In conclusion, the Mothers' Milk Tool shows what is at risk economically if women's important capacity for breastfeeding is not protected, promoted, and supported by effective national policies, programs, and investments. The tool is of value to food and health policymakers, public officials, advocates, researchers, national accountants and statisticians, and individual mother/baby dyads, and will assist consideration of breastfeeding in food balance sheets and economic production statistics. The tool supports the 2015 Call to Action by the Global Breastfeeding Collective by facilitating the tracking of progress on breastfeeding targets.

KEYWORDS

breastfeeding, economic evaluation, feminist economics, milk production, food systems, maternal and child health, reproductive labor, unpaid work and production

Highlights

- Milk provided by breastfeeding mothers is a crucial but largely invisible national food resource.
- The economic value of women's milk production can and should be measured, to ensure this contribution is visible and properly valued.
- Much valuable production of this food is "lost" due to cultural barriers and structural impediments to breastfeeding.
- Supportive breastfeeding culture is an important national capital asset with large economic value.
- Breastfeeding provides food security for a country's children while minimizing food system pressures on the environment.

1. Introduction

1.1. The importance of breastfeeding for nutrition and health

A large volume of epidemiological evidence and many studies reaffirm the nutrition and health impacts of breastfeeding and support a growing global focus on the investment case for breastfeeding promotion. Lack of breastfeeding costs lives, and deprives young children, their mothers, and their countries of important health, human capital, and economic impacts (1–3).

The economic contribution made by women through breastfeeding is still largely invisible in economic data and fiscal decision-making (3). Applying economic frameworks for analyzing human milk production may raise awareness of the public policy importance of women's economic productivity in this unique unpaid care work.

Economists have long been aware of the limitations of conventional economic accounting systems for measuring economic activity and material well-being (4–8). Feminist economists have criticized the failure of the System of National Accounting (SNA) to count women's unpaid and reproductive work as economic production and its exclusion from supposedly objective measures such as Gross Domestic Product (GDP), which, in principle, covers all transactions in economic goods and services. In her 1988 book, *Counting for Nothing*, Marilyn Waring discussed (9) the need to value women's work, including reproductive and care work such as breastfeeding, in GDP.

Economic statisticians and national accounting experts have now acknowledged the crucial, unpaid role of families in building human capital, such as through investments of parental time in health care and education (10). Indeed, a 2009 review of GDP measurement for the French President led by two of the world's leading economists, Nobel prize-winners Amartya Sen and Joseph Stiglitz (11), cited human milk production as an example of how current practices for measuring GDP devalued women's unpaid work and biased policymaking. They stated that breastmilk constitutes a "serious omission in the valuation of home-produced goods, which is clearly within the SNA production boundary, is quantitatively non-trivial and has important implications for public policy and child and maternal health."

The invisibility of women's economic contribution in national economic statistics contributes to policy bias against protecting and resourcing nonmarket production (12). Scholars have pointed out the significant consequences of the lack of recognition of women's unpaid work for policy advocacy, design, implementation, and evaluation (12–14). Policies that acknowledge the importance of the valuable non-market production involved in breastfeeding, and the need to protect it, include "breastfeeding-friendly" health and maternity care services, more adequate paid maternity leave, and effective regulation of marketing and promotion of breastmilk substitutes. Such policies are identified in the WHO/UNICEF *Global Strategy* (15), and more recently represented in the 2015 Call for Action on Breastfeeding (16). The latter particularly emphasized the importance of strengthening monitoring systems to track progress toward achieving global and national policy targets on breastfeeding.

Ignoring breastfeeding also discounts the highly valuable role families, and in particular, mothers, play in human capital development (10). However, more than three decades on from changes to the SNA in 1993 that allow for counting human milk production in GDP, the problem of valuing breastfeeding in economic statistics remains largely unaddressed and ignored in public policy formulation (17).

1.2. Including human milk in food statistics and GDP

Broadly, there are three types of macroeconomic studies of breastfeeding, including studies on (1) the economic and health system costs of low breastfeeding rates; (2) the costs of breastfeeding protection, promotion, and support programs; and (3) the economic value of breastfeeding and economic costs of 'lost milk'.

Two existing online tools - the Cost of Not Breastfeeding (CNB) Tool, and the World Breastfeeding Costing Initiative (the WBCi Costing Tool) - provide the means to calculate the country-level costs of not breastfeeding (2, 18), and the financing needs to invest in implementing strategies on infant and young child feeding (19). The PROFILES Tool for Calculating Health, Child Spacing and Economic Benefits of Breastfeeding (BOB) was developed as part of a larger process of nutrition policy dialogue to calculate the costs of not breastfeeding alongside the macroeconomic value of breastfeeding (18, 20) but has not been widely used or promoted.

The Mothers' Milk Tool has been developed to complement and build on these other tools. The tool makes visible the economic value contributed to society by women's unpaid care work through breastfeeding infants and young children.

1.3. Aims

To develop an online and downloadable tool to estimate the economic value of breastfeeding and the monetary value of "mothers' milk." We envisage that this evidence-based and user-friendly "mothers' milk" tool will be used by policymakers, advocates, national accountants/statisticians, and researchers to estimate the economic value of breastfeeding and the economic

costs of "lost mothers' milk" to support advocacy for breastfeeding-friendly environments. Specific objectives are to (1) describe the development process of the tool, (2) display key features of the tool, and (3) report estimates for selected countries.

2. Methods

The design of the Mothers' Milk Tool draws on more than 40 years of research. The development process used 5 steps: define, measure, analyze, design and develop, and verify - DMADV (21, 22).

2.1. Step 1: Definition

2.1.1. Users and uses

In the first step, existing tools and scholarly literature estimating the economic value of breastfeeding were reviewed to identify uses, approaches, design features, and data that could be adopted in the development and definition of a suitable product. To identify the key design and methodological issues for such studies, a detailed review was conducted to identify all relevant studies of the macroeconomic value of breastfeeding, and extract summary data on their coverage, data, methods, and results.

The review identified that significant but diverse literature exists on the economic value of breastfeeding. The review found around 65 country estimates of the macroeconomic value of breastfeeding, for a total of around 25 countries.

The geographic areas covered included Europe, Asia, America, Africa, and Australasia. Several studies produced estimates for groups of countries, and/or for the whole world. Estimates go as far back as 1908, and up to 2018, and for several countries in the 1950s, 1960s, and 1970s. Most identified the quantities and values of milk produced for infant and young child populations aged 0–23.9 months. However, some country estimates were for ages 0–35.9 months. A small number of estimates were of breastmilk supplied for infants only, aged 0–11.9 months or less. The results of the review confirmed not only the relevance but also the feasibility, utility, and sustainability of counting breastmilk as part of national economic statistics. Norway's reporting systems were identified as a model for initial steps toward making the value of mothers' milk visible within a food surveillance framework.

This review also considered the potential uses and users of the tool. Most studies aimed to improve the visibility of breastfeeding; motivations included the desire to provide better scientific information for public policy and budgeting decisions; reduce the public invisibility of women's productivity, including breastfeeding; and highlight the need for measures to prevent or address declines in breastfeeding. Some studies were conducted by nutritionists working for international agencies, while others advocated for the government to develop breastfeeding policies and programs. For example, in the early 1970s, World Bank nutrition advisor Alan Berg documented the expanding economic loss associated with formula feeding replacing breastfeeding in countries such as Chile, Kenya, Singapore, and the Philippines over the previous decade, aiming to motivate public action to reverse this decline (23). Likewise, pediatrician Jon Rohde (24–26) calculated the quantities of human milk production in Indonesia during the 1970s and 1980s to emphasize the importance of breastfeeding in the second year of that country's food supply and nutrition policies. A study led by nutritionist Stina Almroth in 1979 presented estimates of the economic value of breastfeeding for Ghana and the Ivory Coast to inform FAO considerations of breastfeeding as infant food, for infant health protection, and child spacing (27).

Later studies from the 1990s demonstrated the magnitude of production and the macroeconomic value of mother's milk for countries in Latin America, Sub-Saharan Africa, China, and India (27–32). Studies led by (25, 26) pediatrician Arun Gupta produced estimates for India (28, 32). The PROFILES project (see above) provided estimates of breastmilk production and its financial value for Bolivia, China, and the countries of West Francophone Africa. This showed for example that the volume of human milk produced in China was around 4 billion liters in 2001 (20, 33). Notably, at a time when human milk was priced at around $50 a liter in high-income countries such as the US and Norway, the 1997 study of the countries of Sub-Saharan Africa a study by nutritionists Anne Hatloy and Arne Oshaug found that given a monetary value of just $1 per liter, the economic value of human milk production ranged from 5 to 15% of the GDP of those countries (34). Until 1994 (35), nearly all studies calculated the value of human milk by estimating output in physical units and then valuing it using the market price of an alternative commodity.

2.1.2. Required tool outputs and other capabilities

The review of studies indicated that measures of actual, potential, and lost milk were the common outputs of interest to users. Also, useful would-be comparisons with national or international targets and benchmarks as well as the capacity to calculate results for significant age categories within the 0–35.9 months age range. For example, some studies examined 12–23.9 months, or 0–5.9 months, while the majority looked at 0–23.9 months including 0–11.9 months.

This analysis of the literature also indicated that the tool should have both online and offline versions to cater to diverse uses as well as the intended end use. Potential use includes calculating the production of human milk within food surveillance systems, allowing policymakers to use the results to monitor the results of food security and nutrition policies. Another potential use is the provision of evidence for non-government advocacy, where users from civil society or international agencies could demonstrate the economic significance of breastfeeding and highlight the need for policies targeting breastfeeding protection, promotion, and support.

The review also demonstrated that the tool must present key results for selected countries as well as the world, allowing users to see country-level results from a wider comparative perspective. The design also needed to be flexible to meet the main customization needs of policymakers, advocates, researchers, and individuals worldwide, and to allow for future updates and enhancements.

In light of the available budget for tool development, a basic version was planned for rapid development and release, to add further enhancements over time based on feedback from users. The type of enhancements being considered is further discussed in the concluding section.

2.2. Step 2: Measurement

Step 2 specified the best open access data available for measurement, and assessed which data allowed future modules to be easily updated. Previous studies used a variety of data sources for key inputs to the calculations, making comparisons difficult. This highlighted the need for the tool to use consistently available open-access data for countries to make the best estimates. It is also important for future modules to be easily or automatically updated with key default data in a timely and efficient manner.

There are four key measures. First, the number of infants and young children aged 0–35.9 months is approximated by UNICEF databases (36). UN population estimates data on live births for the base year and estimated number of children in the first, second, and third years of life. Second, we used country survey data on continued breastfeeding rates, such as from Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS), as the basis for predicting breastfeeding rates for infants and young children by month, 0–35.9 months for most countries (37). Third, estimates of human milk intake by child age (i.e., by month, every six months, and overall three years), based on reliable and commonly used studies of energy intake in breastfed children. This is a fixed element of the tool and provides for a total of 431 liters of milk produced over the 36 months of lactation, derived from two authoritative studies, and based on their published estimates for partially breastfed infants, converted from grams to milliliters (34, 38). Fourth, a price per liter of human milk of US$100 per liter is based on the official price for fresh human milk within Norway's human milk banking system (39, 40). Alternative prices are summarized and discussed briefly in Supplementary material 2.

2.3. Step 3: Analysis of tool design options

Due to the different potential uses and users and the limitations of the data, we considered two main stages for the tool development: a basic module and a customizable module.

The basic module would include a dashboard that shows the findings and estimations of a selected country or the world using the newest possible preloaded data. This module can also impute missing values of continued breastfeeding to provide a more precise estimate of the value of breastmilk.

The tool would also provide for customization, so users can input alternative data such as breastfeeding rates, the size of the population, the market value of human milk, and the currency exchange rate for the country of interest.

The tool would allow an individual mother to enter her own breastfeeding experience to calculate the amounts of milk provided for her child.

2.4. Step 4: Tool development

Tool development focused on identifying and pre-loading key data sources and developing a suitable predictive model for breastfeeding rates.

It also required the investigation of a suitable basis for estimating milk production levels and exploring sources of evidence on the daily milk intake of breastfeeding children. A further area of investigation was the biologically feasible potential production. The difference between this and actual production levels is the "lost" milk production calculated by the tool.

The key data sources and analyses behind the estimates are discussed in Supplementary material 1.

2.4.1. Initial development

Initial investigation of the goals for the tool identified the need for a downloadable tool that can be easily updated with low investment. This stage also identified the need for the user to be provided with key parameters which were fixed in the tool, as well as the potential for the user to make calculations using alternative data sources on breastfeeding or numbers of children born and breastfed.

While the main interest was in country-level estimates, sub-national and individual mother calculations were also identified as useful for meeting tool goals.

The primary goal identified was advocacy, but additional potential uses included mothers calculating production volume or values over the breastfeeding period as motivation, as well as health professionals supporting and encouraging breastfeeding mothers.

2.4.2. Internal discussions, external consultation, and improvements

Discussions held fortnightly during 2021 by members of the Organization 1 and Organization 2 teams resulted in agreed-upon priorities for the first stage basic version of the tool, and priorities for enhancement in future upgrades.

The most important revisions during the development phase were to align the tool with the 0–35.9 age group for infant and young child feeding. Many previous studies were for 0–11.9 months, or at most 0–23.9 months. The tool is unique in its provision of data for the extended age range, which fits into the WHO/UNICEF recommendations for breastfeeding beyond 2 years of age.

The development of the tool also considered the maximum biologically feasible levels of breastfeeding. The tool calculates the lost milk on the basis that 98% of mothers can breastfeed, based on contemporary data from Norway (41) and a review of the median weaning age in traditional or non-industrial populations (42).

Data gaps also influenced tool design. Although DHS surveys include breastfeeding data for 0–35.9 months, the MICS did not. Also, few high-income countries consistently collect data, especially beyond 11.9 months, and some had no recent data. Many did not have data on exclusive breastfeeding. With the substantial data gaps evident during the analysis phase, it became necessary to invest in developing a prediction model for monthly breastfeeding rates for children ages 0–35.9 months. The tool bridges these data

gaps to calculate predictions of breastfeeding at each month of age from available national data. This predictor uses a cubic regression model for most countries, though in some countries the best fit was predicted by a linear regression model.

In several countries where traditional breastfeeding practices are largely intact, the value of breastfeeding was substantial to the market economy (as measured by GDP). This pointed to the importance of deciding on how to attribute a monetary value to breastfeeding to allow this comparison with the conventional official measurement of economic value. Few studies attempted to value the act of breastfeeding *per se* (43, 44); while breastfeeding can be conceived of as an unpaid care service within an economic accounting framework, most studies calculated its value by reference to a price proxy for the human milk produced; that is, as a food commodity. The focus was on measuring the economic value of breastfeeding by estimating the national monetary cost of buying or importing commercial milk formula. Nearly all studies used the cost of replacing breastmilk with either fresh or formula milk to infer the economic value of breastfeeding.

The Mothers' Milk Tool places a monetary value of US$100 on human milk produced by breastfeeding women. This is linked to the price of fresh human milk exchanged within the not-for-profit hospital milk bank network in Norway where a US$20 per liter reimbursement of costs is made to donating mothers (39). Price increases are regulated by the Norwegian government and increases reflect cost recovery principles since the 1990s. Alternative prices were evaluated in previous studies (43–45) (see Supplementary material 2).

There were two stages of piloting the Mothers' Milk Tool, which occurred during the early weeks of 2022. We aimed for a range of potential user groups to be represented in the two testing groups, coming from a diverse range of countries and global regions. Several improvements were implemented after piloting, mainly to improve presentation and clarity and address functionality issues.

2.4.3. Formatting the tool

A suggestion from reviewers on the first version was to follow a branding guideline. The branding guidelines from Organization 2 were selected and used consistently to design the Mothers' Milk Tool. Based on the comments, additional information was added, such as the introduction, policy brief, and references, to make the tool more comprehensive and standalone.

2.4.4. Description and display of key features of the tool

Figure 1 illustrates the key functions of the Mothers' Milk Tool, including both country and individual calculators. The individual calculator allows for the estimation of individual production and value for each child of a user based on the duration of breastfeeding. The user is to enter the information on the months she breastfed her child, and the tool will help to estimate the volume and value of breastmilk. The user can enter and obtain information for other children. This function could be used by breastfeeding counselors during breastfeeding promotion and support.

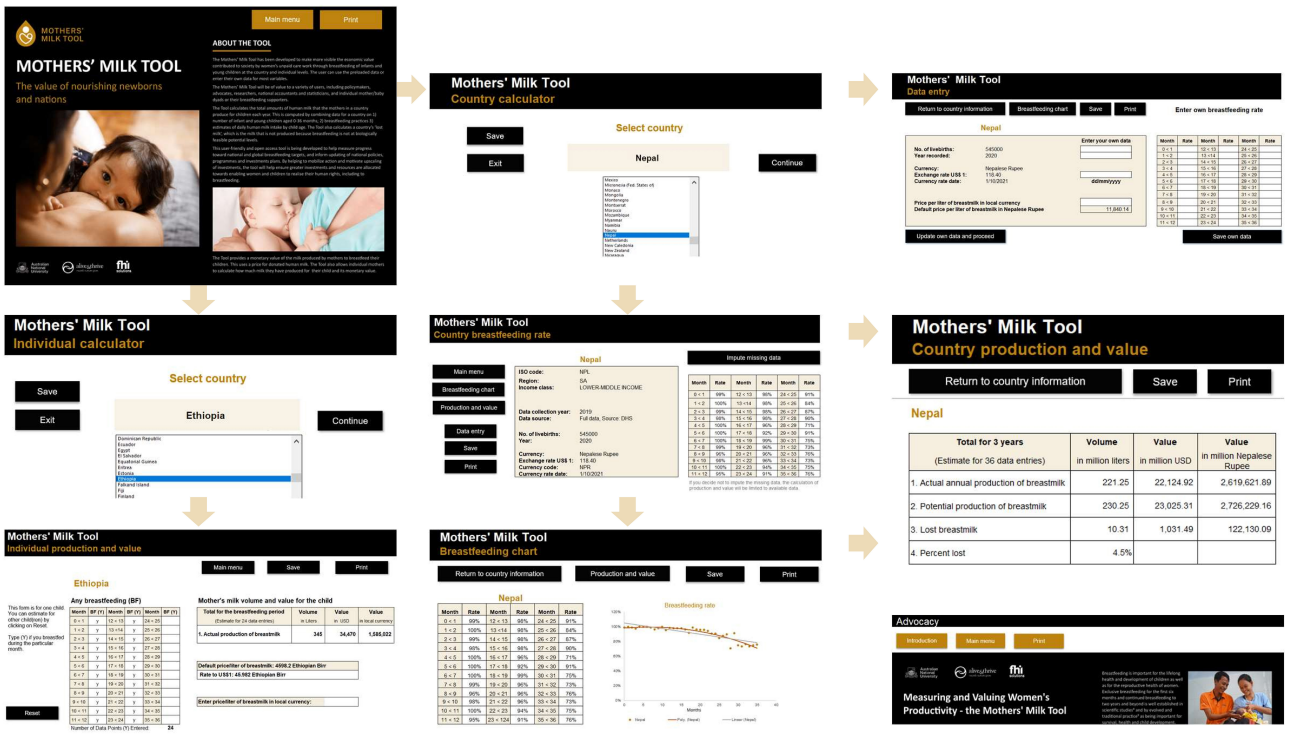

FIGURE 1
Key functions of the Mothers' Milk Tool. Authors created this figure using snapshots of the Mothers' Milk Tool offline (https://mothersmilktool.org). The human identifiable images are licensed for personal, business or commercial purposes.

For the country calculator, the Mothers' Milk Tool will provide the country's breastfeeding rates and chart using preloaded data. When the data are not up-to-date or missing, the users have the option to input the missing data using the predictor or enter their own-source data. Using the data, the Mothers' Milk Tool will estimate the annual

TABLE 1 Estimate of production of human milk.

Child age (months)	Proportion of children breastfed (%)	Number of children breastfed per month	Average volume of breastmilk consumed a day per child (L)	Estimated volume of breastmilk consumed a month per child (L)	Total actual annual production of breastmilk (million L)
0 (<1)	93	55,800	0.59	18	0.99
1	89	53,400	0.68	20	1.08
2	85	51,000	0.71	21	1.08
3	82	49,200	0.68	20	1.01
4	79	47,400	0.69	21	0.98
5	78	46,800	0.59	18	0.83
6	72	43,200	0.55	17	0.71
7	68	40,800	0.4	12	0.49
8	63	37,800	0.48	14	0.55
9	58	34,800	0.67	20	0.70
10	51	30,600	0.5	15	0.46
11	48	28,800	0.48	14	0.42
12	34	20,400	0.37	11	0.23
13	29	17,400	0.37	11	0.19
14	24	14,400	0.37	11	0.16
15	21	12,600	0.37	11	0.14
16	20	12,000	0.37	11	0.13
17	16	9,600	0.37	11	0.11
18	14	8,400	0.37	11	0.09
19	12	7,200	0.37	11	0.08
20	11	6,600	0.37	11	0.07
21	10	6,000	0.37	11	0.07
22	9	5,400	0.37	11	0.06
23	8	4,800	0.37	11	0.05
24	0	–	0.24	7	–
25	0	–	0.24	7	–
26	0	–	0.24	7	–
27	0	–	0.24	7	–
28	0	–	0.24	7	–
29	0	–	0.24	7	–
30	0	–	0.24	7	–
31	0	–	0.24	7	–
32	0	–	0.24	7	–
33	0	–	0.24	7	–
34	0	–	0.24	7	–
35	0	–	0.24	7	–

Methodology based on Norwegian Health Directorate 2020 (46) and Smith et al. 2022 (47).

TABLE 2 Average volume (liters) of human milk intake by a child and by month of age in studies on economic value of breastfeeding.

Authors/Months of infant age*	Months of infant age*		
	0–11.9	0–23.9	0–35.9
Smith (48)	228	307	–
Norwegian Health Directorate (49)	225	306	–
WHO* (38)	291 (214)	–	–
Aguayo et al.* (29)	243 (225)	443 (436)	536 (518)
Smith (44)	224	331	–
WHO* (50)	256 (226)	450 (421)	–
Hatloy and Oshaug (34)	230	369	462
National Nutrition Council (51)	228	307	–
Oshaug and Botten (35)	224	331	–
Gupta and Khanna (32)	201	347	–
Almroth et al. (27)	234	380	–
Rohde (25)	180	288	360
Berg (23)	247	375	–

*Values in brackets are for partial breastfeeding.

production, potential production, and lost breastmilk and their values.

Table 1 illustrates calculations for a single country for a single year for infants and young children aged <36 months.

Table 2 summarizes yields that were assumed in previous studies.

Table 3 provides information on sources of data on births and breastfeeding survey dates used in the calculations.

2.5. Step 5: Tool validation

During development, data from several countries were entered into the tool, and results were compared with results from published studies for the relevant country to assess the validity of tool outputs (Supplementary material 3). This table compares results from the original study, with calculations using the tool. The calculations using the tool use the same birth and breastfeeding data as the original studies, but not the milk intakes/yields assumed in those studies, so differences arise mainly from differences in methodologies or differences in assumed yields. Reasons for variance are indicated in the table on this basis.

The tool was also validated by inviting country IYCF and breastfeeding experts to provide feedback on its functioning, usefulness, plausibility, and reliability of the results and underlying assumptions for that country. A total of 16 potential users responded to the invitation for testing the tool. Respondents were from 12 countries, and their self-described occupations or interest in the tool included advocate, nutritionist, economist, director, peer counselor, nutrition specialist, lactation consultant, medical doctor, and independent consultant. Feedback was centered on the functionality and utility of the tool. User feedback from testing is reported in Supplementary material 4.

2.5.1. Country selection and estimates

Estimates were made for a selection of high-, middle- and low-income countries from the global regions, using the prediction model for all those countries where complete breastfeeding data was not available. These countries reflect a diversity of breastfeeding prevalence, some maintaining intact breastfeeding practices at levels consistent with those reported for non-industrial or historical populations, and others with very disrupted breastfeeding practices. Global production was estimated for low- and middle-income countries (LMICs) only due to data limitations for high-income countries (HICs).

For a small number of countries, the estimates were tested using historical data series, and for other countries, it was possible to compare the results of the tool with published estimates made at another point in time for the same country. The country selection also reflected large, medium, and small populations, which may approximate the extent to which they are a profitable market for the expansion of commercial milk formula and other baby food sales.

2.5.2. Continuous tool improvement

After successfully launching the Mothers' Milk Tool offline, we developed the Mothers' Milk Tool online (Figure 2). We are collecting user feedback to continue improving both online and offline versions. The offline tool is available in English and French, while the online tool is available in almost all languages. There are challenges to the development and use of the tools. Breastfeeding indicators are not or only partially available or out-of-date in select countries, which alters the calculation. Countries need to collect and publish this data regularly. We need to use regional estimates or fill in the information using the predicted model. We need to search for newly available data to update the tool. The currency exchange rate and the number of children born each year have not been updated since the development of the tool. We plan to update the offline tool periodically and develop an option for updating background information in real-time for the online tool.

2.6. Reflexivity statement

This paper is written because of the researchers' shared beliefs that women's unpaid work including breastfeeding is not well addressed by conventional economic studies which focus on the market economy, to the disadvantage of women and children, and that this reduces the resources invested in programs which are important to the health of women and children in particular breastfeeding. Our focus is on low- and middle-income countries but our study includes global and high-income country perspectives due to our concern to highlight that the latter present a pathway on infant and young child feeding which may harm women's and children's health if followed by LMICs.

The authors include one female who is the lead author and three males, and the research team is based in Australia, Vietnam, and London. The three male authors have many years of experience

TABLE 3 Source of breastfeeding data.

Country/Location	Source of breastfeeding data	Year	Annual Livebirths
Australia	Australian infant feeding survey	2010	339,000
Brazil	Health and nutrition survey	2019	2,871,000
Canada	Community health survey	2009	402,000
India	National health family survey	2005–2006	24,143,000
Indonesia	Demographic and Health Survey	2017	4,466,000
Ireland	Breastfeeding on the Island of Ireland, Report 3	2013	57,000
Kenya	Demographic and Health Survey	2014	1,418,000
Nepal	Multiple Indicator Cluster Survey	2019	545,000
Nigeria	Demographic and Health Survey	2018	7,894,000
Norway	Directorate for Health and Social Affairs,	2020	60,000
Philippines	Demographic and Health Survey	2017	1,955,000
United Kingdom	National survey	2011	744,000
USA	National immunization survey	2018	3,991,000
Viet Nam	Multiple Indicator Cluster Survey	2013–2014	1,592,000
Global	UNICEF infant and young child feeding database	2020	136,077,713

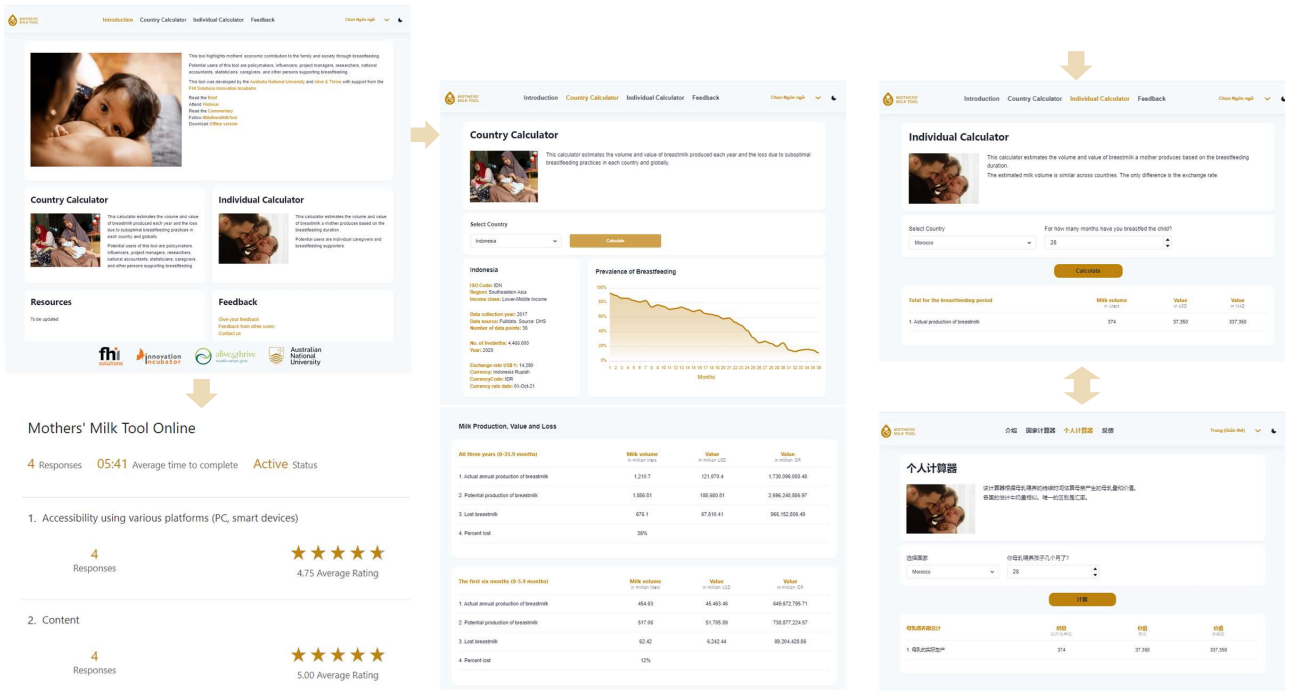

FIGURE 2
Layout and key features of the Mothers' Milk Tool online. Authors created this figure using snapshots of the Mothers' Milk Tool online (https://mothersmilktool.org). The human identifiable images are licensed for personal, business or commercial purposes.

in low- and middle-income countries on programs supporting maternal and child nutrition including in emergencies. The lead author is a former government economist and tax analyst and a qualified breastfeeding counselor in Australia with extensive experience and commitment to supporting women to overcome societal and personal barriers to breastfeeding and to advocate for societal changes to enable them to breastfeed to the extent they see as optimal for their health and wellbeing. The four of us have collaborated since 2020, based on a common interest in improving the measurement of the economic value of breastfeeding and the economic and health system costs of not breastfeeding. In this collaboration, we have sought to develop a robust tool

in collaboration with the diverse users, which draws on positivist economic approaches to monetary valuation of non-marketed production yet is also respectful that many women and cultures view it as unnecessary and even devaluing to place a monetary value on breastfeeding. We also respect the loving care that mothers offer their infants and young children regardless of how they decide to feed their children in the circumstance of their individual lives.

3. Results

3.1. Global estimates and estimates for selected countries

3.1.1. Global production

Global production was around 35.6 billion liters a year. This represents just under half the potential production if women and children 0–35.9 months were universally enabled to breastfeed optimally (Table 4). Valuing the lost milk at around US$ 100 a liter represents a monetary loss of production of US$ 2.2 trillion annually.

Key results for the selected countries (Australia, Brazil, Canada, India, Indonesia, Ireland, Kenya, Nepal, Nigeria, Norway, Philippines, United Kingdom, USA, and Viet Nam) and the world are presented in Table 4.

Among high-income countries, human milk production ranges from around 11 million liters in Norway, 605 million in the USA, and 51 million in Australia (countries where around two-thirds of potential production is lost) to 4 million liters in Ireland. In Ireland, around 80% of mothers' milk is lost.

Among low-income countries, Nepal maintains human milk production at high levels (221 million liters annually) with less than 5% lost. Other countries such as Kenya, Nigeria, and Vietnam currently lose around a third or less of production. Likewise, middle-income countries such as Indonesia and The Philippines lost around a third of potential production.

The most populous country, India, lost nearly 40%, respectively, with a production of around 8.7 billion liters a year.

3.1.2. Monetary values of mothers' milk production

In monetary terms, the value of human milk production is substantial in most of the selected countries (Table 5). The monetary value of lost mother milk ranges from around US$ 146.2 billion in India to US$ 900 million in Nepal.

4. Discussion and implications

4.1. Key findings and strengths of the study

Human milk produced for infants and young children by breastfeeding mothers is a crucial national food system; this production contributes substantially to national and global food security and health, though much is also "lost".

The economic value of this food production by breastfeeding mothers can and should be measured, to ensure that this important economic contribution is visible, properly valued, well-protected, and sufficiently resourced to continue.

A culture of breastfeeding is an important national capital asset with large economic value, which generates a substantial quantity of safe, nutritious, healthy, and environmentally sustainable food for a country's infants and young children. A supportive breastfeeding culture protects the reproductive health of women and minimizes food system pressures on the environment.

Where a breastfeeding culture is not visible, valued, and resourced, breastfeeding will diminish, and milk production capacity is lost, due to market pressures from commercial milk formula, hence countries' important 'cultural capital' of women's breastfeeding knowledge, skills, and experience should be protected, and investments made in breastfeeding protection, support and promotion to prevent and restore Lost Milk.

4.2. Limitations

The accuracy and capabilities of the Mothers' Milk Tool remain limited by the gaps in available data. The tool does not adjust for exclusive breastfeeding rates during the first 6 months because of data limitations for breastfeeding prevalence and milk intake. Breastfeeding prevalence data is particularly lacking in high-income countries. Up-to-date scientific knowledge is also lacking regarding the biologically feasible potential levels of breastfeeding and the usual human milk intake, particularly among young children.

Several enhancements have been identified during development that can be considered for future improvement of the tool. These include modifications to increase its accuracy, flexibility, functionality, and add-on modules to broaden the tool's capabilities.

For example, the basic model could be modified to recognize that infant and young child mortality is high in some countries, and the number of births will be higher than the number of breastfeeding children. Especially if better scientific data were available, greater flexibility could also be added to the tool to vary its assumptions about the milk intake of young children who are breastfeeding. Also, breastfeeding has some energy costs for the mother; users could be given the option of adjusting the monetary value of production for the cost of any additional necessary nutrition for mothers.

Modifications to allow other approaches to placing a monetary value on human milk can also be considered. Options include allowing the user to enter information on wages for women employed as wetnurses to calculate monetary values per liter of milk or per day of breastfeeding. Similarly, the value of maternal time invested in breastfeeding can also provide an input-based proxy for the monetary value of the milk produced. Estimates of maternal time inputs over the breastfeeding period could be incorporated into the existing tool using available data from time-use studies of breastfeeding and childcare. As commercial trade in human milk expands, using new sources of market data can also be explored for monetary valuation.

TABLE 4 Estimated amounts and values of actual and potential human milk production by country for children aged 0–36 months.

Country/Location	Year	Total production, at current breastfeeding rates (million Liters)	Potential production of breastfeeding (million Liters)	% of breastmilk lost
Australia	2010	50.8	143.2	64.5
Brazil	2019	425.4	1,212.9	64.9
Canada	2009	54.5	169.8	67.9
India	2017	8,737.6	10,200.0	14.3
Indonesia	2017	1,210.7	1,886.8	35.8
Ireland	2013	4.4	24.1	81.7
Kenya	2014	450.9	599.1	24.7
Nepal	2019	221.3	230.3	3.9
Nigeria	2018	2,150.4	2,997.1	28.3
Norway	2018–2019	10.7	25.3	57.8
Philippines	2017	574.5	826.0	30.4
United Kingdom	2011	58.0	314.3	81.6
USA	2018	604.5	1,686.1	64.1
Viet Nam	2013–2014	423.3	672.6	37.1
Global	2022	35,556.0	57,490.5	38.2

"Year" refers to the year in which available breastfeeding data is reported.

TABLE 5 Estimated production values and "lost milk" by country.

Country/Location	Year	Value of total breastmilk production (million US$)	Value of breastmilk lost (million US$)	Predicted
Australia	2010	5,079.55	9,242.6	Yes
Brazil	2019	42,538.66	78,756.1	Yes
Canada	2009	5,452.83	11,531.0	Yes
India	2017	873,755.44	146,244.7	No
Indonesia	2017	121,070.40	67,610.4	No
Ireland	2013	440.78	1,967.4	Yes
Kenya	2014	45,093.29	14,814.8	Yes
Nepal	2019	22,125.00	900.3	No
Nigeria	2018	215,038.69	84,670.6	No
Norway	2018–2019	1,069.53	1,465.4	Yes
Philippines	2017	57,446.25	25,149.1	No
United Kingdom	2011	5,796.39	25,636.3	Yes
USA	2018	60,451.21	108,161.7	Yes
Viet Nam	2013–2014	42,334.06	24,925.2	No
Global	2022	3,555,597.42	2,193,451.7	Yes

"Year" refers to the year in which available breastfeeding data is reported.

The individual mother component of the tool could be modified to provide production data for multiple children, and for distinguishing between months of exclusive and partial breastfeeding. Important but more complex programming enhancements that could be added to the tool functionalities for countries include per capita production estimates which would improve its value for cross-country comparisons, as well as flexibility and pre-loaded data to allow time trend analysis. This would also further assist in tracking progress against policy targets.

Where countries have policy targets for breastfeeding, the tool could be enhanced to measure the gap between the actual and target level of human milk production. The tool could also provide a

page with a prefilled advocacy brief for explaining and presenting country results to policymakers in a suitable format to motivate and guide policy action.

Furthermore, by linking the estimates of lost milk production to country data on the volume of milk formula sales or usage, the Mothers' Milk Tool could provide a suitable platform for calculating environmental savings at current breastfeeding rates, and the potential costs (such as increased greenhouse gas emissions, and water use) of further declines in breastfeeding.

The scope for linking the Cost of Not Breastfeeding Tool to Mothers' Milk Tool results for lost milk production could also be explored. Together these tools can help present the investment case for breastfeeding. Furthermore, tools such as the WBC*i* Costing tool are available to estimate the financing costs of breastfeeding policies and programs (19). We suggest the need to also develop ways of linking these tools to facilitate formal economic evaluations of country-level interventions.

4.3. Policy implications

The tool provides the potential for many countries to revisit their current maternal, newborn and child health, early childhood nutrition, and food security strategies. Policymakers will be able to compare the large monetary value of these current losses against larger potential losses if current levels of breastfeeding are not protected; the ability to minimize losses by increasing social investments in building a more enabling environment for breastfeeding will also be made visible.

The tool can also illustrate the extent to which a country's breastfeeding practices are providing mitigation, adaptation, and resilience to climate change risks, and may assist with planning for humanitarian emergency responses.

Human milk is valuable for its nutritional and immunological characteristics. Using a market price to place a monetary value on it is possible because breastfeeding is increasingly commodified. Human milk and human milk products are being bought and sold. This raises important policy issues but is beyond the scope of this study. This important discussion of feminized poverty and lack of adequate policy support for breastfeeding as a key driver of commodification trends is considered elsewhere (52–54).

Several studies have looked at the cost of key policies to better enable women to breastfeed, though a recent review of costing studies concluded that the availability of cost estimates was limited and more standardized costing frameworks are needed (55).

4.4. Implications at the country level

The tool has been verified through comparison with published estimates of human milk production in several countries. This shows good alignment with estimations for a variety of settings and diverse methodologies.

The results show that the $6 billion daily value of lost mother's milk production can be considered alongside the US$1 billion a day of health and human costs directly attributable to not breastfeeding that has been calculated by the Cost of Not Breastfeeding Tool (2).

With advances in the state of scientific knowledge about the acute and chronic disease impacts of not breastfeeding, it could be expected that these estimates would increasingly align (44). For example, some health services are already willing to pay high prices for donor human milk as the health cost savings are well documented for premature or vulnerable infants, and this is reflected in the monetary values used in the Mothers' Milk Tool. However, there remain considerable gaps in data and knowledge about the broader maternal and child health impacts of not breastfeeding and the economic cost consequences. As evidence accumulates on the health differential for non-breastfeeding mothers and children, including for chronic diseases, the measured costs of not breastfeeding will tend to rise.

The lack of key data especially in high-income countries means the important trends in potential health costs and losses arising from insufficient breastfeeding are invisible to policymakers. There is an urgent need for regular, comprehensive, and accurate measurement of breastfeeding prevalence in all countries to track trends and inform a range of public policies. Systematic data collection on prices charged by human milk banks for fresh and pasteurized milk should also be prioritized and published regularly.

5. Conclusions

The Mother's Milk Tool estimates the volume of human milk currently being produced, and the volume that is potentially at risk if women's important production capacity for breastfeeding is not protected, promoted and supported by effective national policies and programs. It also calculates how much is currently being lost at national, regional, and global levels. Monetary values are also indicated.

The estimates show the breastfeeding mothers' substantial contributions to food production, and how much of this healthy and sustainable foundation food is lost or at risk as ultra-processed commercial baby foods, including conventional cows' milk-based commercial milk formula products, are more widely marketed. In some North American and European countries, as much as 70–80% of potential milk production is lost, a phenomenon arising from cultural barriers or structural impediments to breastfeeding. Some middle-income countries are approaching these levels.

The tool also informs on a range of other economically relevant consequences such as a country's potential educational attainments, human capital development, poverty alleviation, non-communicable disease prevalence, and policies for climate change risk, adaptivity, and resilience.

We anticipate the Mother's Milk Tool to be a user-friendly resource that is open-source, adaptable, and useful for a variety of users. The Mothers' Milk Tool can be used by policymakers, advocates, and researchers for their decision-making and programming, and advocacy on the seven policy actions set out in the 2015 Call to Action by the Global Breastfeeding Collective. The tool will especially support the tracking of progress on breastfeeding targets, by assisting food and health policymakers and national statisticians to include breastfeeding in food balance sheets and economic statistics.

This tool can also be used by individual mother/baby dyads to estimate the economic significance of their breastfeeding practices. Future development could include real-time currency conversions, languages other than English, and comparisons across countries, as well as provide for regular maintenance and improvement of the Mothers' Milk Tool.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

Author contributions

Conception or design of the work and critical revision of the article: JS, AI, TN, and RM. Data collection: JS and AI. Data analysis and interpretation and drafting the article: JS, AI, and TN. All authors have read and agreed to the published version of the manuscript.

Funding

This work was supported in part by the Innovation Incubator, FHI Solutions, the Bill and Melinda Gates Foundation (Grant Numbers OPP-50838 and INV-042392), and Irish Aid. The views and opinions set out in this article represent those of the authors and do not necessarily represent the position of the donors. This work was also partly supported by the Australian Research Council under a Future Fellowship held by JS (FT140101260). Under the grant conditions of the Foundation, a Creative Commons Attribution 4.0 Generic License has already been assigned to the Author's Accepted Manuscript version that might arise from this submission.

Acknowledgments

The authors thank Joe Lamport from the Alive and Thrive initiative at FHI Solutions for the comments and suggestions to improve this manuscript.

Conflict of interest

AI was employed as an Independent Researcher.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1152659/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 10 July 2023
DOI 10.3389/fpubh.2023.1173360

OPEN ACCESS

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RECEIVED 24 February 2023
ACCEPTED 14 June 2023
PUBLISHED 10 July 2023

CITATION
Wubetie HT, Zewotir T, Mitku AA and Dessie ZG (2023) Household food insecurity levels in Ethiopia: quantile regression approach. *Front. Public Health* 11:1173360. 10.3389/fpubh.2023.1173360

Household food insecurity levels in Ethiopia: quantile regression approach

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Introduction: Numerous natural and man-made factors have afflicted Ethiopia, and millions of people have experienced food insecurity. The current cut-points of the WFP food consumption score (FCS) have limitations in measuring the food insecurity level of different feeding patterns due to the diversified culture of the society. The aim of this study is to adapt the WFP food security score cut-points corrected for the different feeding cultures of the society using effect-driven quantile clustering.

Method: The 2012, 2014, and 2016 Ethiopian socio-economic household-based panel data set with a sample size of 3,835 households and 42 variables were used. Longitudinal quantile regression with fixed individual-specific location-shift intercept of the free distribution covariance structure was adopted to identify major indicators that can cluster and level quantiles of the FCS.

Result: Household food insecurity is reduced through time across the quintiles of food security score distribution, mainly in the upper quantiles. The leveling based on effect-driven quantile clustering brings 35.5 and 49 as the FCS cut-points corrected for cultural diversity. This corrected FCS brings wider interval for food insecure households with the same interval range for vulnerable households, where the WFP FCS cut-points under estimate it by 7 score. Education level, employment, fertilizer usage, farming type, agricultural package, infrastructure-related factors, and environmental factors are found to be the significant contributing factors to food security. On the other hand, the age of the head of the household, dependency ratio, shock, and no irrigation in households make significant contributions to food insecurity. Moreover, households living in rural areas and farming crops on small lands are comparatively vulnerable and food insecure.

Conclusion: Measuring food insecurity in Ethiopia using the WFP FCS cut-off points underestimates households' food insecurity levels. Since the WFP FCS cut-points have universality and comparability limitations, there is a need for a universally accepted local threshold, corrected for local factors those resulted in different consumption patterns in the standardization of food security score. Accordingly, the quantile regression approach adjusts the WFP-FCS cut points by adjusting for local situations. Applying WFP cut-points will wrongly assign households on each level, so the proportion of households will be inflated for the security level and underestimated for the insecure level, and the influence of factors can also be wrongly recommended the food security score for the levels. The quantile clustering approach showed that cropping on a small land size would not bring about food security in Ethiopia. This favors the Ethiopian government initiative called integrated farming "ኩታ ገጠም እርሻ" which Ethiopia needs to

develop and implement a system that fits and responds to this technology and infrastructure.

KEYWORDS

individual-specific effect, panel data, principal component analysis, food insecurity, unobserved heterogeneity

Introduction

Sufficient, safe, and nutritious food availability, access, and utilization for all people at all times are very important hierarchal pillars that ensure household-level food security (1). Food insecure and vulnerable households are those whose food intake is less than the food intake of food-secure households (2). Food insecurity is a global burden on 928 million of the global population in 2020, which is 148 million more than in 2019 (3).

The underlying factors challenging food security and nutrition are mainly conflicts and wars. In 2020, nearly 75% of the world's stunted children lived in Central and Southern Asia (37%) and sub-Saharan Africa (37%) (3, 4). Drought is the main cause of crop and livestock loss (89%) from climate disasters in Africa (5). In sub-Saharan countries, most of the population are agricultural-dependent and struggle for food; they are severely attacked by drought, internal displacement, conflicts, and desert locust (3, 6, 7) and had a higher rate of hunger as of 2010 (8). Economic slowdowns as a result of trade wars, the Russian - Ukraine war (9, 10), and a global pandemic like COVID-19 (9, 11–15) raise the rate of food insecurity in most countries, especially low-income countries (sub-Saharan Africa) that have higher rates of food insecurity due to income inequality (3, 4, 13, 14). Especially poor's in developing countries faced saver food insecurity and influenced by instable food supply (12, 16) and socio-economic factors (16–18). Studies in Slovak (19), Afghanistan (20), Malawi (18), and Nigeria (21, 22) showed that the impact predictors of food security depend on the level (quantiles) of households' food insecurity scores.

In Ethiopia, millions of households suffer from food shortages each year, and the government and aid organizations (FAO and WFP) support food and shelter in response to hunger and natural disasters by direct food supply, creating jobs on the farm, or cash transfer (23, 24). Several studies have indicated factors that affect a household's food security in Ethiopia (22, 25–27).

Food security measurement is an ongoing problem and different studies have different measurements (22, 28). The FCS was first created by the world food program (WFP) in Southern Africa in 1996 as an alternative (29). FCS is a frequency-weighted diet diversity score multiplied by the relative nutritional importance of different food groups for 7 days of consumption (2, 29–31). The cut points for WFP FCS are 21 and 35, i.e., the household is food insecure if FCS is less than or equal to 21, vulnerable if FCS is between 21.5 and 35, and secure if FCS is greater than or equal to 35.5. However, since the measurement considers the number of times eaten and the nutritional contents of the food, it varies based on the community consumption pattern difference, and WFP suggested an adjustment for the cut points by 7 score (i.e., 27 and 42) for communities that usually (6 or 7 days per week) consume small amounts of sugar and oil (2, 22, 28, 32). However, there is a lack of a universally accepted threshold corrected for other local factors, which results in different consumption patterns in the standardization of food security scores. As literatures also indicated that, the cut points for FCS is an ongoing problem due to local factor like, cultural disparity causing differences in the consumption patterns (30, 31). Recent pieces of literature have suggested alternative cut points to WFP food consumption score cut points; for instance, FAO (31) recommends cut points 45 and 61 for Jordan households, and Baumann et al. (30) used cut points 32 and 43 for the Laos context due to cultural disparities. Since the FCS considers diet diversity (33), classifying the level of food insecurity of sub-national areas by rankings is preferable to the direct score cut-points (34). Baumann et al. suggested further investigations in different cultural settings to get insight into universal threshold considerations of local factors such as the exclusion of small amounts of food items (30).

The response variable "food security score" has a longitudinal nature and may change in shape each time (35–37), and fitting it with a longitudinal model visualizes the evolution of an individual trajectory over time and brings extra information due to the unobserved heterogeneity to the model (35, 37). Unlike the standard regression, the quantile regression does answer the question of how input variables affect the response at different quantiles of the distribution (35, 36, 38–40). Therefore, fitting an extended longitudinal model for quantile regression can help to avoid misleading inferences (38).

As a traditional, historical, and religious country, Ethiopia has a very diverse diet which includes; crops, roots, pulses, fruits, vegetables, meat, fish and other stem foods. Furthermore, in addition to various condiment consumption (like ginger, garlic, butter, cheese, paper & other), a small amount of bread, Enjera, drinks, and other grains are consumed (for instance, bread or Enjera with butter, traditional alcohols (Tela and Areki), roasted barley or maize or beans are eaten at a cultural ceremony, coffee ceremony, and religious events such as "Edir," "Mahiber," and "Arba/Ametat"). Due to the unique nature of Ethiopian diets, a tailored food consumption assessment is needed, and instead of directly applying the WFP FCS cut points, a flexible approach relative to the population is needed to overcome the shortcomings due to the differences in the dieting culture from

Abbreviations: AGSS, Annual agricultural sample survey; AIC, Akaike information criterion; CSA, Central statistical agency; EAs, enumeration areas; FAO, Food and agricultural organization; FCS, Food consumption score; FCSL, Food insecurity score levels; ICC, intra correlation coefficient; LMM, Linear mixed linear model; *lqmm*, Linear quantile mixed model; HH, Household; PCA, Principal component analysis; PPS, probability proportional to the size of the population; SNNP, southern nations and nationalities people of Ethiopia; WFP, World food program.

community to community (30, 41–43). With this universality and comparability limitation of the WFP FCS cut points, making a food security assessment for a multicultural country like Ethiopia is misleading. Therefore, we plan to adopt an approach that is responsive to the Ethiopian context and compare it with the WFP FCS cut points; it needs to show the gaps in the food insecurity levels within the country and help to know the factors that lead to each level of food insecurity for monitoring and mitigation to reach an interesting level of food security based on the country's resources. Hence, we proposed the effect-driven leveling approach with the assumption that if some sequence of the quintiles of the FCS (i.e., insecure, vulnerable, and secure) share the same factors (i.e., largely and significantly), those quantiles can be considered as one level and a cut point is fixed based on the quantile interval.

This study is aimed to address the issue with the WFP FCS cut-points by adjusting for different food consumption patterns due to the diversified culture of the society by identifying major indicators that can cluster quantiles of the FCS, which considers the evolutional variability (sustainability over time) of the food security score. Therefore, we adopted an approach by conditioning quintiles of the longitudinal households' food security scores on causal factors and grouped household scores as one food security score level that shares common major causing factors. Furthermore, we checked these quantiles clustering by using the principal component analysis of the FCS quantiles after coding zero and one for insignificant and significant effects of factors, respectively. Because these clusters of quintiles share some common significantly affecting factors, they should contribute largely to a principal component representing the food security score level. These factors are input for leveling FCS, and monitoring based on those factors can enhance the likelihood of controlling food insecurity for public health improvement beyond the uncertainty of physical phenomena not included in the model. The longitudinal nature of this data can help to find out the evolutional effect of driving factors on households' food insecurity levels, and the statistical modeling of FCS using those input driving factor values can bring an approximate to each level and do more precise prediction for the future. Focusing on food insecurity reduction brings an improvement in public health because as a frequently drought-affected and unstable low-income country, the resulting food insecurity directly impacted public health in Ethiopia through newborns' birthweight, stunted and wasted children, and women with anemia (11). Therefore, policymakers and researchers should give attention to measuring and combating food insecurity.

Methods

Data

This study analyzed household-based panel data for 3 years (2012, 2014, and 2016) covering the whole region of the country. This panel data recorded households' weekly (7 days) food consumption and other related factors repeatedly three times. A total sample size of 11,505 (3,835 households with three replications for the years 2012, 2014, and 2016) was taken from the Ethiopian Socioeconomic Survey (ESS) of the World Bank data set, which is the first panel data in Ethiopia collected by a project of the World Bank and central statistical agency (CSA) of Ethiopia to quantify household-level food security and related factors in rural and urban (small and medium town) areas. The ESS sample is a two-stage probability sample. The first stage of the sampling is selecting enumeration areas using simple random sampling from the sample of the Annual Agricultural Sample Survey (AgSS) enumeration areas (EAs). The AgSS EAs were selected based on probability proportional to the size of the population (PPS). The second stage is selecting households for the first survey by simple random sampling from the enumeration areas, but the 2nd and 3rd surveys will collect the data repeatedly from those selected households. The original data set used in this study was taken using this URL link.[1]

Variable

The response variable of this study is the food security score calculated based on the FAO (2016) FCS formula for 7 days of food consumption recorded from households at the enumeration area level (32). A principal component analysis (PCA) is used to reduce the dimension of the data by merging predictors based on natural relations through a few uncorrelated latent variables without losing much information, each of which is a linear combination of the original variables that can maximize the variance accounted for (44). The principal component analysis was performed as a variable reduction method for Agricultural, Geographic, and Assets factors, and for clustering quantiles of food security score. The components are taken by considering the Eigenvalue (>1), the proportion of variance explained from the total variance, and the subjective meaning of highly contributing components (44, 45). After dimension reduction and exploratory analysis, a total of 42 explanatory variables (x's) are analyzed (The list of all 42 variables is given in Appendix Table 1).

Model

Repeatedly taken measurements from a household are correlated and the assumption of traditional regression (constant variance and independent error) fails to fit the modeling procedure, which leads us to consider a longitudinal quantile mixed model instead of other models like time series analysis due to a larger number of subject/households and smaller repeated measurements per subject (46, 47). Accordingly, this study applied a longitudinal conditional quantile regression model to detect and control the unobserved heterogeneity that affects dependency between observations of repeated measures from the same subject to visualize the evolutional variability of the quantiles of household food security scores for the causal effect of those subject predictors. The linear quantile mixed effect model package (*lqmm*) in R-software was used for the analysis (48–50). The longitudinal data in quantile regression can be fitted by a marginal or conditional model. Since our data has a longitudinal nature, conditional quantile regression is appropriate (38).

The proposed model considers individual-specific parameters to account for dependence between longitudinal data, and conditional quantiles are estimated simultaneously by minimizing a weighted

1 https://stage-data.kimetrica.com/id/dataset

piecewise linear quantile loss function. Based on the distribution of the individual-specific parameter, conditional quantile regression has used two modeling approaches: the distribution-free and likelihood-based methods. A distribution-free approach considers a fixed individual-specific intercept and is treated as pure location shift parameters common to all conditional quantiles. This implies that the conditional distribution for each individual has the same shape but different locations as long as the individual-specific effects are different (51, 52).

In the likelihood approach, individual-specific parameters, $\gamma_i s$, are assumed to be independent and identically distributed random variables; the corresponding distribution allows us to explain differences in the response quantiles across individuals or showed a distributional shift for each individual (53). The longitudinal data considered by this study have a small number of repeated measures, and it is not able to reflect a distributional shift and may bring biased estimates for coefficients; however, it can better show a fixed individual-specific location-shift effect (51, 52). Therefore, the fixed individual-specific intercepts are considered and treated as pure location shift parameters (distribution-free) specific to a quantile being estimated. In modeling the random effect, the Gauss-Hermite quadrature allows for all types of covariance matrix implemented in *lqmm*; therefore, the random effect is taken as Gaussian random effects (i.e., Gauss-Hermite quadrature).

The conditional τ – quantile of y_{it} (food security score for tth repeated measure of the ith individual) denoted by $Q_\tau\left(y_{it}|\beta(\tau)|,\gamma_i,x_{i,t}\right)$ is given by Equation (1) as follows:

$$Q_\tau\left(y_{it}|\beta(\tau),\gamma_i,x_{i,t}\right)=\gamma_i(\tau)+x_{i,t}^{'}\beta(\tau) \quad (1)$$

For a realization of τ^{th} quantile of $y_{i,t}$ Equation (1) can be given as:

$$y_{i,t}=\gamma_i(\tau)+x_{i,t}^{'}\beta(\tau)+\varepsilon_{i,t} \text{ in matrix form } y=\gamma(\tau)+X\beta(\tau)+\varepsilon \quad (2)$$

where $\tau\mathcal{C}(0,1)$, $\varepsilon\sim N\left(0,\sigma^2\right)$ is an error term whose τ^{th} conditional quantile is identically null, that is, $Q_\tau\left(\varepsilon_{i,t}|\beta(\tau),\gamma_i,x_{i,t}\right)=0$, or equivalent to the conditional quantile restriction:

$$P\left(\varepsilon_{i,t}(\tau)\le 0|\beta(\tau),\gamma_i,x_{i,t}\right)=\tau \quad (3)$$

while $\beta(\tau)$ summarizes the effect of the covariates $x_{i,t}$ on the ith household's food security score, $\gamma_i(\tau)$ individual specific variability/effect, and the τ^{th} response quantile for a subject whose baseline level is equal to $\gamma_i(\tau)$; conditional on $\gamma_i(\tau)$, repeated measures are no longer dependent. The degree of unobserved heterogeneity is characterized by τ-specific variance parameters $\gamma_i(\tau)$: $\gamma_i\sim N\left(0,\sigma_{\gamma_i}^2\right)$. The $\gamma_i(\tau)$ has a pure location shift effect on the conditional A-quantiles of the response (50, 51).

The method of removing unobservable heterogeneity by differencing or other transformations does not work in longitudinal/panel quantile regression models as regression models. For example on the differencing: $y_{i,t}-y_{i,t-1}=(x_{i,t}-x_{i,t-1})'\beta_0(t)+\underbrace{\varepsilon_{i,t}(t)-\varepsilon_{i,t-1}(t)}_{=v_{i,t}(t)}$, $v_{i,t}(t)$ does not satisfy the desired conditional quantile restriction (3) (49, 50, 54, 55).

In this study food security assessment applied is in a perspective of "effect driven leveling of FCS" governed for difference food pattern due to Ethiopia's cultural diversity, with cut-points fixed by clustering those conditional quantiles of FCS shared some common major causing factors as one level. Furthermore, we have checked these quantiles clustering by using the principal component analysis of the FCS quantiles after coding zero and one for insignificant and significant effects of factors, respectively. Because these clusters of quintiles shared some common significantly affecting factors, they should contribute largely to a principal component representing that level.

Results

From exploratory analysis, the principal component analysis reduces the dimension of geographic variables from 19 to six components with an Eigenvalue greater than one which explains 76.12% of the total variation; similarly, 12 agricultural variables combined into four components with an Eigenvalue greater than one explaining 53% of the total variation, and 47 assets variables merged into 12 components with an Eigenvalue greater than one explaining 50.11% of the total variation.

The descriptive result in Table 1 indicates that the food security score has improved over time over the quantiles. The mean approximates the median, and other quantiles (25 Vs 75 and 10 Vs 90) are approximately at an equal distance from the median. The longitudinal quantile regression given by Equation (1) has better precision (smaller standard error) compared to the linear mixed model (Appendix Table 1) and linear quantile regression estimates (Appendix Table 2), with more significant variables. In addition, the tails of the quantile plot suggested the presence of heterogeneous variance on lower and upper quantiles (Appendix Figure 3). Therefore, the suitable model is longitudinal quantile regression with the free distribution assumption of covariance structure in which the individual-specific intercept is

TABLE 1 Quantiles of FCS for the years 2012, 2014, and 2016, and longitudinal data of 2012–2014-2016.

Year	q0.1	q0.25	q0.35	q0.5	q0.75	q0.9	Mean
2012	23	35	39	47	60.5	76	48.41
2014	24.5	36.5	42	49	63	76.8	50.59
2016	26.5	37	42	49.5	63	77	50.94
Longitudinal	24.5	35.5	41.5	49	62.5	76.5	49.98

just a location shift for each individual. Although for these three-time replications, the covariance structure has to be modeled by distribution-free, an alternative modeling by different models was tried and a convergence criterion was not met.

The key result for the longitudinal quantile model is given in Table 2 (the full result is given in Appendix Table 3). The major effects of the conditional quantiles' distribution of food security score suggested three clusters of quantiles which leveled the FCS into three clusters with approximate cut points at the 25th and 50th quantiles. Since each cluster of quantiles of the FCS is dominantly influenced by some significant effects, through coding significant effects by one and zero for less influencing (statistically non-significant) effects, we can strengthen the suggestion of effect-driven clustering for households' food security score. Accordingly, the principal component analysis result in Appendix Table 4 based on the significance of major effects given in Appendix Table 5 comes with the same cut points as the above-suggested three clusters of quantiles of food security score. Specifically, the cut points are 35.5 and 49, and using these cut points, the food insecure, vulnerable, and secure households are 25, 27.1, and 47.9% of the total household population. This indicates that correcting the WFP FCS cut-points based on leveling the FCS using effect-driven quantile clustering governed for Ethiopia's cultural diversity has an

TABLE 2 Longitudinal quantile regression and linear mixed model (LMM) results for factors that have significant and larger effects.

Estimates	q0.10	q0.25	q0.35	q0.5	q0.75	q0.9
Intercept	−1421.9***	−1432.5***	−1438.5***	−1439.1***	−1440***	−1425.6***
Year (x_1)	0.72***	0.74***	0.74***	0.74***	0.74***	0.74***
Urban *Vs* Rural (x_3)	4.23	0.85	0.27	2.06	4.09***	4.6**
Read and write (x_5)	0.65	0.55	−1.98*	1.98***	2.59***	3.41***
Shock (x_6)	−3.33***	−1.43*	−0.58	−1.89***	−0.98*	−0.66
Fertilizer (x_7)	−0.65	−0.18	1.44**	0.2	2.28***	2.24**
Adult equivalence (x_8)	−1.45	−1.48**	−0.8	−1.31**	−0.99*	−1.07**
Age of household head (x_9)	−0.08*	−0.07***	−0.03*	−0.01	−0.02	0
Coping strategy index (x_{11})	−0.12	−0.14**	−0.12***	−0.06**	−0.05	−0.05*
Dependency ratio (x_{12})	−1.22**	−1.05***	−0.71***	−0.45**	−0.1	−0.16
Employed (x_{14})	3.38	3.14**	3.21***	3.91***	4.65***	5.35***
Farm type (x_{15}): [Livestock]	4.65	5.9**	6.44***	8.82***	8.87***	6.6**
Farm type (x_{15}): [Both farms]	−0.79	1.33	1.07	1.77***	4.24***	2.88*
Health problem (x_{18})	−0.63	−1.79*	−2.19**	−1.81***	−0.64	−0.55
Household size (x_{19})	1.78**	1.39***	1.04*	1.5***	1.29***	1.6***
Small-size land ownership (x_{20})	−3.86*	−3.78***	−2.74**	−2.61***	−0.96	−2.17
Soil property related (x_{24})	0.75	0.85*	0.64*	0.4	1.44**	1.49**
Agro-ecological and distance from border-related (x_{25})	0.25	0.71	0.24	−0.91***	−0.95**	−0.52
Rainfall and greens related (x_{26})	−0.71	−1.4**	−0.86**	−1.15***	−1.18**	−1.77**
Agricultural package related (x_{30})	1.14	1.41***	0.44	1.08***	0.7*	0.65*
Drinking water (x_{33})	−0.83	−0.09	0	0.41	0.15	0.47
Irrigation-related (x_{37})	0.74	1.67***	0.01	−0.15	−0.15	−0.48
Non-agricultural business related (x_{38})	0.54	0.67	0.78***	0.9***	0.84**	0.47
Sanitation-related (x_{41})	0.57	0.72*	1.19***	1.32***	1.43***	1.55***
AIC	100,833	99,616	99,189	98,979	100,717	102,742
Log-likelihood	−50,362	−49,753	−49,539	−49,434	−50,304	−51,316
The covariance matrix of the random effects: (Individual-specific variability, $\sigma^2_{\gamma_i}$)	105.9	108.3	81.44	70.14	108.9	165.7
Residual scale parameter: (standard deviation, $\sqrt{\sigma^2}$)	2.087 (21)	4.397 (18.54)	5.391 (17.49)	5.959 (16.85)	4.624 (19.5)	2.205 (22.18)
ICC= $\frac{\sigma^2_{\gamma_i}}{\sigma^2_{\gamma_i}+\sigma^2}$	0.19	0.24	0.21	0.20	0.22	0.25

Significances: ***for 99%, **for 95% & *for 90%.

effect on feeding patterns and brings a wider interval by a score of seven for insecure households with larger proportions, but the interval for vulnerable households is equivalent compared to WFP cut-points 28 and 42.

The results in Table 2 reveal that the household-specific variability across time on the model is high on the food insecure and secure compared to the vulnerable, with a random effect covariance matrix ranging from 81.44 to 190.6. A smaller intra-correlation coefficient (ICC) ranging from 0.19 to 0.25 is observed over quantiles of food security scores. It is an indication of a low correlation between any two repeated measures within the subject. In general, even if households' FCS showed smaller progress across all quantiles, better change has been shown in households in food-secure households.

The results in Table 2 and Figure 1 (with Appendix Figures 1, 2) indicate that relative to rural households, urban households have significantly higher FCS mainly in insecure and secure households; the gap rise from 4 to 12 times in secure households and four to 8 in insecure households. Food security score also differs across regional states. Education has a stronger positive significant effect on higher FCS quantiles of households who can read and write compared to those who cannot, with an effect ranging from 1.98 to 7.31. Households led by younger heads are food insecure, and food security increases with the age of households' heads, ranging from −0.19 (−0.31 — -0.06) to 0.02 (−0.06 — 0.09). Male-headed households are more food secure across the quantiles. Household size has a significant positive effect across all levels of the food security score distribution, but this effect is higher on insecure households, and it rises from 1.78 to 2.07.

Employed-headed households have better food security, and its effect is larger on higher quantiles; its effect increases as quantiles of food security increase, from 3.14 (0.76 — 5.52) to 5.35 (1.75 — 8.96). The component score for non-agricultural business-related has a significant positive effect on the middle quantiles, and its effect declines to the ends of the quantiles of the food security score.

The dependency ratio and shock that occurred have a higher significant negative effect on food-insecure households, and its effect decreased in vulnerable households and became insignificant in food-secure households. Adult equivalence has a proportionally constant negative effect across the quantiles of the food security score. On the other side, the sanitation component score (such as solid waste disposal and bathing and toilet facilities) and getting drinking water have an increasingly positive effect as the quantile of food security scores rises. Households getting health assistance have an increasingly positive effect as the quantiles of FCS rise, whereas facing health problems has a negative higher effect on middle quantiles of food security score relative to the end.

Soil property component score (soil nutrient content and irrigation, oxygen availability, excess salt, and toxicity) or good soil quality has increased food security, mainly on the lower and upper quantiles. The component score for agro-ecological zone, T°, and Elevation and Distance from the border and the component score for rainfall and greens have a significantly higher effect on the higher quantiles, and its effect decreases on the lower quantiles. The

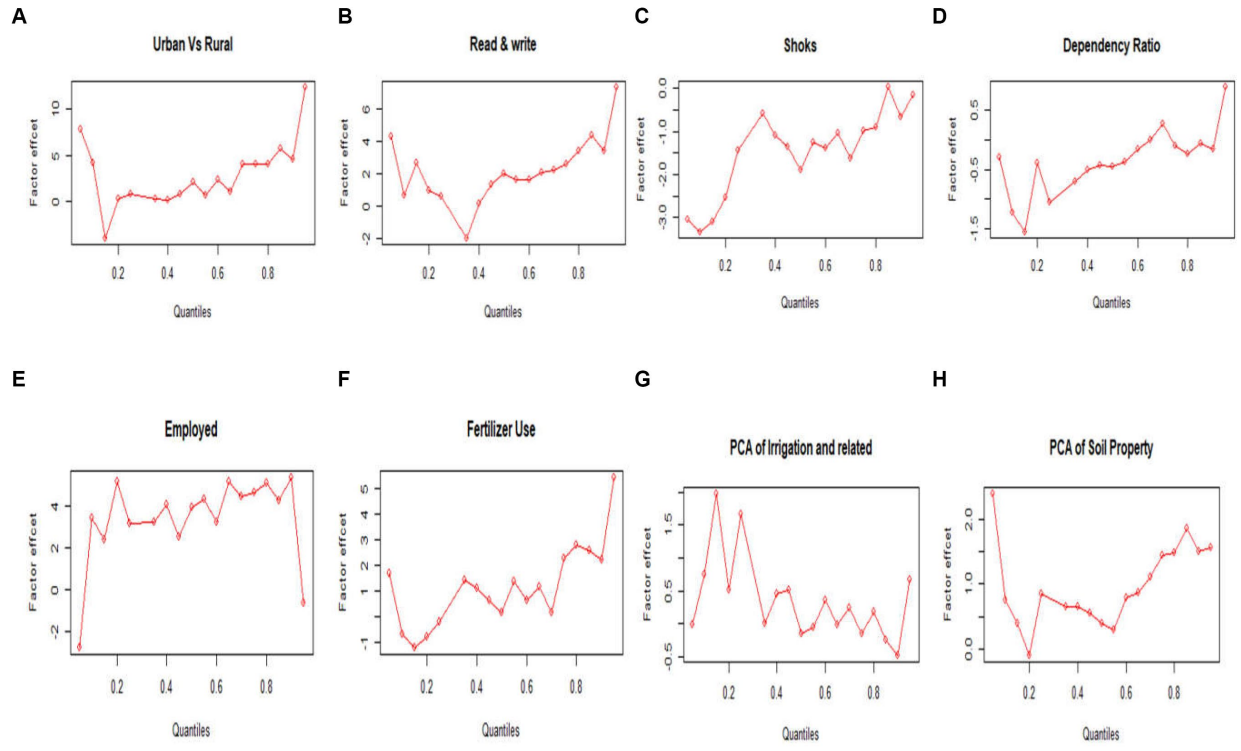

FIGURE 1
The distributional plot of longitudinal quantile regression coefficients estimate or effect on households' FCS: **(A)** Urban *Vs* rural, **(B)** Can read and write (yes/no), **(C)** Shock occurred (yes/no), **(D)** Dependency ratio, **(E)** Employed (yes/no), **(F)** Fertilizer used (yes/no), **(G)** Component of irrigation-related, and **(H)** Component of soil quality.

component score of irrigation, mixed cropping, crop damage, and erosion has a significant effect on the 15th and 25th quantiles of the food security score.

The agricultural package component score such as advisory service, extension program, credit for agriculture, and crop rotation has a significantly higher effect on the middle and higher quantiles of FCS. Farming-type livestock or livestock with cropping and fertilizer usage has an increasingly positive effect as the quantile of food security scores rises. Having a small-size land (either owned or rented) for cropping has a higher negative effect on quantiles of food security score except on higher quantiles. The severe/higher copping strategies are significantly reducing the middle quantiles food security score. The component scores of information source, housing quality, and electronic and furniture-related have an increasingly significant positive impact across the quantiles of the food security score distribution.

Discussion

Cultural diversity across the globe brings different patterns to feeding culture. The relevance of the assessment and comparison of households' food insecurity based on weekly diet-dish data for households with different feeding pattern is questionable, and therefore society's cultural diversity effect on feeding patterns need to be considered. Therefore, there is a need for a universally accepted threshold that is corrected for local factors for those resulting in different consumption patterns in the standardization of food security score. Accordingly, the regression approaches are proposed to adjust the WFP-FCS cut points by adjusting for local situations through driving factors.

Standard regression found the marginal causes of the response at the mean, but it cannot answer the question of how input variables affect the response at different parts of the distribution. Rather, quantile regression can help to assess this effect. Longitudinal quantile regression is an appropriate model when the interest is on the upper or/and lower quantiles of the distribution for repeatedly taken measurements (35, 37, 48, 50, 51, 54, 56, 57). The longitudinal quantile regression model with a fixed individual-specific intercept with free distribution covariance structure results was selected for fitting repeated measures in finding out the exact effect of the factors compared to linear quantile regression and linear mixed model. In the analysis, the fitting of the alternative likelihood approach for the error covariance model with different covariance structures did not converge.

Based on the evidence from the major contribution of the above factors over the quantiles of FCS, the food security score can be categorized into three classes; the food security score less than the 25th quantile ($FCS \leq 35.5$) is food insecure, the food security score between the 25th and 50th quantile ($35.5 \leq FCS \leq 49$) is vulnerable to food insecurity, and a score greater than the 50th quantile ($FCS \geq 49$) of food security score is food secure. Using the effect-driven leveling cut points, 35.5 and 45, the coverage of food insecure, vulnerable, and secure households is 25, 27.1, and 47.9% of the total household population. The statistical approach using principal component analysis for clustering quantiles by these major effects also gives the same cut point for these three classes, which strengthens the effect-driven clustering of quantiles into three levels.

The yearly quantiles of 2012, 2014, and 2016 indicated an increasing pattern of the food security score across time even if the change is smaller. Even though the individual-specific variability over time is high in food-insecure and secure households compared to vulnerable households, the progress in food-secure households is better. The reduction in food insecurity through time was also indicated by previous studies (19, 22).

Urban area households have significantly higher food security compared to rural households. This result aligns with the Ethiopian government's plan for mechanized farming and industrial parks to create jobs mostly for employees from rural areas, and it is also supported by previous studies (19, 22, 58). Similarly, food security score differs over the regions across quantiles; specifically, Deredwa and Gambella have better food security across quantiles, and the southern nation and nationality people (SNNP) have a lower food security distribution. Literature also supports the presence of regional food insecurity variation (59–61).

The household head who can read and write has a stronger positive significant effect on food-secure households relative to the insecure households. The positive effect of education on the reduction of food insecurity has been indicated by previous researchers (18, 25, 27, 59, 62–66). Except in food insecure households, the effect of employment on households' food security is significant in vulnerable and secure households, and its effect increases as quantiles of food security increase. This result is also supported by previous researchers (27, 58, 65, 67).

Household size has a significant positive impact across all levels of the food security score distribution, but the magnitude of this effect decreases in food secure households. This result is in contrast with previous studies (63, 68, 69). This may be attributed to children being seen as a source of wealth in Ethiopia, and they work on farms or in any business area to bring money to the family. The effect of the sex of the household head is not significant even though male-headed households have a better food security score as suggested by many studies (64, 65, 70). The age of the household head has a higher negative significant effect on lower quantiles of food security score. The effect of age is indicated by previous studies (27, 64, 65).

The sanitation and drinking water component scores have a significantly higher effect in food-secure households, whereas the effect decreases in insecure households. Previous studies also point out drinking water and sanitation as an input in the reduction of food insecurity studies (18, 22, 71). Facing health problems has a high effect on the vulnerable to food insecure households relative to the food insecure and secure households. The health problem effect on food insecurity was also reported by previous researchers (20, 25).

The shock that occurred in the household is significantly higher in food-insecure households, and its effect decreases in food-secure households. The effect of shock, like a rise in the price of food items, an increase in the price of inputs, illness of a household member, and drought, on food insecurity was also indicated by several researchers (22, 70–72). The effect of the dependency ratio is significantly high on food-insecure households, whereas its effect decreases as the level of food security increases. The negative effect of the dependency ratio on the reduction of food insecurity is indicated by a previous study (22, 27). Adult equivalence has a negative effect all over the levels of the food security score distribution. The higher adult equivalence or a large number of consumption units per household

reduced food security score over all levels and previous studies also indicated the negative effect of higher adult equivalence on food insecurity reduction (25, 73).

Farming-type livestock or livestock with cropping has a significantly higher effect on higher quintiles of food security scores, whereas the effect decreases on the lower quantiles. Many studies agreed on the adoption of drought-resistant farming in food-insecure areas (58, 62, 64, 69, 74). Having a small-size land either owned or rented for cropping has a higher negative effect on insecure and vulnerable households, and the effect decreases and becomes insignificant in secure households/upper quantiles. This result is supported by Cheema et al. (2020) (27, 58, 66, 69, 71, 74), and agrees with the Ethiopian government's initiative on integrated farming.

The agricultural package or component score of advisory service, extension program, credit for agriculture, and crop rotation has a significantly higher effect on vulnerable and secure households. The improvement obtained in food security from agricultural package implementation is also indicated by previous researchers (58, 64). The usage of fertilizers has a significantly high effect on food-secure households, and its effect decreases in food-insecure households. This result suggested that cropping using fertilizers can lead to a higher level of food security score. Previous studies also supported the importance of fertilizer for food insecurity reduction (66, 69, 75).

Soil property component score has a significant positive effect on food-insecure and vulnerable households; this implies that soil quality has a positive effect on the reduction of food insecurity. This result is aligned with previous studies (58, 64) and the Ethiopian government's agricultural package policies on soil conservation by planting trees, grass, and terrace farming. The component score for agroecological and distance from border-related and the component score for rainfall and greens have a significantly higher effect on the food secure households and its effect decreases on the food insecure households. This result is supported by previous studies (60, 64, 68, 70). The non-agricultural business and related factors component scores have a significant positive effect on vulnerable households and its effect declined to the end of the quantiles of the food security score. This result is aligned with previous studies (27, 63, 64). The component score of irrigation, mixed cropping, crop damage, and erosion has a significant effect on lower quantiles (25th and 35th) of the food security score. This result is supported by previous studies (22, 60, 63, 76, 77).

Information sources, housing quality, and the electronic and furniture-related component scores have an increasingly significant positive impact across the quantiles of the food security score distribution. This result is aligned with previous studies (18, 22, 25, 65). The severity of the coping strategy has a significant effect on vulnerable households. Previous research found that different coping strategies are applied by households based on the magnitude of food shortage (22, 78).

The corrected WFP FCS cut points split out the significant association of ability to read and write with vulnerable and food-secure households, residence in urban areas with food security, fertilizer usage with food-secure households, farming livestock or/and crop with food-secure and vulnerable households, shock with food insecure households, dependency ratio with food insecure and vulnerable households, sanitation-related with food insecure and vulnerable households, age of household head with food insecure households, and health problem with vulnerable households.

Compared to the WFP cut points for FCS, the effect-driven approach cut points used in this study bring a wider interval for food insecure households, with the same interval range for vulnerable households. The result revealed that measuring food insecurity in Ethiopia by FCS with WFP cut points (28 and 42) underestimates households' food insecurity levels by a score of seven. If we adopt the WFP FCS cut-points 28 and 42; some households will wrongly assigned on each levels, especially the proportion of secured households will inflate and the proportion of food insecure households will be under estimated, and factors will wrongly recommend for their influence on the levels of food security score. For example, if we use the WFP cut points, the health problem of the household head will have no totally significant effect on insecure households, small-size land ownership and the dependency ratio will also be recommended as an influential factor on food secure households, and residence in urban areas have no statically significant difference on being vulnerable to food insecurity relative to rural households. Previous studies also suggested further work on the need for threshold correction due to local factors such as cultural diversity, which resulted in consuming small amounts of food. Similarly, WFP adjusted the FCS by a score of seven for a high frequency of consumption of small amounts of sugar and oil and gave the alternate cut-offs to be 28 and 42 (29). Previous research also reported households' FCS cut points to be 45 and 61 for Jordan (31) and 32 and 43 for Laos due to cultural disparities (30).

Strengths, limitations, and future work

Previous research on food security used cross-sectional data and focused on investigating the effects of factors on the lower quantile of food security (food-insecure only). This paper has several strengths; even if the currently available data have smaller replication, it is the only long term available panel data. Furthermore, this paper addressed measurement problems based on effect-driven classification of quantiles, and identifies mitigations at a local level by considering the evolutional variability (sustainability over time) of food security score over the quantiles. As a result, this paper found the major factors and a universally accepted local threshold corrected to local factors for food insecure, vulnerable, and secure households by considering the longitudinal effect that can be an input for future researchers and policymakers.

We have used the available data that is older than 7 years since recent data is not yet collected by the concerned body due to many problems faced in Ethiopia including political instability, war, and displacement. On the other hand, even if the sample size is large enough ($n = 3,835$), due to the small number of repeated measurements in households (in 2012, 2014, and 2016), the likelihood approach error covariance model does not converge, and error covariance modeling is done by free the distribution covariance structure.

Therefore, as future work one can extend the work using sufficiently repeated measurements based on the panel data that will be released in the future. There is also a need for comprehensive research that considers cultural disparities across nations which affect consumption patterns to fix a universal threshold or some robust estimate.

Conclusion

The effect-driven approach cut points for FCS leveled the food security of Ethiopian households into three with cut points 35.5 and 49, which brings wider intervals for food insecure households and the same interval size for vulnerable households, while the WFP cut points (28 and 42) underestimates households' food insecurity levels by a score of seven. Therefore, applying WFP cut points will wrongly assign households on each level; especially, the proportion of secure households will inflate and the proportion of food insecure households will be underestimated, and factors will be wrongly recommended for their influence on levels of food security score.

Ethiopian households' food security showed improvement over time across all quintiles of food security score distribution. The progress is higher in food insecure and secure compared to vulnerable households; mainly the improvement in the food secured households is higher. Food security scores differ across regions throughout the quantiles of the FCS. Households living in urban areas have better food security compared to rural areas.

In general, the quantile regression approach adjusts the WFP-FCS by adjusting for local situations/factors. Accordingly, this study has agreed with the suggestion of previous studies and suggested the need for a universally accepted threshold corrected for local factors, like cultural disparity which resulted in different consumption patterns in the standardization of food security score.

The proposed approach is constrained by driving factors in leveling food security and identifies mitigation at a local level to eliminate food insecurity for better public health. The suggested result of this study can help policymakers to intervene in mitigation at each level for the improvement of households' food security levels for better public health and social security in Ethiopia. Especially, integrated farming "ኩታ ገጠም እርሻ" using irrigation, mitigation for controlling shocks, and reducing dependency ratio can save food insecure households from severe risks. Correspondingly, to achieve better households' food security, working on access to education, urbanization, sanitation and drinking water, infrastructure, fertilizer delivery and farming of both livestock and crops, protection of the environment, and land degradation is essential.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

HW was involved in the conception, data management, data analysis, and interpretation of this study. TZ contributed to the conception, design, review, and revisions of the manuscript. AM contributed to the interpretation of the analysis and review of the manuscript. ZD contributed to the data management, interpretation, and revisions of the manuscript. All authors have read and approved the final manuscript.

Acknowledgments

The authors extend their heartfelt gratitude to reviewers for their careful reading of the manuscript and their helpful comments that improved the presentation of this work. The authors also thank the World Bank and the Ethiopian Central statistics agency for the data source access. We thank the data delivery organizations and the participant households for their positive response to the data collection. We also thank Bahir Dar University and the University of Gondar for their kind help with internet and other material access.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1173360/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 12 July 2023
DOI 10.3389/fpubh.2023.1212254

OPEN ACCESS

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RECEIVED 27 April 2023
ACCEPTED 21 June 2023
PUBLISHED 12 July 2023

CITATION
Osei Bonsu E, Afetor M, Munkaila L, Okwei R, Nachibi SU, Adjei BN, Frimpong E, Arimiyaw AW, Adu C and Peprah P (2023) Association of food insecurity and sleep difficulty among 189,619 school-going adolescents: a study from the global in-school students survey.
Front. Public Health 11:1212254.
doi: 10.3389/fpubh.2023.1212254

Association of food insecurity and sleep difficulty among 189,619 school-going adolescents: a study from the global in-school students survey

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Introduction: Adolescents' sleep disturbances are associated with chronic and dramatic physical, emotional, and mental development and school performance consequences. Although food insecurity could significantly contribute to these effects, few studies have explored the effect of food insecurity on sleep disturbances among adolescents. The study aimed to examine the relationship between adolescents' food insecurity and sleep disturbance.

Methods: Data on 189,619 adolescents were drawn from the cross-sectional global adolescent health surveys conducted between 2015 and 2018 in 35 countries and territories. Univariate and multivariable multinomial regression models were fitted to examine the hypothesized associations.

Results: Overall pooled prevalence of moderate [45.2% (95%CI = 43–47)] and severe [5.8% (95%CI = 5–6)] food insecurity levels were reported. About [52.6% (95%CI = 51–54)] moderate and [8.6% (95%CI = 8–9)] severe worry-induced sleep disturbances were found. Considering the fully adjusted multinomial logistic model, moderate food insecurity was significantly associated with moderate (AOR = 1.70 CI = 1.59–1.81; $p < 0.0001$) and severe (AOR = 1.63 CI = 1.42–1.87; $p < 0.0001$) sleep disturbances. Also, adolescents reporting severe levels of food insecurity had moderate (AOR = 1.88 CI = 1.68–2.11; $p < 0.0001$) and severe (AOR = 4.07 CI = 4.74–6.11; $p < 0.0001$) sleep disturbances. Females and those aged between 15 and 17 years and 18 or more were at higher risk of moderate and severe sleep disturbances in the context of food insecurity.

Conclusion: Reducing food insecurity could be an effective policy strategy for enhancing adolescent sleep quality.

10.3389/fpubh.2023.1212254

KEYWORDS

food insecurity, sleep disturbance, adolescents, global health, multinomial

Introduction

Recent estimates of access to food present a troubling picture of global food insecurity. For instance, in 2020, between 720 and 811 million people across the globe were estimated to have faced hunger (1). This report presents a substantial problem in attaining the United Nations' Global Goals for Sustainable Development, which call for the global eradication of extreme hunger and all types of malnutrition by 2030 (1). Food insecurity is defined as the interruption of food consumption or patterns of eating due to a lack of money and other resources [(2), p. 27]. Although food insecurity is not limited to only developing countries, a large proportion comes from the developing world. For example, between 2019 and 2020, developing countries accounted for over 80% of the sharp increase in food insecurity (3). Thus, food insecurity is a major global issue affecting developing and developed countries (4).

Among adolescents and children, food insecurity is associated with poor academic performance due to learning difficulties, nutrient deficiencies, and poor outcomes in terms of physical health and mental health (5–8). Food insecurity is strongly linked with sleep through psychological distress, depression, anxiety, and hunger disturbance, especially among adolescents (9–11). For instance, among adolescents from 68 countries, Wang (11) established that severe food insecurity increases the risk of sleep disturbance in 48 countries. Lee et al. (9) also reported that adolescents in the persistently low food insecurity group and persistently moderate food insecurity group faced more sleep difficulties than those in the food-secure group in Taiwan. Even beyond adolescents, previous studies have found that food insecurity impacts sleep negatively among older adults (2, 10, 12, 13).

Poor sleep quality and sleep disturbances are significant public health concerns (2, 14). Chronic poor-quality sleep is associated with numerous adverse health outcomes such as psychological distress, all-cause mortality, type 2 diabetes, obesity, and chronic cardiovascular diseases (14–17), stress, depression, and anxiety (10).

With the recent increase in food insecurity (3), heightened sleep disturbances and related adverse health outcomes are likely, especially among adolescents (11, 18). Reports from previous studies show that the proportion of adolescents who are food insecure is higher than other subpopulation groups, and one-third of adolescents across the globe experience sleep difficulties (11, 16, 19). Examining the association between food insecurity and sleep is essential for public health and policy intervention for sleep disturbance-related disease burden control. However, published studies on the association between food insecurity and sleep are limited, especially among adolescents (11). The limited literature, however, predominantly focuses on the adult and aged populations (2, 10, 12, 13). Few studies that examined adolescent sleep disturbances have only focused on the mental health implications (4, 9, 20).

To the best of our knowledge, the only study examining food insecurity and sleep disturbances among adolescents using data from multiple country surveys was conducted by Wang (11). However, Wang's (11) study has three significant limitations requiring further analysis. For instance, Wang's study used relatively old Global School-Based Student Health Surveys' (GSHS) data. Some of the data included in the analysis were collected in 2007, which is more than a decade ago and might not reflect the recent or current reality of food insecurity and sleep issues. The present study uses data from surveys conducted between 2015 and 2018, which remain the most current GSHS data in the countries included. More importantly, previous findings have indicated that the age and sex of an individual may differ in health status and also predict psychological state, including sleep patterns (21), which was not examined in Wang's study. Age and sex are important determinants of health because of the biological, social, economic, psychological, and behavioral changes attributed to them (22). For instance, increasing age declines physical health, whereas stress levels, psychological health, and social health have been found to also increase with age (23). Meanwhile, the differential vulnerability hypothesis (24) suggests that exposure to social health determinants such as food insecurity remains varied. For instance, age and gender differences may relate differently, mainly due to differences in social and economic deprivations (2). Furthermore, as the adolescent population includes more females than males, sex and age are critical determinants for food insecurity and sleep. Again, potential biological factors such as hormonal changes and genetic factors may also have a negative impact on the relationship between food insecurity and sleep quality (14). Lastly, Wang's study measured food insecurity and sleep disturbances using dichotomous variables and analyzed them through a binary regression approach. However, using such an approach appears simplistic. Food insecurity has been widely categorized into moderate and severe levels (4, 25). Moderate food insecurity indicates that the quantity/quality of food intake has been compromised, and severe food insecurity points to decreased food consumed and disrupted eating patterns (7). These categories, therefore, represent a better operationalization of food insecurity (7).

Thus, using a multinomial logit analytical approach, this study intended to examine whether food insecurity is associated with sleep disturbances among a representative sample of 189,619 adolescents from 35 countries and territories using the most recent GSBHS data. We also examine the modifying roles of age and sex in the association between food insecurity with sleep disturbance. We hypothesized that (1) adolescents who are moderately and severely food-insecure would have increased risks of sleep disturbance and (2) females and increasing age also increase the likelihood of sleep disturbance.

Methods

Data source

This cross-sectional, multi-country study used publicly available data from the GSHS among 35 countries. The GSHS is a representative and extensive health survey of risk factors and behaviors of students.

US Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO), and other United Nations (UN) allies and country-specific institutions developed this survey (1, 26). Content from this survey was drawn from the CDC Youth Risk Behaviors Survey (YRBS) to establish its reliability and validity (27). The information included in the survey is the objective, methodology used in the survey, and the procedure for sampling the GSHS is available at http://www.cdc.gov/gshs/.

In summary, though the participants for the GSHS are primarily school-going adolescents aged 13–17 years, those below 13 and above 17 years were also included in the survey. The sampling procedure included a two-stage standardized probability sampling approach for selecting participants within each country in this survey. In the first stage, the schools were selected through probability proportional to size sampling design. In the second stage, students between the ages of 13 and 17 were randomly selected from their various classrooms in each selected school. Irrespective of the student age in the selected classrooms, all students were eligible to participate in the survey. In this study, we employed the most current data available in GSHS participating nations and territories in this investigation. Countries and territories with data released before 2015 were removed from the analysis. These criteria ensured that the analysis reflects and represents recent or current trends. Also, we excluded data that did not have the variables of interest for the present study. By applying the inclusion and exclusion criteria, data from 35 countries and territories were considered recent and eligible to be included in the analysis. Thus, our analysis included data from 35 countries and territories released between 2015 and 2018. To account for non-response and probability selection, the data was weighted to enable the generalization of results to the targeted population (28, 29).

Data collection procedure

Trained enumerators collected data from local social work agencies and other research institutions during a regular class period. The GSHS questionnaire was designed to be close-ended and was written in English before being translated into each country's native language. Multiple-choice questions were included in the questionnaire. The questionnaires were administered after informed consent was obtained from children, parents, and school authorities. Before the questionnaires were given, the trained enumerators thoroughly described the purpose of the study and the instructions to the students.

Furthermore, through anonymous and voluntary participation, the survey ensured that students' privacy was respected. The study followed the Helsinki Declaration, and all GSHS surveys were evaluated and approved by institutional review boards or ethics committees in each nation. Details of the systematic techniques used to gather student data can also be obtained at http://www.cdc.gov/gshs/.

Assessing food insecurity (hunger)

We assessed food insecurity (hunger) by asking, "During the past 30 days, how often did you go hungry because there was not enough food in your home?" The item had 5-point response options: never, rarely, sometimes, most of the time, and always. It has been argued that single-item measures can be easier to capture and more cost-effective in large-scale surveys like the GSHS than multiple-item measures (30). A single item should be sufficient for the variable, and the attribute of the variable measured is "concrete" to the participants (31). We believe the single item assessing food insecurity in the GSHS was an example of such a concrete measure. Given the exploratory nature of the present study, we believed that the single-item question was a sufficient measure of food insecurity, consistent with previous studies (4, 17, 32, 25). For analytic purposes and in line with other previous studies, we categorized never as no food insecurity, rarely and sometimes as moderate food insecurity and most of the time and always as severe food insecurity. These categories were named as such because evidence suggests that moderate food insecurity is often considered to indicate that the quality/quantity of food intake has been compromised. In contrast, severe food insecurity refers to reduced food intake and disturbed eating patterns (7).

Assessing sleep disturbances

Sleep disturbance was assessed based on the question, "During the past 12 months, how often have you been so worried about something that you could not sleep at night?" Responses were never, sometimes, most of the time, and always. This item has been used in previous global studies involving adolescents using the GSHS (11, 33). In this study, never was categorized as no sleep disturbance, sometimes as moderate sleep disturbance, and most of the time and always as severe sleep disturbance for analytic purposes.

Covariates

We included empirically and theoretically defined variables as confounders. These covariates were selected because they both have direct and indirect relationship with food insecurity and sleep quality in previous studies (4, 17, 32, 34, 25). Sociodemographic variables included age (11–14 years; 15–17 years; 18+ years) and sex (male; female). Health-related and behavior variables included bullying victimization (no; yes), loneliness (no; yes), suicidal ideation (no; yes), cigarette smoking (no; yes), alcohol use (no; yes), marijuana use (no; yes), physical activity (no; yes), close friends (no; 1–2; 3+), amphetamine use (no; yes), and parents understand adolescent problems (no; yes).

Statistical analysis

Stata 14.0 was used to perform the statistical analysis. The 'svyset' command in Stata was used to adjust for the complex sampling design employed by the GSHS survey using the weight, primary sampling unit (psu) and stratum variables. A p-value ≤ 0.05 was used to assess the statistical significance. Frequencies and percentages were calculated to describe the characteristics of respondents. Country-specific prevalence of food insecurity and sleep disturbance were summarized using proportions and 95% confidence intervals by sex. A series of stepwise multinomial logit regression analysis was performed to assess the independent effect of food insecurity on sleep

disturbance. Three separate models were fitted to estimate the association. Model 1 calculated the crude regression estimates by predicting the effect or influence of food insecurity on sleep quality. In Model 2, we added sociodemographic variables that could predict food insecurity or sleep disturbance. In Model 3 (full model), we included covariates related to lifestyle, support, and health-related variables. Further, moderation analyses of age and sex were performed to examine their modifying roles in the association between food insecurity and sleep disturbance.

Result

Background characteristics of respondents

A total of 189,619 adolescents from 35 countries and territories were involved in the study. Females (50.4%) were more than the males. The majority, 53.8% of adolescents, were between 15 and 17. The majority (66.4%) of adolescents were not bullied; 65.4% were lonely; 89.6% had no suicidal ideas; 74.3% had more than three close friends; 88.8% had not used cigarettes; 83.8% had not used alcohol; 96.2% had not used marijuana; 96.8% had not used amphetamine; 68.6% were physically active, and 77% had parents who understood their problems (Table 1).

TABLE 1 Distribution of relevant variables among adolescents in 35 countries.

Variable	*N* = 189,619 (%)	Weighted % (95% CI)
Sex		
Male	90,054	49.6 (50.3–52.5)
Female	99,565	50.4 (48.2–50.4)
Age		
11–14 years	84, 418	41.6 (39.5–44.6)
15–17 years	95,512	53.8 (50.8–57.5)
18+ years	9,260	4.6 (4.2–5.1)
Bullied		
No	119,285	66.3 (65.6–68.7)
Yes	61,114	33.7 (32.4–35.8)
Loneliness		
No	66,439	34.6 (34.2–36.6)
Yes	120,799	65.4 (64.5–66.3)
Suicidal Ideation		
No	153,483	89.6 (89.5–90.6)
Yes	26,304	10.4 (10.3–11.8)
Close friend		
No	3,945	5.1 (5.5–6.5)
1–2	47,479	20.6 (19.2–22.8)
3+	126,582	74.3(72.7–76.1)
Cigarette Use		
No	147,923	88.8 (88.7–90.2)
Yes	24,789	11.2 (10.5–12.3)
Alcohol Use		
No	100,442	83.8 (83.2–85.8)
Yes	49,681	16.2 (15.0–17.5)
Marijuana Use		
No	5,401	96.2 (96.2–97.7)
Yes	8,188	3.8 (3.5–4.6)
Amphetamine Use		
No	156,364	96.8 (96.1–97.3)
Yes	4,713	3.2 (3.0–4.1)
Physical Activity		
No	42,469	31.4 (30.5–33.9)
Yes	128,388	68.6 (67.7–70.8)
Parents understand adolescent problems		
No	39,821	23.0 (22.8–24.6)
Yes	125,254	77.0 (76.2–78.5)

Prevalence of food insecurity and sleep disturbance among adolescents

Tables 2, 3 present the overall and country-specific prevalence of food insecurity and sleep disturbance, respectively. The overall pooled prevalence of food insecurity (moderate and severe) was 51%. Food insecurity was more common among males (52%) than females. Overall pooled prevalence of sleep disturbance (moderate and severe) was 61.2%. Unlike food insecurity, sleep disturbance was more common among female adolescents (64.9%) than male adolescents (see Table 2). Regarding gender, the highest prevalence of food insecurity among male adolescents was reported in Samoa (75.7%), and the lowest prevalence was found in Curacao (25%). Among females, the highest prevalence of food insecurity was reported in Samoa (72.3%), and the lowest was found in Curacao (25%). Regarding sleep disturbance, the highest among males was reported in the Philippines (73.3%), and the lowest was observed in Suriname (44.9%). Among females, the highest was reported in the Philippines (79.7%), and the lowest was seen in Myanmar (47.2%; see Table 3).

Association between food insecurity and sleep

Table 4 shows a series of multinomial regressions predicting sleep disturbance. Model 1 estimated the crude effect of the association, whilst Models 2 and 3 controlled for sociodemographic, health and lifestyle-related variables. In Model 1, adolescents who were moderately food insecure relative to those who were food secure were 2.09 times more likely to have a moderate sleep (AOR = 2.09 CI = 1.98–2.20) and severe (AOR = 1.90 CI = 1.71–2.12) sleep disturbances. Similarly, adolescents who were severely food insecure were 2.28 and 5.38 more likely to experience moderate (AOR = 2.28 CI = 2.10–2.48) and severe (AOR = 5.38 CI = 4.74–6.11) sleep disturbances, respectively, relative to their food secure counterparts.

In Model 2, there was a slight change for each outcome, indicating a marginal role of the sociodemographic factors in explaining the

TABLE 2 Overall pooled prevalence of food insecurity and sleep disturbance among adolescents in 35 countries.

Food Insecurity	Frequency *N* (%)	Overall Prevalence	Males (95% CI)	Females (95% CI)
No food insecurity	105,286 (55.98)	49.0 (48.2–51.5)	47.7 (46.5–49.8)	51.5 (50.1–53.2)
Moderate food insecurity	72,028 (38.30)	45.2 (43.0–47.3)	46.3 (45.4–48.6)	43.8 (42.3–46.4)
Severe food insecurity	10,752 (5.72)	5.8 (5.2–6.7)	6.0 (5.1–7.6)	4.7 (4.7–5.6)
Sleep disturbance				
No sleep disturbance	66,089 (35.18)	38.8 (38.0–40.3)	42.5 (41.3–44.0)	35 (33.5–36.8)
Moderate sleep disturbance	99,117 (52.76)	52.6 (51.9–54.5)	49.8 (48.8–51.0)	55.4 (54.5–57.3)
Severe sleep disturbance	22,666 (5.37)	8.6 (8.8–9.5)	7.8 (7.8–8.9)	9.5 (8.3–10.4)

outcome variables. Model 3 was adjusted for lifestyle, health, and health-related variables (Full model). The results showed that adolescents who were moderately food insecure relative to those who were food secure were 1.70 and 1.63 more likely to experience moderate (AOR = 1.70 CI = 1.59–1.81) and severe (AOR = 1.63 CI = 1.42–1.87) sleep disturbances, respectively. Likewise, adolescents who were severely food insecure were 1.88 and 4.07 more likely to experience moderate (AOR = 1.88 CI = 1.68–2.11) and severe (AOR = 4.07 CI = 3.40–4.87) sleep disturbances, respectively, relative to their food secure counterparts (see Table 4).

Age- and sex-wise associations of food insecurity status with sleep disturbance

As displayed in Table 5, moderation analysis was performed to determine the modifying effect of age and sex on the association of food insecurity and sleep disturbance. The age-wise analysis used the interaction effect of age to determine the association between food insecurity and sleep disturbance. There was a significant association between moderate food insecurity and moderate sleep disturbance among adolescents aged 15–17 (AOR = 3.39 CI = 3.39–3.93) and a similar association between moderate food insecurity and severe sleep disturbance among adolescents aged 18 and older (AOR = 3.24 CI = 2.40–4.38). Moreover, there was a significant association between severe food insecurity and severe sleep disturbance among adolescents aged 15–17 (AOR = 1.15 CI = 0.97–1.33), severe food insecurity and severe sleep disturbance among adolescents aged 15–17 (AOR = 1.75 CI = 1.45–2.06), moderate food insecurity and severe sleep disturbance among adolescents aged 18 or older (AOR = −1.60 CI = 0.81–1.24). With sex-wise analysis, the interaction effect of sex was used to assess the association between severe food insecurity and severe sleep disturbance. There was an association between moderate food insecurity and severe sleep disturbance among females (AOR = 2.77 CI = 2.30–3.33), severe food insecurity and severe sleep disturbance among females (AOR = 8.58 CI = 6.95–10.57; see Table 5).

Discussion

Main findings

In this multi-country analysis, 45 and 5.3% were reported to be moderately and severely food insecure, respectively. Similarly, 52.5 and 8.6% of moderate and severe sleep disturbances were found. Adolescents with moderate and severe food insecurity were at higher risk of sleep disturbance than food-secure adolescents. The association between food insecurity and sleep disturbance was evident after adjustments for multiple potential variables. In addition, the effect of food insecurity on sleep disturbance was found in female adolescents. Also, adolescents aged 15–17 years and 18 years or older were found to have an increased effect of food insecurity on sleep than those aged 11–14 years. The study indicates that interventions for quality sleep among adolescents should include ensuring adequate food security.

Findings interpretation

The study contributes to a growing area of research that broadens understanding of food insecurity and adolescent sleep disorders. Overall, the prevalence of moderate (45.2%) and severe (5.8%) food insecurity were found. Thus, our study's food insecurity prevalence was within the range of previously documented estimates in multi-country studies (4, 35). The threats of global environmental change in food production systems, sky-rocketing food prices, and natural (and human-induced) disasters could be impacting food insecurity (hunger) prevalence (36). Also, about 52.6% moderate and 8.6% severe sleep disturbances were found, consistent with the rates reported in one multi-country analysis (11). The high prevalence of sleep disturbance among adolescents is troubling because studies have associated poor sleep quality with anxiety disorders, behavioral challenges and psychiatric ailments (37, 38).

Consistent with our first hypothesis, adolescents with moderate and severe food insecurity levels were at higher risks of severe sleep disturbance than those who were food secure. Our findings resonate with prior literature. In a longitudinal study assessing food insecurity among economically challenged households, adolescents in low and moderate-food-insecure households/groups had more sleep disturbances than their counterparts in food-secured households (9). Conterminously, among 223,561 adolescents sampled for a multi-country study on the association between food insecurity and sleep disorders, it was reported that severe food insecurity was significantly associated with a higher risk of sleep disturbance in 48 of the 68 countries studied (11). Transcending the adolescent groups, other studies have reported similar findings among older adults (2) and the general population (10, 13).

Even though the exact mechanisms linking food insecurity (hunger) and sleep disturbances are unclear, some biological and socioeconomic mechanisms may offer plausible explanations. First, considering biological mechanisms, an individual's metabolic activity

TABLE 3 Country-specific prevalence of food insecurity and sleep disturbance among adolescents in 35 countries by sex.

Country		Food Insecurity						Sleep disturbance					
	Frequency	No food insecurity		Moderate food insecurity		Severe food insecurity		No sleep disturbance		Moderate sleep disturbance		Severe Sleep disturbance	
	N (%)	Males % (95% CI)	Female % (95% CI)	Males % (95%CI)	Female % (95% CI)	Males % (95%CI)	Female % (95% CI)	Males % (95% CI)	Female % (95% CI)	Males % (95% CI)	Female % (95% CI)	Males % (95% CI)	Female % (95% CI)
Anguilla	812 (0.44%)	58.1(53–63)	55.9(50–61)	35.3(30–40)	39.9(34–45)	6.6(5–9)	4.2(3–7)	49.3(43–55)	28.9(25–34)	43.6 (38–49)	58.6(54–64)	7.1(5–10)	12.4 (9–16)
Argentina	56,873 (31.11%)	68.4 (66–69)	68.5(67–70)	29.3(28–31)	29.7(28–31)	2.3(1–2)	1.7 (1–2)	38.1 (37–23)	21.6 (20–23)	53.8(52–55)	60.4(59–62)	8.1 (7–8)	18.0 (17–19)
Bahrain	7,137 (3.90%)	43.5 (40–47)	43.4(39–48)	45.6(42–48)	45.2 (41–49)	10.9(9–13)	11.4 (10–13)	41.6 (38–44)	21.8(19–25)	47.26 (44–51)	56.5(54–58)	11.2(10–13)	21.7(18–25)
Benin	2,535 (1.39%)	39.0(33–46)	50.9(44–58)	41.4(37–46)	34.0(30–39)	19.6(15–25)	15.0(11–20)	26.7(24–30)	28.9(24–34)	52.0(48–55)	51.3(45–57)	21.2(18–25)	19.8(16–24)
Cooks Island	689 (0.38%)	31.6(26–38)	28.7(23–35)	59.5(54–65)	60.3(52–68)	8.8(6–13)	11.0(7–17)	44.4(38–50)	24.4(20–29)	46.5(41–52)	55.9(51–61)	9.2(6–13)	19.6(16–24)
Curacao	2,755 (1.51%)	74.9(72–77)	75.0(73–77)	21.1(19–24)	21.8(20–24)	3.9(3–6)	3.2(2–4)	53.0(49–56)	30.2(27–34)	39.5(36–43)	55.1(51–59)	7.5(6–9)	14.7(13–17)
Dominican Republic	1,464 (0.80%)	62.0(54–69)	66.6(59–73)	35.4(28–44)	30.7(25–38)	2.5(1–5)	2.6(2–5)	42.8(37–48)	29(23–35)	50.2(45–55)	58.0(53–62)	7.0(4–10)	13.4(10–18)
Fiji	3,673 (2.01%)	41.0(36–46)	39.2(34–45)	48.5(45–52)	48.9(45–52)	10.5(8–13)	11.9(10–14)	45.6(41–51)	38.8(34–44)	42.0(39–45)	47.1(43–51)	12.5(9–16)	14.1(13–16)
French Polynesia	3,210 (1.76%)	37.5(34–41)	32.9(30–36)	52.1(49–55)	55.4(53–58)	10.4(8–13)	11.6(10–14)	45.5(43–48)	32.2(29–35)	46.0(42–50)	52.5(50–55)	8.5(7–10)	15.3(14–17)
Guatemala	4,319 (2.36%)	60.0(55–64)	65.4(58–72)	37.7(33–43)	31.0(25–37)	2.6(1–6)	3.6(2–6)	47.8(43–53)	34.6(30–40)	47.3(42–53)	56.4(52–61)	5.0(3–7)	8.9(7–12)
Indonesia	11,124 (6.09%)	42.6(40–45)	46.7(43–50)	52.7(50–55)	49.6(46–53)	4.6(4–6)	3.7(3–4)	51.0(48–54)	42.8(39–46)	44.0(41–47)	53.0(50–56)	5.0(4–6)	4.2(4–5)
Jamaica	1,659 (0.91%)	53.3(46–60)	47.8(44–52)	38.8(33–45)	46.2(43–50)	7.9(6–9)	6.0(4–8)	49.9(44–56)	35.1(30–41)	41.2(36–47)	48.2(44–52)	8.8(7–11)	16.7(14–20)
Kuwait	3,605 (1.92%)	52.5(49–55)	49.8(45–54)	41.2(39–43)	40.9(37–45)	6.3(5–9)	9.3 (8–11)	34.0(31–37)	20.5(18–23)	50.4(47–54)	53.0(49–57)	15.6(12–19)	26.5(23–31)
Lao Republic	3,633 (1.99%)	48.1(41–55)	53.3(47–59)	51(44–57)	45.5(40–52)	1.1(0.4–3)	1.2(0.5–3)	37.9(35–41)	27.9(25–31)	57.9(55–61)	66.1(63–69)	4.1(3.0–5.6)	6.0(5–7)
Lebanon	5,692 (3.11%)	69.1(66–72)	69.2(67–72)	27.4(24–31)	27.6(25–30)	3.5(3–5)	3.2(3–4)	41.6(39–44)	26.2(23–29)	48.7(46–52)	56.6(54–59)	9.6(8–12)	17.2(15–20)
Liberia	2,661 (1.46%)	31.0(27–35)	33.0(27–40)	50.4(46–55)	52.3(47–58)	18.5(15–22)	14.7(12–19)	28.6(25–33)	22.1(19–25)	53.5(50–57)	56.3(52–60)	17.9(15–21)	21.5(19–24)
Mauritius	3,009 (1.65%)	56.4(52–61)	57.0(51–63)	38.4(35–42)	33.5(29–38)	5.2(4–6)	10.0(6–15)	47.9(44–52)	31.2(26–36)	44.7(40–49)	58.0(54–62)	7.5(6–9)	10.8(9–13)
Morocco	6,633 (3.63%)	62.9(60–66)	69.5(67–72)	27.5(24–31)	22.1(20–24)	9.6(8–12)	8.4(7–10)	45.4(42–48)	32.8(29–37)	40.7(37–45)	47.0(44–50)	13.8(12–16)	20.2(18–22)
Mozambique	1,889 (1.03%)	47.9(39–57)	55.5(46–64)	40.2(33–48)	34.1(26–43)	11.9(9–15)	10.5(7–14)	41.0(37–45)	34.5(27–43)	50.3(46–5)	53.3(45–61)	8.7(6–13)	12.2(8–17)
Myanmar	2,828 (1.55%)	66.1(63–69)	71.2(68–74)	31.0(29–34)	26.9(24–30)	2.9(2–5)	2.0(1–3)	54.9(52–58)	52.8(49–56)	41.8(39–45)	43.4(40–46)	3.4(3–4)	3.8(3–5)
Nepal	6,481 (3.55%)	67.3(62–72)	66.5(61–71)	27.9(24–32)	29.1(25–34)	4.8(3–8)	4.3(2–9)	50.9(48–54)	50.1(47–54)	44.4(42–47)	45.8(43–49)	4.7(4–6)	4.1(3–6)
Oman	3,456 (1.89%)	60.8(57–65)	63.1(59–67)	33.3(30–37)	33.2(30–37)	5.9(5–8)	3.7(3–5)	36.9(34–53)	20.0(17–23)	49.9(47–53)	56.9(53–61)	13.2(12–15)	23.2(21–26)

(Continued)

10.3389/fpubh.2023.1212254

TABLE 3 (Continued)

Country		Food Insecurity						Sleep disturbance					
	Frequency	No food insecurity		Moderate food insecurity		Severe food insecurity		No sleep disturbance		Moderate sleep disturbance		Severe Sleep disturbance	
	N (%)	Males % (95% CI)	Female % (95% CI)	Males % (95%CI)	Female % (95% CI)	Males % (95%CI)	Female % (95% CI)	Males % (95% CI)	Female % (95% CI)	Males % (95% CI)	Female % (95% CI)	Males % (95% CI)	Female % (95% CI)
Paraguay	3,101 (1.70%)	69.3(67–71)	72.0(68–76)	27.9(26–30)	26.1(22–30)	2.8(2–4)	1.9(1–3)	40.6(36–45)	28.4(24–33)	52.6(49–56)	59.7(56–63)	6.8(5–8)	11.9(10–14)
Philippines	8,756 (4.79%)	28.3(26–31)	31.5(29–34)	63.5(62–65)	61.6(59–64)	8.2(7–10)	6.8(6–8)	26.7(24–29)	20.4(19–22)	63.9(62–66)	67.1(65–69)	9.4(8–11)	12.6(11–14)
Samoa	1,924 (1.05%)	24.3(20–29)	27.7(23–32)	63.1(58–68)	60.0(56–64)	12.6(9–17)	12.3(9–16)	46.0(40–52)	42.3(39–46)	44.5(39–50)	48.7(46–51)	9.5(7–12)	8.9(7–11)
Seychelles	2,538 (1.39%)	57.1(53–61)	55.2(51–59)	29.0(26–32)	33.7(31–37)	13.8(11–17)	11.1(9–14)	47.7(44–51)	30.9(28–34)	43.3(40–47)	55.8(53–58)	9.0(7–11)	13.3(11–15)
Sri Lanka	3,261 (1.78%)	68.3(63–73)	74.8(71–79)	28.6(24–33)	22.2(19–26)	3.2(2–4)	2.9(2–4)	52.2(48–56)	58.0(53–62)	43.4(40–47)	36.9(33–41)	4.4(3–7)	5.1(4–6)
Suriname	2,119 (1.16%)	59.2(53–65)	52.1(47–58)	30.4(25–36)	34.8(31–39)	10.5(8–13)	13.1(11–15)	55.1(51–59)	38.5(34–43)	36.1(33–39)	45.6(42–49)	8.8(7–11)	15.9(13–19)
Thailand	5,877 (3.21%)	43.6(40–47)	48.0(44–52)	51.9(49–55)	48.7(45–52)	4.6(3–6)	3.3(3–4)	37.6(34–42)	30.1(26–34)	53.3(49–57)	61.2(58–64)	9.1(7–11)	8.7(7–11)
Timor-Leste	3,630 (1.99%)	48.1(45–51)	49.3(46–52)	39.8(37–43)	39.9(37–43)	12.1(10–14)	10.8(9–13)	43.8(39–49)	47.8(4353)	43.0(39–48)	41.0(37–45)	13.2(11–16)	11.1(9–14)
Trinidad and Tobago	3,858 (2.11%)	46.9(42–52)	51.4(47–55)	43.6(3948)	41.9(38–46)	9.6(8–12)	6.7(6–8)	49.2(46–52)	35.4(32–39)	40.1(38–43)	47.9(45–51)	10.8(9–13)	16.6(14–19)
Tonga	3,328 (1.82%)	28.6(26–32)	39.4(36–43)	59.2(56–62)	50.7(48–54)	12.2(10–14)	9.9(8–12)	28.6(26–32)	39.4(36–43)	59.2(56–62)	50.7(48–54)	12.2(10–14)	9.9(8–12)
UAE	5,826 (3.19%)	54.3(50–59)	51.8(48–56)	37.8(35–41)	38.2(35–41)	7.9(6–10)	9.9(8–12)	40.2(36–44)	24.9(22–28)	47.9(44–52)	54.5(52–57)	11.9(10–14)	20.5(18–23)
Vanuatu	2,136 (1.17%)	34.3(30–39)	42.4(38–47)	56.2(52–61)	50.9(47–55)	9.5(7–12)	6.6(5–8)	45.1(41–49)	43.9(39–49)	48.7(45–53)	48.5(45–52)	6.1(5–8)	7.5(6–10)
Wallis and Futuna	1,110 (0.61%)	36.5(32–41)	35.8(31–41)	50.0(46–54)	48.3(44–52)	13.4(10–17)	15.9(13–20)	43.4(39–48)	34.9(30–40)	43.1(38–48)	47.3(42–53)	13.4(11–17)	17.8(15–21)

10.3389/fpubh.2023.1212254

TABLE 4 Multinomial regression models estimating the effect of food insecurity on sleep disturbance among adolescents in 35 countries.

	Model 1		Model 2		Model 3	
Variable	OR (95% C.I)	*p*-value	OR (95% C.I)	*p*-value	OR (95% C.I)	*p*-value
No sleep disturbance (Base outcome)						
Moderate sleep disturbance						
Food security	**1**		**1**		**1**	
Moderate food insecurity	2.09 (1.98–2.20)	**<0.001**	2.11(2.00–2.23)	**<0.001**	1.70 (1.59–1.81)	**<0.001**
Severe food insecurity	1.90 (1.71–2.12)	**<0.001**	1.91 (1.72–2.13)	**<0.001**	1.63 (1.42–1.87)	**<0.001**
Severe sleep disturbance						
Food security	**1**		**1**		**1**	
Moderate food insecurity	2.28 (2.10–2.48)	**<0.001**	2.31 (2.12–2.51)	**<0.001**	1.88 (1.68–2.11)	**<0.001**
Severe food insecurity	5.38 (4.74–6.11)	**<0.001**	5.23 (4.62–5.92)	**<0.001**	4.07 (3.40–4.87)	**<0.001**

p-value = ****0.0001, C.I = confidence interval, RR = relative risk. Model 1: Unadjusted model. Model 2: Adjusted for sociodemographic characteristics (age, sex). Model 3: Adjusted for sociodemographic characteristics and other relevant variable (age, sex, loneliness, suicidal ideation, cigarette smoking, alcohol use, close friends, parental understanding, physical activity). Bold values are significant values.

may disturb his/her state of vigilance due to lower nutrition, leading to insomnia (39). In addition, chronic stress or psychological distress because of one's financial ability to access safe and nutritious foods may influence stress related to physiological arousal mechanisms, leading to the instigation of the sympathoadrenal medullary and hypothalamic–pituitary–adrenal-cortical systems that are noted to cause sleep disturbances (10). Besides, adolescents with food insecurity tend to encounter nutritional deficiencies and obesity, which can affect their sleep (40). Similarly, several studies suggest that food insecurity is associated with adverse physical and mental health outcomes that affect sleep (41, 42).

For socioeconomic mechanisms, poverty is a significant risk factor for poor sleep quality (4, 43). While poverty typically does not occur in isolation, with a tight household budget, the family may be unable to pay for food, housing, clothing, health care, and other living expenses simultaneously (43). Consequently, food insecurity is always associated with housing insecurity, and poor housing conditions may link to sleep disturbance due to concerns about personal safety, exposure to more noise from neighbours, and environmental situations within the house (44). This study has a policy implication because addressing food insecurity may be crucial to improve sleep quality and other phycological problems. However, further longitudinal and clinical research is necessary to confirm these hypotheses and explore more complex mechanisms that may underlie adolescent food insecurity and quality sleep.

In line with the differential vulnerability concept, the analysis found significant age-wise differences in the relationship between food insecurity and sleep disturbance. The effect of food insecurity on sleep disturbance was found in adolescents aged 15–17 years and 18 years or older than those between 12 and 14 years. A possible explanation may be due to the socioeconomic conditions of the households, such as poverty and other socioeconomic deprivations, which might cause older adolescents to sacrifice their food intake for younger ones in times of limited household food access. The age differences may be addressed further by decreased brain capacity and functionality as we age, as measured by hippocampal sizes. In the setting of food insecurity, this may raise the likelihood of sleep problems.

Further mixed-method studies would be required to clarify and provide reasons for this result, as this is the first study coming forth with this finding. We found statistically significant sex-wise differences in the relationship between food insecurity and sleep disturbance. This finding agrees with previous propositions that females are less likely than males to achieve their dietary requirements due to general socioeconomic deprivations among females, especially in developing countries (24). Another study on the hidden penalties of gender inequality also found that females likelihood of achieving all the dietary requirements is lower than their male counterparts (45). Our finding, therefore, suggests that boys and girls in the study are disproportionally affected by food insecurity compared to food security. The finding further supports the male–female health survival paradox suggesting that women generally present higher lifetime health problems (46), such as poor sleep and their associated social determinants of health, including food insecurity, than men. Thus, future studies would benefit from further examination of sex differences in the association between food insecurity and sleep disturbances.

Policy implications

Our study findings suggest that policymakers, guardians, and stakeholders should know that food insecurity (hunger) could be an underlying factor for adolescents' sleep disturbances. Our results can help facilitate more empirical research to explore sleep disorders within the context of poverty and social inequality, with hunger being a relevant daily stressor that can impact poor sleep outcomes. Evidence exists on interventions addressing the negative impacts of food insecurity in children and adolescents (47). However, such interventions are mostly not multi-faceted to address this area of need (3). For instance, the World Food Programme (WFP) was implemented to support school meal programs in 71 countries in 2017 (48). However, one study reports that the benefits of school-based programs do not address food insecurity holistically as adolescents also require to be fed outside the school environment [for instance, dinner, weekends, holidays, and breaks (3)]. Again, these

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TABLE 5 Age- and sex-wise associations of food insecurity status with sleep disturbance among adolescents in 35 countries.

Variable	Model 1		Model 2	
	OR (95% C.I)	*p*-value	OR (95% C.I)	*p*-value
No Sleep disturbance (Base outcome)				
Moderate sleep disturbance				
Age				
11–14	**1**			
15–17	1.75 (1.63–1.88)	**<0.001**		
18+	2.39 (2.01–2.82)	**<0.001**		
Food Insecurity				
Food Security	**1**		**1**	
Moderate food insecurity	2.08 (**1**.93–2.24)	**<0.001**	2.12 (2.01–2.24)	**<0.0001**
Severe food insecurity	2.07 (1.78–2.41)	**<0.001**	1.97 (1.77–2.20)	**<0.0001**
Age * food security				
11–14 * food security	**1**			
15–17 * moderate food insecurity	3.64 (**3**.39–3.93)	**<0.001**		
15–17 and severe food insecurity	2.89 (**2**.50–3.34)	**<0.001**		
18+ * moderate food insecurity	4.23 (**3**.55–5.04)	**<0.001**		
18+ and severe food insecurity	3.24 (**2**.40–4.38)	**<0.001**		
Sex				
Males			**1**	
Females			1.41 (1.33–1.49)	**<0.001**
Sex * food insecurity				
Females * no food insecurity			**1**	
Females * moderate food insecurity			2.99 (2.75–3.25)	**<0.001**
Females * severe food insecurity			2.77 (2.30–3.33)	**<0.001**
Severe sleep disturbance				
Age				
11–14	**1**			
15–17	0.77 (0.66–0.89)	**<0.001**		
18+	1.48 (**1**.28–1.68)	**<0.001**		
Food Insecurity				
Food security	**1**		**1**	
Moderate food insecurity	0.81 (0.73–0.89)	**<0.001**	2.33 (2.15–2.53)	**<0.001**
Severe food insecurity	1.61 (1.48–1.73)	**<0.001**	5.63 (4.96–6.41)	**<0.001**
Age * food security				
12–14 * food security	**1**			
15-17*moderate food insecurity	1.15 (0.97–1.33)	**0.0001**		
15-17*severe food insecurity	1.75 (1.45–2.06)	**0.0001**		
18+ * moderate food insecurity	1.60 (0.81–1.24)	**0.0001**		
Sex				
Males			**1**	
Females			1.58 (**1**.46–1.71)	**<0.001**
Sex* food security				
Females* food security			**1**	

(Continued)

TABLE 5 (Continued)

Variable	Model 1		Model 2	
	OR (95% C.I)	*p*-value	OR (95% C.I)	*p*-value
Females*moderate food insecurity			3.74 (3.31–4.23)	**0.0001**
Females*severe food insecurity			8.58 (6.95–10.57)	**0.0001**

p-value was considered significant when less than 0.05, CI = confidence interval, OR = odds ratio. Model 1: Moderation effect of age on food insecurity and sleep difficulty. All Models adjusted for sociodemographic characteristics and other relevant variables such as age, sex, bullying, loneliness, suicidal ideation, cigarette smoking, alcohol use, marijuana use, close friends, amphetamine use, parental understanding, and physical activity.

programs would not benefit those who are not in school. Thus, a long-term solution would be alleviating poverty and acquiring agricultural inputs so that households can potentially meet their dietary needs to address sleep problems. Again, one solution may be free or subsidized nutrition programs that promote access to adequate food for adolescents in food-insecure households. Future interventions and programs to address food insecurity and sleep disturbances should consider demographic factors such as age and sex.

Strengths and limitations

There are particular strengths and limitations to the present study. Drawing evidence from 35 countries and territories, this study contributes to the limited knowledge base by assessing the association of food insecurity (hunger) with sleep disturbance among school-going adolescents. Our sample used nationally representative datasets with large sample sizes and across several countries and territories, increasing the study findings' generalizability. The GSHS followed best standard practices regarding technique and employed professional and well-trained interviewers. Notwithstanding these advantages, our findings should be evaluated and viewed in light of the following limitations. Although we controlled for most known potential confounders, residual confounding may exist and affect or explain the results.

Furthermore, reliance on self-reports implies that recollection and social desirability biases cannot be ruled out. In addition, food insecurity is limited to indicating only food insecurity experiences in the last 30 days, while worry-induced sleep disturbance in the previous 12 months indicates a potential timeframe imbalance between the measures. Again, the use of a single-item measure approach is an important limitation in this study because it does not capture all the different dimensions of food insecurity. Future studies are needed to further validate single-item food insecurity measures among adolescents across regions of the world.

Previous studies have established that of those who are currently food insecure, most were food insecure in the past year (4, 11, 32). In addition, notable studies using the same GSHS studies used the past 30 days and 12 months timeframe for the assessment of key variables (4, 49–53). Moreover, given that this was a cross-sectional observational study, causal relationships and implications from the association between food insecurity and sleep disturbance cannot be inferred. Thus, future research should investigate the associations of interest utilizing longitudinal cohort designs that allow for examining reasonable causal inferences.

Conclusion

This cross-sectional study among adolescent populations from 35 countries and territories showed a significant association between food insecurity and sleep disturbance. Furthermore, age disparities in this association were evident such that females and those aged between 15 and 17 years and 18 years or older experienced higher risks of sleep disturbances than those between 12 and 14 years. Our findings indicate the potential importance of addressing food insecurity (hunger) and social inequality to improve global sleep quality/outcomes among adolescents across countries and world regions. Reverse causation cannot be excluded, and the results must be interpreted cautiously.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

EO, PP, and CA conceived the study. EO, BA, and PP acquired and analyzed the data. EO design the work and the creation of tables. RO, SN, and MA performed the design and drafted the work. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers | Frontiers in Public Health

TYPE Policy and Practice Reviews
PUBLISHED 22 August 2023
DOI 10.3389/fpubh.2023.1256390

OPEN ACCESS

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RECEIVED 10 July 2023
ACCEPTED 08 August 2023
PUBLISHED 22 August 2023

CITATION
Tomori C (2023) Global lessons for strengthening breastfeeding as a key pillar of food security.
Front. Public Health 11:1256390.
doi: 10.3389/fpubh.2023.1256390

Global lessons for strengthening breastfeeding as a key pillar of food security

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Breastfeeding is identified as a central pillar of food security by the World Health Organization, however globally significant challenges remain in achieving breastfeeding targets for early initiation, exclusive breastfeeding for 6 months, and continued breastfeeding for 2 years and beyond. Inadequate support in health systems, poor maternity protections and workplace policies, and insufficient regulation of commercial milk formulas, among other barriers, continue to undermine this key pillar across nations. This paper highlights the central importance of breastfeeding for food security across diverse global settings by examining three case studies: Honduras, Pakistan and the USA. The cases highlight the complex layering and intersections of key challenges that threaten breastfeeding in the era of pandemics, the climate crisis, conflict and global inequality. Lessons drawn from these case studies, combined with additional insights, reinforce the importance of multisectorial collaboration to scale up investment in creating equitable, enabling environments for breastfeeding. These structural and systems approaches can successfully strengthen the breastfeeding ecosystem to ensure greater first food system resilience in the face of global crises, which compound maternal and infant vulnerabilities. Additionally, the cases add urgency for greater attention to prioritizing breastfeeding and incorporating IYCF-E protocols into disaster preparedness and management into the policy agenda, as well as ensuring that first food security is considered in energy policy. An integrated approach to policy change is necessary to recognize and strengthen breastfeeding as a pivotal part of ensuring food security across the globe.

KEYWORDS

breastfeeding, food security, climate change, infant and young child feeding in emergencies (IYCF-E), COVID-19 pandemic, disasters, commercial milk formula marketing, health policy

Introduction

Breastfeeding is a cornerstone of infant and young child food security and healthy development (1). Globally, over 800,000 deaths of children under 5 years of age could be prevented by following optimal breastfeeding practices of early initiation (within the first hour), exclusive breastfeeding for 6 months, and continuing to breastfeed with appropriate complementary foods for 2 years (2, 3). Breastfeeding is the optimal first food – it is readily available in response to the infants' needs, it provides both necessary nutrition and hydration, protection from infectious and noncommunicable diseases, and provides a sophisticated communication system between mother and child (2). It comprises a complex "biopsychosocial

system" that provides the basis for infant and young child development (2). While these facts are appreciated in global health, action to implement policies that enable breastfeeding have not kept apace (2). This negatively impacts the food security of millions of children worldwide with far reaching impacts for their own survival, health and development, as well as for future generations (1, 2, 4).

Globally less than half of newborns are put to breast within the first hour, and a similar proportion are breastfed exclusively under 6 months (2). The 2023 Lancet Breastfeeding Series explored both the global epidemiology of breastfeeding and what solutions are necessary to create an enabling environment so that all who wish to breastfeed can do so. The Series highlighted the importance of multisectorial collaboration and systems-based approaches to bring together the necessary components of this environment, from the health system to the workplace to marketing regulations (2, 5). The present paper builds on this framework to explore the layering of influences that can challenge breastfeeding as the foundation of first food security through three case studies from Honduras, Pakistan, and the USA.

The three cases were selected based on geographic, cultural and socioeconomic diversity, and because of available literature that demonstrates the intersecting influences on breastfeeding through the lens of food security. The cases highlight threats to breastfeeding as the basis of first food security in an era of rapid change, marked by the increasing impacts of the climate crisis, pandemics, global inequality and conflict. All three cases highlight the impacts of the COVID-19 pandemic, which disrupted maternity care services (6, 7) and increased food insecurity globally (8). Pandemics highlight the intersecting impacts of shocks to an interdependent global economic and food systems brought about by attempting to reduce viral transmission, as well as the impacts of climate change, since climate change fuels increasing risk of future pandemics (9). The cases also provide additional insights into how the increasing impacts of climate change intersect with the landscape of complex systems that shape the first food environment that are already marked by profound inequality. The experiences drawn from each case highlight how existing inequities across and within nations make first food systems vulnerable, and how these vulnerabilities accumulate in the context of multiple emergencies, disasters and conflict. As we plan for resilient first food systems in the 21 century and beyond, we must direct special attention to these intersections so that we can prevent and mitigate the compounding harms that arise when multiple vulnerabilities collide.

Honduras

Honduras was the site of several key trials for programs that successfully increased breastfeeding, reduced the routine use of commercial milk formula (CMF) at hospitals, and reduced malnutrition during the 1980s through 2012 (10). Significant progress was made in the implementation of breastfeeding training and breastfeeding-friendly policies, leading to increased breastfeeding indicators in the country (10). Demographic Health Survey (DHS) data from 2011 shows that breastfeeding initiation was high at 96%, although timely initiation (within first hour) was much lower at 64, and 44% received prelacteal feeds (11). Prelacteal feeds are strongly associated with early supplementation, self-reported insufficient milk as well as premature breastfeeding cessation (12). Breastfeeding at 6 months was 85.8% and 75.7% at a year (11). However, exclusive breastfeeding (EBF) under 6 months was only 31.2% (11).

Recent research highlights the multiple, intersecting layers of influence that influence infant and young child food security in the context of COVID-19, climate change, and local and global political circumstances (13). Honduras has faced significant challenges prior to the pandemic, including high prevalence of poverty, food insecurity and malnutrition, with one fifth of children experiencing stunting in 2020 (8). These patterns vary substantially across regions, and disproportionately affect Indigenous populations. Existing challenges were amplified during the COVID-19 pandemic (13). High rates of unemployment (40%) and the majority of employment in the informal sector (80%) were coupled with reliance of remittances from migrant labor. Strains on labor meant reductions in income, and ability to purchase food. Supply chain disruptions also meant lower availability of food. Access to existing nutrition programs was also limited by measures to slow the transmission of the virus, such as closure of schools where food was distributed and restrictions on transportation, which made food accessible. This meant additional strain on families trying to meet their basic nutritional needs. Such challenges always place pressure on breastfeeding because women often have to prioritize seeking work to generate income and provide adequate food for their families and face limited ability to continue breastfeeding in many of these work settings, particularly in the informal sector, where most people are employed in Honduras (10, 14–16). Even when women can take advantage of maternity leave in the formal sector, leave costs are only partially born by the employer. This may contribute to the relationship of employment being associated with lower EBF (16). The COVID-19 pandemic has also disrupted maternity services globally, with contradictory guidance issued by Honduras that discouraged skin to skin contact but also endorsed WHO Early Newborn Care Practices, which include skin to skin contact (17). The impact of disruptions on breastfeeding has not yet been examined.

Another major source of pressure exacerbating stress and food insecurity on Honduran families is international and domestic conflict (13). Fertilizer prices rose during Russia's invasion of Ukraine beginning 2022, further limiting the availability of food production, and highlighting the vulnerabilities of interconnected global supply chains. Moreover, internal conflict has undermined safety and security in Honduras, putting additional pressure on breastfeeding families seeking to secure wages and food for themselves their families, and on accessing breastfeeding support. Existing research highlights the high risk of maternal and child malnutrition in conflict settings as well as the stress of conflict, which – in the absence of adequate support – may lead to perceptions of insufficient milk and early breastfeeding cessation (18).

Climate change poses acute risks to first food security. Honduras is vulnerable to extreme weather events, which are accelerating in scale and frequency driven by the climate crisis (13). The country has been subject to floods, landslides, and drought. Critically, during the acute phase of the COVID pandemic in the fall of 2020, two Category 4 hurricanes hit Honduras, affecting nearly half the population and causing massive destruction. The hurricanes caused mass evacuations, and agricultural destruction which undermined the food supply, leading to insufficient supply and major price increases that made what was available inaccessible to many. The damage to roads and infrastructure made accessing food further problematic and also led to water contamination.

It was in this context that unsolicited CMF donations from wealthy settings started pouring into the country (13). Such donations violate the International Code of Marketing of Breast-Milk Substitutes and have been consistently linked to undermining breastfeeding and increasing diarrheal illness and malnutrition (19). Operational guidance on infant and young child feeding in emergencies (IYCF-E) (20) provides detailed discussion on how to ensure continued breastfeeding support. The guidance also provides resources on relactation, wet nursing, or donor human milk when infants are not breastfed, and appropriate purchase, distribution, and safe preparation of CMF when breastfeeding is not possible or available (20). Assistance can be appropriately channeled to support IYCF-E efforts with appropriate financial and technical assistance resources instead of harmful mass distribution of CMF. Efforts were made to stem these unsolicited donations by UNICEF and Pan-American Health Organization (PAHO) (13), but the above example demonstrates the particularly harmful influence of the CMF industry in the context of disaster circumstances. The example also draws attention to the importance of wealthy nations' infant feeding norms and their misperception of necessities for safe infant feeding in emergencies in poorer settings, especially in this time of climate crisis.

Pakistan

Pakistan provides another case study for the layered influences that shape the first food environment. Prior to the pandemic, Pakistan also had a high prevalence of food insecurity driven by poverty and even more acute malnutrition compared with Honduras, with significant regional variation and much higher prevalence of food insecurity in some regions (21). There are significant intergenerational elements of malnutrition, with mothers being chronically malnourished, which leads to poor nutrition during pregnancy, smaller babies at birth who are already at greater risk for poor growth, and mothers who may have difficulty caring for their babies (21). Without sufficient support for maternal nutrition, breastfeeding and nutritious complementary foods, the cycle of malnutrition continues. Based on data from the National Nutrition Survey of 2018, malnutrition was the leading cause of death among children under 5 years of age (~50%), with over 40% of children stunted and nearly a fifth experiencing wasting (17.7%) (22).

Breastfeeding has a key protective role in infant and child health in Pakistan. In a nationally representative survey, breastfeeding was associated with a 98% lower risk of neonatal mortality, 96% lower risk of infant mortality, and 94% lower risk of mortality among children under 5 years of age (23). From the latest data (2017), breastfeeding at six months and at 1 year was 86% and 71.2%, respectively, both of which represent declines over a 9-year period. At the same time, gains were made in exclusive breastfeeding, from 37.1% in 2006 to 47.5% in 2017 (24).

Previous work shows that work conditions are a major barrier to breastfeeding. For example, one study from Karachi (25) showed that after a 3-month paid maternity leave only 15% of employers offered breastfeeding breaks and few offered any breastfeeding support, such as a breastfeeding corner, nursery, refrigerator, or pump. A 2020 qualitative study carried out prior to the COVID-19 pandemic in a different setting of the rural district Matiari of Sindh (22), highlighted numerous additional barriers to exclusive breastfeeding. These included different work demands, since women were needed to carry out field labor, as well as lack of awareness of the importance of EBF, prelacteal feeds, perceived insufficient breastmilk and concerns about maternal malnutrition. The influence of CMF marketing are apparent even in this small study, where a mother who perceived her breastmilk to be insufficient was advised by a doctor to feed her baby formula, without providing her any support for addressing potential breastfeeding challenges. Such advice is common globally due to lack of adequate lactation training for healthcare providers (HCPs) combined with CMF marketing to HCPs who are considered authorities on infant feeding (2, 5). This kind of advice has particularly detrimental consequences in the context of poverty and malnutrition.

As in other settings, the COVID-19 pandemic also profoundly affected food security in Pakistan, with food insecurity doubling during the first year of the pandemic (26). These impacts disproportionately affected already poorer households, and those relying on wage-earning labor compared to those who relied on agriculture, which may have buffered their ability to secure food for their households. Pakistani guidance was supportive of skin to skin contact and breastfeeding during COVID-19 (17), however widespread disruptions to maternity services were reported (27). Limited literature indicates that those who had shorter hospital stays were more likely to breastfeed, pointing to inadequate breastfeeding support at the hospital (28), but it is difficult to interpret these findings without pre-pandemic comparative data.

Unfortunately, Pakistan faces significant impacts from climate change, which has further eroded food security. In 2022 the country faced historic floods, which left over a third of the country under water (29). This presented an immediate threat to life, affected 33 million people, and caused enormous destruction of crops and livestock as well as infrastructure, including health facilities. 7.6 million people were displaced, and many continue to face hunger and malnutrition (30). Basic health services have been profoundly disrupted, with devastating consequences for pregnant people and children in particular (29) – including impacts on breastfeeding support. Repairing roads, bridges, and other critical infrastructure remains ongoing. As of spring 2023, 10 million people remained without safe drinking water (31).

Ethnographic research (32) focusing on internally displaced people due to prior flooding events in 2015 has identified a number of protective factors as well as barriers to breastfeeding in these challenging circumstances. While breastfeeding was a culturally valued practice that was often supported by family and community networks, there was little formal support for it and there was pressure to introduce tea, other milks and foods early on. Even in the context of internal displacement, CMF was sold and encouraged by some to address infant crying, which was interpreted as a sign of hunger. This interpretation of infant behavior is a common reason globally for introducing CMF (33), but in the context of high rates of malnutrition and unsafe water, the use of CMF often has devastating outcomes. Participants (32) identified the lack of health services that support breastfeeding as a key problem – an interviewee started feeding her baby CMF because she felt that her milk was insufficient. This is a common perception during disasters, but one can be resolved through skilled support (19). Scholarship is still emerging on the impacts of the most recent floods, but the lack of adequate breastfeeding support identified is magnified because of the much larger scale of the 2022 floods.

In hopeful developments, Pakistan has passed a new maternity leave law in July 2023 that guarantees the right to take 6 months paid leave after the first child, and 4 and 3 months for the subsequent two children and provides one month of paternity leave as well (34). Additionally, the Provincial Assembly of Sindh – which includes the capital of Karachi – passed the Sindh Protection and Promotion of Breastfeeding and Young Children Nutrition Act 2023, which protects breastfeeding from commercial influence in health settings and promotes breastfeeding (20). These steps provide much-needed policies for protecting first food security in Pakistan.

US

The US, a high-income country with high level of internal inequality, provides the third case for analysis. In recent decades, the US had achieved significant increases in breastfeeding indicators overall, with 83% initiating breastfeeding, 55.8% continuing to 6 months, and 35.9% at 1 year (35). However, exclusive breastfeeding rates as well as breastfeeding duration drop off sharply within a month, down to 24.9% by 6 months (35). This drop-off is driven primarily by the lack of paid leave, which sets the US apart from all other wealthy nations (15). Additionally, due to structural racism, significant racial and ethnic disparities persist in breastfeeding across the entire spectrum of indicators (36, 37). Existing inequities, the inadequate social safety net, and lack of paid leave also sets up a paradox whereby whose facing poverty and food insecurity may be less likely to breastfeed because they have to return to work quickly and face additional stressors (15, 38–40). Many work settings do not accommodate breastfeeding, especially among low wage and hourly workers or those who may face hostile work conditions, such as undocumented workers. Employment breastfeeding protections until recently only applied to select groups of workers – the PUMP Act, enacted in 2023, now grants many more workers protections and the right to breaks to express milk while at work although gaps still remain (e.g., in the airline industry) (41).

The US's inequities are reflected in the representation of women and children served by governmental nutrition programs: over half of infants in the US are supported by the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) (42). Moreover, racial and ethnic minorities are overrepresented in WIC because of the aforementioned structural inequities (37, 38). WIC has invested significantly in increasing breastfeeding support and has achieved much higher breastfeeding initiation rates, rising from 48.3% in 2002 to 78.5% in 2017 (43). These rates, however, are lower than eligible non-participants enrolled in Medicaid (43). Previous work has shown that lower food secure WIC participants stop breastfeeding sooner than desired, with Black women stopping sooner because of a need or desire for others to feed their babies, while Hispanic mothers who faced food insecurity stop sooner than desired because they worry about the adequacy of their milk (38). These persistent inequities reinforce the need for policy interventions that enable breastfeeding and provide additional culturally appropriate support for racial minority populations (43, 44).

The COVID-19 pandemic caused major disruptions throughout the country, including access to employment and consequently housing, food, and the first food environment (37). Multiple governmental policy measures were put in place to mitigate these impacts, including expanded access to Medicaid, unemployment and eviction protections, and food aid supplementation (45). Worker protections from COVID itself, however, were relatively limited, which meant that significantly more poor, racial minorities suffered COVID deaths than white people, particularly early in the pandemic (46). These impacts affected the most marginalized families who were considered essential workers, including pregnant people and their newborns. There were also major disruptions in maternity services, including a period in spring of 2020 when mother-infant separation was recommended in contradiction to WHO guidance (47). This guidance was later reversed during the summer of 2020 (47). Separation is well-known to undermine breastfeeding (7), and coupled with lack of breastfeeding support, it had predictable negative effects on breastfeeding (48). Additionally, pregnant and lactating women faced delays in guidance on vaccination, therefore facing a lengthy period of additional risks from the SARS-COV-2 virus (47), leading to more cases of acute illness, which once again undermined the health of the mother and infant, and threatened their ability to stay together.

The US faced an additional disaster during the COVID pandemic, caused by corporate disregard for CMF safety regulations. In 2022, after reports of multiple cases of infant illness and deaths due to contaminated formula, Abbott shut down production at its largest facility, which produced approximately a quarter of the nation's formula (37). For WIC participants, this meant a particularly acute crisis because WIC participants rely more on CMF and are restricted to a specific brand that their state has contracted with. Although these restrictions were eased, the supply remained low, and lactation support was not adequately scaled up. Many news stories depicted the plight of desperate parents seeking formula for their infants. Although some were able to seek lactation support or obtain milk from human milk banks or from informal human milk sharing networks, some turned to diluting formula or making it at home (49). Investigative journalists revealed that the shutdown was preceded by years of undermining regulations aiming to improve safety (37), and cases where formula contamination led to serious harm but were suppressed by aggressive legal strategies (50).

The impacts of the crisis were magnified for many across the nation who have faced chronic lack of access to safe water – situations that are magnified by the climate crisis. For instance, 48% of Native households living on reservations lack running water (51), and many cities, such as Flint, Michigan, have face lead contamination as instantiations of environmental racism and injustice (52). In 2022 Jackson, Mississippi, a city with predominately Black population, experienced an acute water crisis due to decades of racist neglect of water infrastructure coupled with flooding propelled by climate change (53, 54). The city continues to struggle. In these cases, both the formula supply and opportunities for safe preparation are threatened, but to date there is not sufficient investment in national or state efforts to scale-up breastfeeding support and IYCF-E that meet current and future needs. Although the formula crisis has abated, communities who face lower breastfeeding rates and lack adequate support remain vulnerable to the impacts of unsafe formula preparation and additional shocks due to future crises. This fundamentally undermines infant and young child food security.

Discussion

Each of these cases highlights the importance of breastfeeding as a foundation of food security and health, as well as the complex

intersections of multiple sectors and drivers of challenges that threaten breastfeeding in an era of pandemics and the climate crisis. As the recent 2023 Lancet Breastfeeding Series discussed, creating an enabling environment for breastfeeding requires collaboration and investment, bringing together policies and practices across health systems, workplaces both in the formal and informal sectors, and regulations that govern trade and marketing (2). Examining the importance of breastfeeding in food security highlights each of these domains as well as the broader context of social inequities which shape these systems (1).

The broader patterns of global social inequities across nations and inequities within nations, both linked to historical patterns of colonization and exploitation, structure the landscape in which breastfeeding exists (1, 4, 55, 56). It is these inequities that shape access to basic resources, such as housing, food, healthcare and work. For instance, underlying maternal malnutrition driven by poverty places newborns at increased risk of malnutrition and infection, and their mothers require additional support for their own health as well as in supporting breastfeeding. Food insecurity and work demands, coupled with a lack of supportive work environment often force women to leave their infants in others' care so that they can provide for their families, which leads to early introduction of complementary foods and premature breastfeeding cessation. These impacts can be seen even in wealthy settings such as the US, due to internal inequities driven by structural racism. Existing inequities also shape access to resources and quality care that can mitigate these impacts and provide the support necessary to initiate and sustain breastfeeding. A key element of addressing underlying inequities is valuing care work (57), and the process of breastfeeding itself. The Mothers' Milk Tool is an effort to provide a quantification of the economic value of breastfeeding and mothers' milk in order to highlight the often-overlooked value of breastfeeding in the broader economy (58).

Shocks like the COVID-19 pandemic have exacerbated challenges to meet these basic needs, and disrupted maternity care services, which often undermined timely initiation of breastfeeding and ongoing breastfeeding support (7, 59, 60). The impacts of the pandemic were unequally distributed – disproportionately impacting already poor nations and those who are most socially marginalized within wealthier settings (61, 62). Importantly, pandemics are likely to accelerate with rising global temperatures and increasing intermingling of humans and other species due to habitat destruction (9), so these compounding effects must be taken into account as we plan for the future. We have an opportunity to learn from the lessons of the COVID-19 pandemic and implement pandemic preparedness protocols that follow WHO guidance and prioritize keeping mothers and infants together and the provision of breastfeeding support (63).

Climate change is the largest threat to food security overall and first food security in particular. Researchers have shown that the scale and diversity of impacts on food security alone has likely been underestimated (64), and the impacts on human life are complex, multiple, and accelerating (65). These impacts put existing progress towards creating enabling environments for breastfeeding at risk and threaten to undermine future efforts to scale up these efforts. Climate change exposes underlying weaknesses in systems and places infants who are already vulnerable at even greater risk, especially if they are mixed feeding or formula dependent. The formula supply itself can be quickly undermined, and safe preparation of formula often becomes impossible, leading to infection, dehydration and malnutrition. The impacts of climate change are profoundly unequal. While the extraction of fossil fuels is driven primarily by the consumption in high income countries in the Global North, the consequences are disproportionately borne by poor countries in the Global South. The Pakistan floods of 2022 illustrated these climate injustices on a very large scale (66), and Honduras and the US provide additional warning signals for policymakers. Ensuring that breastfeeding is prioritized during non-emergency times creates a greater climate resilience so that limited emergency resources can be directed appropriately for IYCF-E. Additionally, the implementation of IYCF-E policies must be enhanced. Driven partly by marketing efforts that have normalized CMF feeding as the baseline cultural practice, and the lack of appreciation for the importance of breastfeeding and safe infant feeding practices in emergencies, wealthier settings often lack knowledge about IYCF-E protocols (67). In the US, for instance, the Infant and Young Child Feeding in Emergencies Toolkit only became available last year (68), and much work remains to scale up IYCF-E support. In Honduras, the Global Nutrition Cluster and UNICEF Honduras have been collaborating to develop groundwork for an IYCF-E action plan which will form the basis of a national strategy (69), and Pakistan is continuing efforts to strengthen and implement its own IYCF-E strategy (70).

Unethical marketing and corporate misconduct are another throughline that tie the cases together. Unethical marketing undermines breastfeeding and makes it much more likely that infants become formula dependent (5). For instance, in the US years of undermining and subverting safety regulations to increase short-term profits led to the need to shut down production, which compromised supply, and compounded the impacts of unethical marketing (37). Unethical CMF marketing also contributes to climate change, driven by the greenhouse gas (GHG) emissions generated primarily from cow's milk production (71). The estimated excess GHG generated by 6 months of CMF feeding for each child is 228–288 kg of carbon dioxide (71). Together, these impacts lead to negative health consequences across settings, that are more accentuated among poor nations and among those who are most marginalized within settings. While the rise of climate-driven disasters continues to disproportionately impact poorer countries, even those in wealthier settings become vulnerable to these impacts, once again with poorer and more marginalized groups bearing the majority of burdens. Donations of CMF in the context of emergencies further multiply these impacts. Indeed, corporate behavior of CMF companies parallels that of fossil fuel companies, which are at the root of the climate crisis, and have systematically engaged in merchants of doubt tactics to downplay and cast doubt on evidence to delay policy action (5, 72).

Conclusion

In the face of extreme global challenges, including pandemics, the climate crisis, and global inequity and conflict, it is especially important to put breastfeeding at the center of policy action (73). Lessons drawn from the case studies in this paper reinforce the need to address underlying social inequities and multisectorial collaboration across health, work, and trade/marketing policies (2), with special

attention to integrating breastfeeding and IYCF-E into disaster preparedness and emergency management (74). Additional efforts should be taken to integrate first food security considerations into energy policy, particularly in nations most responsible for fossil fuel consumption, and those that contribute to excess GHG via failure to regulate predatory CMF marketing (71). Concerted effort and political will are needed to ensure that breastfeeding is recognized and appropriately supported as a key pillar of food security.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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frontiers | Frontiers in Public Health

TYPE Brief Research Report
PUBLISHED 25 September 2023
DOI 10.3389/fpubh.2023.1251768

OPEN ACCESS

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RECEIVED 02 July 2023
ACCEPTED 01 September 2023
PUBLISHED 25 September 2023

CITATION
Sridhar S, Kang JS, Madzorera I, Zulu E, Makasa J, Cross SB and Hamer DH (2023) Undernutrition in older children and adolescents in peri-urban Zambia. *Front. Public Health* 11:1251768. doi: 10.3389/fpubh.2023.1251768

Undernutrition in older children and adolescents in peri-urban Zambia

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Background: Adolescents make up roughly a quarter of the population in Zambia; however, most nutrition-related programming is targeted at the under-five population. Understanding the scale of undernutrition in older children and adolescents is fundamental to alleviating food insecurity and addressing undernutrition across all age groups.

Methods: A cross-sectional survey was performed in four low-income, peri-urban compounds in Chilanga District which included anthropometric measurements of children between ages 6 months-19 years and a household-level diet diversity and food security questionnaire. Wasting was used for children under 5 and thinness for children 5–19 years. Descriptive analysis and multivariate logistic regression were conducted to quantify the prevalence and distribution of malnutrition and understand the impact of food security.

Results: We surveyed 393 households and 1,004 children between the ages of 6 months and 19 years. Children aged 6–9 years had the highest prevalence of severe thinness (5.2%) and adolescents (10–19 years) had the highest rates of moderate thinness (6.5%). Across all age groups, more than 75% of children were in households that worried about running out of food in the previous month. 24.9% of adolescents and 28.4% of older children were in households were more likely to go a whole day without eating compared to 16.9% of children under 5.

Conclusion: Our survey indicated that malnutrition in adolescents and older children living in Chilanga district was comparable to those under 5. Interventions to address undernutrition must be targeted at older children and adolescents in order to ameliorate this burden.

KEYWORDS

adolescent, malnutrition, undernutrition, adolescent malnutrition, Zambia malnutrition, wasting

Introduction

There are roughly 1.8 billion adolescents worldwide, 90% of whom live in low- and middle-income countries (LMICs) (1). In Zambia, adolescents (aged 10–19 years) comprise about 25% of the population (2). While there have been multiple calls in recent years to further understand the impact of adolescent undernutrition (1, 3, 4), most research and programming on a global scale has focused on the under 5 (U5) population (4, 5). The importance of malnutrition in older children and adolescents has come into greater focus over the last several years given that the importance of this population is a crucial demographic to maintain a healthy society and workforce (1).

Adolescence is an important period of growth and development during which children have specific health and nutritional needs (1). Adequate nutrition is essential for several key growth and development parameters that occur during adolescence, including puberty, linear growth (which has its first peak in the first 2–3 years of life and then again in adolescence), and weight gain. During adolescence, children gain 50% of their adult weight, 40% of their peak bone mass (1) and 15–20% of their height (6). In addition to growth, the nutritional status of adolescents has notable impacts on long-term cardiovascular fitness, risk of non-communicable diseases and immunity (4) which affects the overall health indicators of a population over time. Furthermore, significant cognitive development occurs during adolescence (4) which has long-lasting impacts on their choices and their economic status into adulthood. Adequate nutritional intake is critical not only for the growth of these adolescents, but for their future families as their own health status will have significant intergenerational impacts on the nutritional well-being of their children and families (4, 7).

Globally, more than one-third of women are married by the age of 18 (1) and more than 20% of births to adolescent mothers occur in sub-Saharan Africa and Latin America. One study showed that more than 25% of mothers between the ages of 15–19 met criteria for stunting (1), a marker for poor nutrition (6). Pre-pregnancy stunting in adolescent girls is especially important given its association with pre-term birth and low birth weight, conditions which ultimately perpetuate a multigenerational cycle of undernutrition (1, 4). In Zambia, the 2018 Demographic and Health Survey (DHS) found that 29% of adolescent girls (15–19 years) have begun childbearing. This is particularly relevant in women who live within the lowest wealth quintile because 46% of these women have already begun childbearing in their adolescence (2).

Despite the noted importance of nutrition in child and adolescent health, there have been few studies quantifying the prevalence of malnutrition or undernutrition among older children and adolescents in sub-Saharan Africa, particularly in Zambia (5, 6, 8, 9). Moderate and severe thinness among children and adolescents globally is 8.4% in girls and 12.4% in boys (1). While there have been significant strides in U5 malnutrition rates, older children and adolescents are often neglected. One study from Uganda showed that the prevalence of thinness was higher for children 5–17 years compared to U5 children (5.5% vs. 3.8%) (5). This can largely be attributed to the limited availability of nutrition programs and interventions for children over 5 years (5).

While much of the mortality and economic hardship is based on U5 data, there is likely an unreported degree of malnutrition in children over 5 years. Currently, no global targets have been identified for adolescent undernutrition (4). Given the paucity of research into the adolescent population, we aimed to provide a descriptive analysis of the prevalence of adolescent malnutrition as compared to other pediatric age groups in Chilanga district within Lusaka, Zambia. We also evaluated the rates of stunting, thinness, and obesity across age groups in Chilanga, the characteristics of these groups and the impact of food security on nutritional status.

We hypothesize that the rates of undernutrition, specifically thinness and stunting, are as prevalent in older children and adolescents as in children U5, and therefore interventions must be targeted at this population. By understanding the prevalence of malnutrition in older children (6–9 years) and adolescents within the community, we can develop effective intervention strategies to address food insecurity and malnutrition. This knowledge is crucial for implementing interventions and scaling policies to address malnutrition and hunger in all forms (10).

Methods

We conducted a cross-sectional survey of households in the Chilanga district of Lusaka Province in Zambia between February 1st and February 14, 2022. I4life, an Irish-based, non-governmental organization (NGO), focused on community-based nutrition care, was the implementing organization for this survey. They are based locally in Chilanga district and work closely with this community; therefore, we chose this location to better understand the population being served. Ethical approval was provided by the University of Zambia (UNZA) Biomedical Research Ethics Committee and the Brigham and Women's Institutional Review Board. Logistical support was provided by Right to Care Zambia.

Study site and population

This study was conducted in 4 compounds (neighborhoods) within Chilanga district: Freedom, Kazimva, Linda, and Mwembeshi. Chilanga district has a population of roughly 107,000 people, with about 32,000 under the age of 9 years and 26,500 between the ages of 10–19 (11). The study population included 1,004 children aged 6 months to 19 years who lived in Chilanga district. This age range was used to group children based on the WHO categorizations of childhood: under 5, older child (age 6–9 years), and adolescent (10–19 years). The full range of childhood and adolescent ages were included in order to assess differences in the prevalence of malnutrition across the three age categories.

Sampling procedure and data collection

Within the district, households from the four different compounds were sampled. Purposive sampling was chosen to identify streets to sample within each compound because publicly available documents were not available to ascertain an accurate household number in the district and therefore, we did not have an accurate population size to define our household level population. Furthermore, we aimed to ensure that vulnerable individuals such as

non-traditional families and unhoused or insecurely housed individuals were included in our data set as these are likely the populations who will likely benefit from future interventions. However, within each area of the neighborhood, the data collectors used a systematic randomized sample approach and identified every third house within a neighborhood and households were only included if they had at least one child aged 6 months to 19 years. Each data collector pair was responsible for a different region of the neighborhood to avoid double counting. Data collectors were instructed to ensure that at least 50% of their households had 1 child greater than 10 years of age. Households of data collectors within the community were excluded. Based on data collectors' financial and time constraints, we aimed to survey 100 households in each compound. I4life staff familiar with the area identified the compounds to be included *a priori* based on their assessment of greatest nutritional need in the community. The four compounds had an even number of households.

Local and district approvals were obtained for community engagement. Informed consent was obtained from each household. Consent forms were provided in either Nyanja or Bemba (depending on the needs of the interviewee) and read to the participant in the relevant language if the participant did not have the necessary literacy level to read the form. Data collectors were members of the community fluent in the local language. They were trained on how to identify households, conduct the questionnaire, and perform anthropometric measurements. An adult in the household, typically the mother, responded to the household diet questionnaires. This questionnaire, which included the food security component was adapted from a questionnaire developed by the Africa Research Implementation Science Education (ARISE) research group to evaluate the impact of COVID-19 on adolescent health in several sub-Saharan African countries (12).

Trained research assistants collected anthropometric data, including height for children over 2 and length for children under 2 (in centimeters), weight (in kilograms), and mid-upper arm circumference (MUAC; in millimeters) of each child in the home, along with a household diet questionnaire. Anthropometric data was collected using standardized MUAC measuring tapes and UNICEF height boards for children under 5 and for children over 5 a standard tape measure was utilized. A standardized UNICEF standing electronic scale was used to obtain weights. For children unable to stand, the mother held the child on the scale. The scale was able to be zeroed out if the mother was on the scale. If a child was not present (i.e., they were in school), data collectors returned after the school day had ended to collect the data. All anthropometric measures were calculated into z-scores using the WHO Child Growth Standards STATA igrowup package for 0–5 years (13) and WHO AnthroPlus for 5–19 years (14).

Data management

Study data were collected and managed using REDCap (Research Electronic Data Capture, Vanderbilt University, Nashville, Tennessee, United States), a secure web application for building and managing online surveys and databases hosted at Brigham and Women's Hospital (15). Paper surveys were available in English and Nyanja for data collectors to use in case of technical challenges. Completed paper surveys were subsequently input into REDCap manually. No identifiers were obtained during data collection.

Categories of nutritional status were based on standard WHO categorizations: severe wasting or thinness, moderate wasting or thinness, moderate and severe stunting, normal nutritional status, overweight and obese (16). Wasting was defined using weight-for-height z-scores (WHZ) for U5 children and thinness was defined using body mass index (BMI) for age for children aged 6–19 years. WHO growth standards were used to calculate z-scores (13, 17). Children under 5 were considered to be moderately wasted with a WHZ between of <-2 and ≥ -3 and were characterized as severely wasted if their WHZ was less than -3. We also calculated the BMI-for-age for children under 5 for consistency with the definition for older children and adolescents. There was no difference noted in the number of children qualifying as moderate of severe thinness. Therefore, in order to maintain comparability with other studies, we presented the data using the WHZ criteria for children under 5 in our results section. The outliers were cut off using WHO standards (13, 17), where extreme values of WHZ, i.e., z-score larger than 5 or less than -6, were considered as missing variables.

WHO Child Growth Standards for children aged 6–19 years were used to calculate BMI-for-age z-scores (17). BMI z-scores between -2 and -3 were considered moderate thinness and less than -3 were severely thin for children aged 6–19 years. All children with a height-for-age z-score (HAZ) between -2 and -3 were considered moderately stunted and less than -3 were considered severely stunted. Overweight children aged 6–19 were defined as a BMI-for-age z-score greater than +1 and less than or equal to +2 and obesity was defined as a z-score greater than +2. For children U5, overweight was defined as a BMI-for-age z-score greater than +2 and smaller or equal to 3 and obese as BMI-for-age z-scores larger than +3 (18). Following WHO standards (13, 17), BMI-for-age z-scores larger than 5 or less than -5 were considered as outliers and not included in the analysis. Missing data was also excluded from data analysis. Similarly, HAZ larger than 6 or less than -6 were considered as outliers.

Statistical analysis

The primary outcomes were the number of households in which older children or adolescents met the criteria for moderate or severe thinness and/or stunting. Secondary outcomes included factors associated with thinness in this population.

A descriptive analysis of nutritional status was conducted using the WHO guidelines for z-score by BMI for children over 5 and WHZ for children U5. For categorical variables, frequencies and prevalence for categorical variables and means and standard deviation (SD) for continuous variables were used to summarize population and household demographics. About 70% of the children included in the survey had birth dates included; the other 30% did not. We used DHS data imputation methodology to impute the relevant birthdates (19). A sensitivity analysis was performed between the data sets including imputed dates and the data set without dates which showed no statistically significant difference in mean ages between the 2 data sets (Welch's *t*-test,

$p = 0.10$). The full imputed data set was used for the remainder of the data.

Multivariate logistic regression, controlling for clustering by household, was used to investigate the impact of several factors on undernutrition among children aged 6 months to 19 years old. Our models include: age (U5, 6–9 years old, 10–19 years old), sex (male/female), HIV positive status (no/yes), school absences (no/yes), respondent's occupation (unemployed, business owner, wage employment, self-employment, casual worker, and other), monthly household income (less than K1000, K1000-2400, over K2500), worry about running out of food in the past month (no/yes), skipped a meal in the past month (no/yes), went without eating for a whole day in the past month (no/yes), and received any assistance in the past month (no/yes). We selected potential confounders based on the association from the univariate regression models at $p < 0.25$. Thus, variables including access to clean water and soap, HIV status, school absences, and receiving any assistance in the past month were not included in the final regression model. Although sex and household income had a larger value of p than 0.25, these variables were included as various literature has shown the significant associations (20, 21). Odds ratios (OR) for all variables were determined using a 95% confidence interval (CI).

Data were analyzed with STATA 17.0 software. A significance level of $p = 0.05$ was used for all statistical tests and analyses.

Results

A total of 393 households and 1,004 children were surveyed. The average household size was 5 people and 93% of households had access to water. Approximately 89.2% of households made less than 2,400 kwacha (about 135 USD in February 2023) per month (Table 1). Only 3.1% of respondents of the household survey had completed any tertiary education. Slightly over half (52.6%) of the children sampled were female (Table 1). 8.8% of children across all age groups were categorized as either severely or moderately underweight. One-third (33.4%) of all children were categorized as moderately or severely stunted.

The prevalence of severe thinness in adolescents was comparable to wasting in U5 children (2.7% in adolescents and 2.8% in U5 children; Table 2). Children aged 6–9 years had the highest rates of severe thinness (5.2%). Adolescents had the highest proportion of moderate thinness (6.5%) compared to 4.6% in older children and 5.2% wasting in children under 5. Stunting (moderate and severe) was most prevalent in children under 5 (48.2% compared to 25.7 and 30.3% in older children and adolescents, respectively). Age categories were closely matched with 273/1022 (27.2%) of children aged U5, 320 (31.9%) were age 6–9 years, and 411 (40.9%) were aged 10–19 (Table 2). More than 75% of children with thinness in all age groups worried about running out of food in the previous month and more than 60% across the age groups stated that they had skipped at least 1 meal. Interestingly, 91/320 (28.5%) of older children and 102/411 (24.9%) of adolescents had skipped a whole day of meals compared to 73/271 (16.8%) of children under 5 (Table 2).

We found that there were 68 households (17.3%) with at least one child categorized as severe or moderately underweight and 196 households (49.9%) with at least one stunted child. There were 55 households (14.0%) in which there was an older child or adolescent who met criteria for moderate or severe thinness without a child U5

TABLE 1 Socio-demographic characteristics of study households.

	Total			
	n	%	Mean	SD
Total children	1,004	–	–	–
Sex			–	–
Male	479	47.2		
Female	537	52.6		
Number of HIV positive children	18	2.0	–	–
Number of children with a positive TB history	1	0.1	–	–
Number of children with any past medical history[a]	31	3.0	–	–
Number of children with a history of hospitalization for malnutrition	12	1.2	–	–
Severe thinness across all age groups[b]	31	3.6	–	–
Moderate thinness across all age groups[b]	45	5.2	–	–
Normal weight	639	73.3	–	–
Overweight/obese	75	8.6	–	–
Moderate stunting	180	20.0	–	–
Severe stunting	119	13.4	–	–
Total households (*n*=393)				
Number of family members in household	–	–	5.6	0.11
Presence of any family member with HIV	77	19.6	1.2	0.02
Presence of any family member with TB	17	4.4	1.0	0.01
Access to clean water	365	93.1	0.9	0.01
Role of respondent (*n*=391)				
Mother	304	77.8	–	–
Father	38	9.7	–	–
Grandparent	16	4.1	–	–
Child	19	4.9	–	–
Other	14	3.6	–	–
Income level of household (*n*=389)				
<1,000 kwacha[c]	216	55.5	–	–
1,000–2,400 kwacha	131	33.7	–	–
>2,500 kwacha	42	10.8	–	–
Occupation of respondent (*n*=392)				
Unemployed	109	27.8	–	–
Business owner	108	27.6	–	–

(Continued)

10.3389/fpubh.2023.1251768

TABLE 1 (Continued)

	Total			
	n	%	Mean	SD
Casual worker (maid or gardener)	83	21.2	–	–
Wage employment	52	13.3	–	–
Self-employed	35	8.9	–	–
Other	5	1.3	–	–
Education level of respondent (*n*=389)				
None	23	5.9	–	–
Some/completed primary school education	171	44.0	–	–
Some/completed secondary/high school	181	46.5	–	–
Tertiary education	12	3.1	–	–
Other (literacy class, religious school)	2	0.5	–	–
Water, sanitation, and hygiene				
Access to clean water for washing hands (*n*=392)	369	94.1		–
Access to clean water for cooking (*n*=392)	365	93.1		–
Water source (*n*=393)				
Borehole	113	28.7	–	–
Communal tap	86	21.9	–	–
Protected dug well	17	4.3	–	–
Tapped running water	155	39.4	–	–
Other	22	5.6	–	–
Soap in the household (*n*=390)				
Yes	292	74.9	–	–
No	98	25.1	–	–
Number of children in each compound (*n*=994)				
Linda	296	29.8	–	–
Kuzimbva	263	26.5	–	–
Mwembeshi	239	24.0	–	–
Freedom	196	19.7	–	–

[a]History of medical problems include: asthma, neuro-related disorders (autism, epilepsy, and cerebral palsy), kidney problems, and sickle cell disease.
[b]Analysis were run using both BMI for age across all age groups (6 months-19 years) and WHZ in children under 5 and BMI for age in children 5-19 years and results were unchanged.
[c]18.38 kwacha = 1 USD as of Feb 4, 2022.

meeting criterion. However, there were only 11 households (2.8%) in which only the U5 child in the household met criteria, but older children and adolescents did not meet the criterion. Demographics, including income, household size and education of households with only thin older children were similar to those with only U5 children who were underweight.

Food security at the household level was similar as well. Households in which only the older child was categorized as moderately or severely thin (79.2%) were more likely to have a child who had skipped a meal in the last month compared to the other age groups (58.3% in children U5 and 65.5% in adolescents). More than 85% of households across all age groups with at least one malnourished child worried about running out of food (Table 3). Despite more households with only an adolescent meeting criterion for thinness, none of the households with only an adolescent experiencing thinness received assistance.

There was an inverse relationship between stunting and thinness (OR 0.39, 95% CI 0.20 to 0.76, $p < 0.05$; Table 4). We also did not find significance in relationship between thinness and monthly household income or parent occupation as we expected. Similarly, we expected to find an association between food security and thinness, but no association was noted.

Discussion

In Chilanga district, a relatively low socio-economic community in Zambia, we found that the prevalence of undernutrition in the adolescent population was similar to or even slightly higher than that of the traditionally measured U5 population. While our sample was generally comparable to national nutritional data, we found a slightly higher prevalence of stunting and wasting in Chilanga district in the under 5 population when compared to national DHS data. 48.2% of our population was stunted compared to 35% of the national population and 4 % of the national population is characterized as wasted, whereas 8.8% in our population were wasted (2). Of note, the DHS does not quantify the rates of undernutrition in older children or adolescents, which we found to have an equal or even greater need for nutritional intervention; however, due to insufficient published data, we are unable to compare to the national need of these two age groups to the findings in our study.

It bears noting that this survey was also conducted immediately after the Omicron surge of the COVID-19 pandemic. The pandemic has significantly impacted food security and malnutrition globally (22, 23) and higher rates of malnutrition that we saw may also present nationally, but have not yet been quantified. These higher rates of malnutrition will likely persist for the next several years given the long-term ramifications of public health policies and health effects of the pandemic (22).

The inverse relationship between stunting and thinness was a surprising finding as it does not correlate with the broader literature. This may have been related to the higher incidence of obesity in the U5 population relative to the older age groups given that the U5 population also had the highest rate of stunting. This difference in stunting rates between these two age groups is also unclear as these children are from similar families and locations. It was considered that this difference was due to the impact of the COVID-19 pandemic and the higher incidence of food insecurity and malnutrition globally in the two-year period preceding this survey. However, none of the food security indicators were associated with stunting in our models. This may be related to the small sample size, or given that there were 393 households with 1,004 children total, many children would have come from the same house resulting in a relatively homogenous population which was not accounted for. Additional investigation should be pursued.

10.3389/fpubh.2023.1251768

TABLE 2 Nutritional classification and food security for children across age categories.

	Total		Under age 5		Age 6–9		Age 10–19		
	n	%	*n*	%	*n*	%	*n*	%	*p*-value
Nutritional classification									
Total	1,004	–	273	27.2	320	31.9	411	40.9	
Severe wasting/thinness	31	3.6	6	2.8	15	5.2	10	2.7	0.17
Moderate wasting/ thinness	45	5.2	8	3.7	13	4.6	24	6.5	0.27
Normal weight	639	73.3	137	62.8	220	76.9	282	76.6	<0.001
Overweight/obese	157	18.0	67	30.7	38	13.3	52	14.1	0.23
Moderate Stunting	180	20.0	57	25.2	57	19.0	66	17.7	0.07
Severe stunting	119	13.2	52	23.0	20	6.7	47	12.6	<0.001
Food security*									
Worry about running out of food in the last month									0.72
No	215	21.6	59	21.7	73	23.0	83	20.4	
Yes	781	78.4	213	77.0	245	77.0	323	79.6	
Skipped a meal in the last month									0.59
No	334	33.3	97	35.5	101	31.6	136	33.1	
Yes	670	66.7	176	64.5	219	68.4	275	66.9	
Went without eating for a whole day in the last month									0.55
No	736	73.5	199	73.2	229	71.6	308	75.1	
Yes	266	26.5	73	16.8	91	28.4	102	24.9	
Received any assistance in the last year									0.94
No	928	93.2	254	93.5	295	93.0	379	93.4	
Yes	68	6.8	18	6.6	23	7.2	27	6.7	

*Differences for food security questions were assessed using χ^2tests of association which were all shown to have no significant difference ($p > 0.5$).

TABLE 3 Household level food security with thinness stratified by age group.

	Households with only U5 children with thinness		Households with only older children (age 6 to 9 years) with thinness		Households with only adolescents (age 10 to 19 years) with thinness	
	n = 12	%	*n* = 24	%	*n* = 29	%
Worry about running out of food (*n*=387)						
No	1	8.3	3	12.5	4	13.8
Yes	11	91.7	21	87.5	25	86.2
Skipped a meal (*n*=389)						
No	5	41.7	5	20.8	10	34.5
Yes	7	58.3	19	79.2	19	65.5
Went without eating for a whole day (*n*=388)						
No	8	66.7	18	75.0	23	79.3
Yes	4	33.3	6	25.0	6	20.7
Received any assistance (*n*=387)						
No	11	91.7	22	91.7	29	100.0
Yes	1	8.3	2	8.3	0	0.0

In particular, we did not capture whether an adolescent might also be the mother of a young child in some multigenerational homes. In our survey, the majority of the study population made less than 150 USD per month which is roughly on par with the national income *per capita* in Zambia of 1,120 USD per year (24). The majority of households (78.4%) worried about not having enough food and 66.7% had skipped a meal in the previous month. Given this, it is likely that many children are not receiving adequate nutrition at home. One potential opportunity would be to explore the utility of food programs within schools. While private schools may be equipped with such programs, these programs do not exist in the public or government school system in Zambia. While data are mixed regarding the effectiveness of school feeding programs, some evidence suggests that in children with moderate thinness, there is an improvement in height, cognition, and school feeding programs (25). Interestingly, there did not appear to be a direct correlation with adolescent malnutrition in the household with the number of children in the family as might be expected. Understanding these factors further is crucial to developing effective interventions within these communities.

Our study has many strengths. This is one of the few studies we identified which has quantified the prevalence of adolescent malnutrition in Zambia. This is a novel survey since it evaluated the prevalence of adolescent undernutrition when compared to younger

TABLE 4 Univariate and multivariate logistic regression for factors associated with thinness in Chilanga district among children age 6 months to 19 years.

	Univariate		Multivariate	
	OR	95% CI	OR	95% CI
Age				
<5 years	ref			
Age 6–9 y	1.58	0.81, 3.08	1.08	0.53, 2.20
Age 10–19 y	1.48	0.78, 2.83	0.96	0.46, 1.35
Sex				
Male	ref			
Female	0.86	0.54, 1.37	0.79	0.46, 1.35
Stunting	0.37*	0.19, 0.69	0.31*	0.15, 0.66
Occupation				
Unemployed	ref			
Business owner	1.16	0.47, 2.85	0.85	0.27, 2.68
Wage employment	0.57	0.07, 4.98	0.92	0.09, 9.26
Self-employed	0.70	0.23, 2.08	0.82	0.23, 2.94
Causal worker (maid or gardener)	1.22	0.47, 3.18	1.38	0.44, 4.30
Other	0.96	0.35, 2.66	1.05	0.31, 3.50
Household income				
Less than K1000	ref			
K1000–K2400	0.82	0.49, 1.38	0.95	0.53, 1.73
K2500 and above	0.73	0.32, 1.67	0.73	0.26, 2.09
Worry about running out of food				
No	ref			
Yes	1.78	0.92, 3.44	1.27	0.54, 2.97
Skipped a meal				
No	ref			
Yes	1.44	0.85, 2.42	0.94	0.44, 2.00
Went without eating for a whole day				
No	ref			
Yes	1.55	0.94, 2.56	1.67	0.89, 3.16
Received any assistance				
No	ref			
Yes	0.55	0.17, 1.80	0.47	0.11, 2.05

*$p < 0.05$, **$p < 0.01$.

children within the same household. This allowed us to quantify the absolute rates and understand the epidemiology of the burden of disease within our community. This survey was adapted from a comprehensive survey including questions around water and sanitation (WASH) and food security which allowed us to understand the broader context of access within communities (23).

Our study also has a few limitations. While our findings are specific to the Chilanga district in Lusaka Province, our results are only applicable to that of a peri-urban environment and may not be generalizable to more rural communities where resources such as transportation or access to food, education, and work may differ. However, given that in Zambia there are higher malnutrition rates overall in rural areas, we anticipate that these findings may be even more pronounced in those settings.

Additionally, our assessment of predictors of undernutrition did not reveal any significant risk factors. This may be due to the relative homogeneity of our population as noted above. Given our smaller sample size, we did not perform an initial cluster analysis to account for this homogeneity. This may also contribute to being underpowered to make further generalizations. While this survey was intended to inform local communities about the current epidemiology in their community, expanding this survey to a larger, randomized group may be helpful in further elucidating the factors associated with thinness among older children and adolescents as we were likely underpowered to make more general conclusions. Furthermore, while our sensitivity analysis demonstrated minimal difference when we included imputed data, our data are somewhat limited as only 726 (69.1%) of the participants had included dates of birth and the rest were imputed using the DHS method.

The findings of our survey are notable as much of the current policies and programming target children under 5. While the U5 population is undoubtedly a critical cohort since the majority of the direct health costs associated with malnutrition occur in the first year of life (26), in a context in which almost 30% of adolescent females have a child (2), addressing malnutrition in this age group will have long lasting beneficial effects. Additionally, as children age and experience persistent thinness and stunting, they receive less schooling and ultimately are not able to contribute to the local workforce (26) which has long-term impacts on the perpetuation of poverty and the health and well- being of a society.

Conclusion

Further research into undernutrition related to older children and adolescents is crucial as the drivers of poor nutrition and ultimately interventions to address this issue differ in this population compared to the U5 children. Adolescents in particular have more choice of what they eat (27) and many may have their own families to feed (28). A multidisciplinary approach to addressing this burden is necessary along with greater global investment (4).

Our survey was a first step in identifying and quantifying this burden of disease in Chilanga district; however larger scale surveys should be conducted in varied settings across the country to further understand the burden of adolescent malnutrition. The burden of undernutrition in the Chilanga district is a significant issue across childhood and adolescents, not only in U5 children. Additionally, households with malnourished adolescents in our cohort received the least assistance. This suggests that additional focus should be placed on older children and adolescent populations, both for further research to understand the scope of the problem and drivers of undernutrition as well as to design relevant interventions that address the perpetuation of malnutrition.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies were approved by Brigham and Women's Hospital Institutional Review Board and the University of Zambia Ethical Review Board (UNZAREC). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

All authors have made a substantial contribution to the concept or design of the article, or the acquisition, analysis, or interpretation of data for the article. All authors have drafted the article or revised it critically for important intellectual content and approved the version to be published. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding

Research reported in this publication was supported by the Fogarty International Center and National Institute of Mental Health, of the National Institutes of Health under Award Number D43 TW010543. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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frontiers | Frontiers in Public Health

TYPE Community Case Study
PUBLISHED 03 October 2023
DOI 10.3389/fpubh.2023.1251912

OPEN ACCESS

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RECEIVED 02 July 2023
ACCEPTED 15 September 2023
PUBLISHED 03 October 2023

CITATION
Owens C, Cook M, Goetz J, Marshburn L, Taylor K, Schmidt S, Bussey-Jones J and Chakkalakal RJ (2023) Food is medicine intervention shows promise for engaging patients attending a safety-net hospital in the Southeast United States.
Front. Public Health 11:1251912.
doi: 10.3389/fpubh.2023.1251912

Food is medicine intervention shows promise for engaging patients attending a safety-net hospital in the Southeast United States

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Public health organizations, including the Academy of Nutrition and Dietetics and the American Hospital Association, recognize the importance of achieving food and nutrition security to improve health outcomes, reduce healthcare costs, and advance health equity. In response, federal, state, and private agencies are increasingly seeking to fund healthcare-based interventions to address food insecurity among patients. Simultaneously, nutrition-based interventions targeting chronic diseases have grown across the United States as part of the broader "Food is Medicine" movement. Few studies have examined the successes, challenges, and limitations of such efforts. As Food is Medicine programs continue to expand, identifying common approaches, metrics, and outcomes will be imperative for ensuring program success, replicability, and sustainability. Beginning in 2020, the Food as Medicine (FAM) program, a multipronged, collaborative intervention at Grady Health System has sought to combat food insecurity and improve patient health by leveraging community resources, expertise, and existing partnerships. Using this program as a case study, we (1) outline the collaborative development of the FAM program; (2) describe and characterize patient engagement in the initial 2 years; and (3) summarize strengths and lessons learned for future hospital-based food and nutrition programming. As this case study illustrates, the Food as Medicine program provides a novel model for building health equity through food within healthcare organizations.

KEYWORDS

food security, nutrition, food is medicine, healthcare, chronic disease, intervention, diabetes, hypertension

Introduction

Food insecurity, a state in which an individual or household lacks social, economic, or physical access to nutritious foods to support a healthy and active life, impacts approximately 11% of all individuals in the United States (1). Food insecurity disproportionately affects marginalized groups in the US, including those experiencing poverty (2), unstable housing (3), and among racial and

ethnic minority groups (4). Studies demonstrate a negative relationship between food insecurity and diet quality in North America (5–7) including recent systematic reviews demonstrating negative associations between food insecurity and dietary patterns recommended for cardiometabolic health, including Dietary Approaches to Stop Hypertension and the Mediterranean diet, particularly among women (8). In addition, food insecurity and associated social determinants of health may compound barriers to healthcare access (3). In the face of such barriers, numerous studies have documented associations between food insecurity and adverse health outcomes, including hypertension (9–11), diabetes mellitus (12, 13), and cardiovascular disease risk (14). As a consequence of these co-morbid conditions, individuals living with food insecurity also exhibit higher healthcare utilization and costs compared to those who are food secure (15–17).

As a public health concern and a prevalent social determinant of health, food insecurity is a primary target of interventions to alleviate diet-related chronic diseases. Though intervention approaches vary widely, many apply principles of the "Food is Medicine" movement (18). "Food is Medicine" programs leverage the expertise and authority of healthcare providers to encourage participation and lifestyle change among patients (18). Within this movement, Food or Produce Prescription Programs and "Fresh Food Farmacy Programs" have emerged as on-site healthcare-based interventions that may offer access to nutrition counseling, evidence-based cooking and nutrition classes, or free or subsidized nutritious foods (19). In such programs, healthcare systems often collaborate with community partners, including nonprofit organizations, to provide resources to improve food security and diet-related health outcomes and, in the long term, reduce healthcare costs and expenditures (18). Food is Medicine programs also answer prominent calls for health-systems to actively address social determinants of health and work toward achieving health equity (20, 21).

To our knowledge, this is one of few manuscripts to detail the real-world implementation of a Food is Medicine program, and to describe the characteristics and engagement of patients who enroll. The partnerships of this program enable rigorous evaluation in real-world settings to assess program outcomes. By describing program characteristics and initial outcomes, this manuscript aims to address gaps in the current literature to enhance the sustainability, scalability, and transferability of these interventions to other hospital and clinical settings. The Food as Medicine (FAM) partnership, which began in 2020, operates as a collaboration between a large hospital system in the Southeast US and local nonprofit organizations. Akin to similar interventions across the nation, the FAM program targets patients living with or at-risk for food insecurity and hypertension or diabetes mellitus.

Context and rationale

Over 11% of individuals living in the Southeast experience food insecurity—the highest prevalence of any region in the US (1). Across the US, prominent disparities in the experience of food insecurity among historically marginalized and minoritized communities are evident; food insecurity disproportionately affects those living in households with incomes below the poverty line and Black and Hispanic households (4). The Atlanta Metropolitan Statistical Area (MSA), defined by the US Census, is the ninth largest city in the country—with a higher percentage of non-white residents than the country overall. In a recent analysis, Shannon and colleagues found high rates of food insecurity in core urban neighborhoods in the Atlanta MSA, along with increasing challenges in suburban areas (22). As their findings suggest, there remains a critical need for food security efforts across the region, particularly those that can serve as "one-stop shops" for food and medicine.

The Grady Health System is the busiest level 1 trauma center in Georgia and has over 158,000 Emergency Department visits annually. Comprised of a hospital with 853 licensed beds and six neighborhood health centers across two counties in the Atlanta MSA, Grady serves over 2,300 patients per day. The Population Health team at Grady seeks to design, deliver and coordinate care to address the critical needs of the community in accordance with overall health status. A key priority for the Population Health team is to contribute to a coordinated system of care delivery within and outside the clinical setting the team does so by working at the nexus of three key social determinants of health: housing, transportation, and food. Previous needs assessments estimated that the prevalence of food insecurity among patients attending Grady Health System is nearly four times higher than in Atlanta overall. Based on these assessments, approximately 50% of the patient population may experience food insecurity at some point in the year; moreover, since these assessments were conducted before the COVID-19 pandemic, current patient needs are likely even greater. Recognizing this need, the aims of the Food as Medicine partnership are threefold: 1. Increase access to healthy, affordable food for patients and their families, employees, visitors, and the wider community; 2. Leverage community resources and expertise to address food insecurity and chronic disease; and 3. Improve the health and overall quality of life of patients.

Intervention development

In 2016, Grady announced the examination and alleviation of diabetes, hypertension, and social determinants of health as community health needs priorities. At this time, the early inceptions of Food as Medicine began with a pilot Fruit and Vegetable Rx Program, discussed and evaluated at length in (23). By 2017, Grady formalized the Food as Medicine partnership by executing a Letter of Intent (LOI) with community partners outlining shared goals, a plan to address food insecurity and chronic disease, and shared fundraising targets to bring the plan to fruition. In tandem, Grady implemented Supplemental Nutrition Assistance Program (SNAP) screening and food pantry referrals at a clinic site located 1.5 miles from the pantry. From 2017 to 2019, 1,119 patients were screened for SNAP and food pantry referrals; however, a low engagement with the food pantry (10%) prompted partners to redevelop the vision for FAM. Seeking to further integrate food into the clinic space, bi-monthly food distribution was established at one clinic in 2019 and construction of the Jesse Hill Market on Grady Health System's campus, erected at the site of a former fast food restaurant, began. Over this period, partners developed a vision for a multifaceted pronged FAM program.

Establishing critical partnerships

Grady formed the Food as Medicine (FAM) program as a collaboration between Grady Health System, Atlanta Community Food Bank, and Open Hand Atlanta. Constructing a shared vision and

goals across partners proved critical to the program's success in its inception and initial stages. A Feeding America affiliate, the Atlanta Community Food Bank has a long history of working to provide access to nutritious meals for those in need within their 29-county service area. Open Hand Atlanta, a non-profit agency, seeks to eliminate disability and untimely death due to nutrition-sensitive chronic disease and medically-tailored meals and nutrition education. By working in coordination with the Atlanta Community Food Bank and Open Hand Atlanta, the FAM program leveraged the experience and resources of existing community-based food and nutrition security resources in the development, design, and implementation of programming. Finally, partnerships with Emory University researchers enable evaluation of this program. These non-governmental, private, and research sector partnerships have proven vital to the implementation and maintenance of the FAM program over its initial 3 years. This case-study focuses on one of the integral prongs of the FAM program: The Food Prescription Program. Given the increase in food prescription programs across the U.S., Grady prioritized disseminating evaluation findings from the Food Prescription Program prong, with other aspects of the program to be evaluated and shared more widely in the future.

Programmatic elements

The Food Prescription Program, a service line within the larger Grady FAM program, is a multi-pronged intervention that provides eligible patients with nutrition counseling, cooking classes, and fresh food (purchased from the Atlanta Community Food Bank). The Food Prescription Program operates within the Jesse Hill market space to serve as a hub for nutrition and well-being for Grady patients, employees, and the greater community. The Jesse Hill market also houses a teaching kitchen that focuses on plant-based cooking and nutrition and chronic disease education.

Theoretical framework

Food security is often conceptualized as being comprised of four pillars: availability, accessibility, utilization, and stability. Scholarly examination of these pillars is varied, with an arguable over-representation of dimensions of availability and access in commonly used measurement tools and studies of insecurity and health. The Food Prescription Program attempts to address multiple pathways proposed to underlie food insecurity and adverse health outcomes, including nutritional, compensatory, and psychological pathways, as outlined by Te Vazquez and colleagues in a recent systematic review (24). The nutritional pathway connecting food insecurity with chronic disease occurs through constrained dietary options and lower diet quality, specifically lower consumption of fruits, vegetables, whole grains, and lean meats (5–7, 13, 25). Alongside nutritional and dietary constraints, compensatory measures such as trade-offs between food and medications or other basic needs may reduce capacities to manage well-being or existing conditions (26). Psychological factors, including depression, anxiety, and feelings of shame or embarrassment, may increase experiences of psychosocial and physiological stress and decrease self-efficacy (27–31). Many scholars suggest that these pathways collectively promote cycles of insecurity and disease. As shown in Figure 1, the Grady Food Prescription Program attempts to address these mechanisms through key program outputs: food distribution, cooking classes, nutrition counseling with a dietitian, and appointments with a primary care provider. Receipt of fresh fruits and vegetables, whole grains, and plant-based proteins meats intends to simultaneously reduce dietary constraints and improve diet quality, which dietitians and instructors bolster through nutrition and food preparation knowledge. The knowledge and education components of the program also work to improve patients' self-efficacy, targeting the psychological pathway. Finally, appointments with the provider enable more monitoring of health and pre-existing conditions to improve capacities for self-management. The Food Prescription Program aims to simultaneously improve food security and cardiometabolic health through these outputs and program outcomes.

Methods

Recruitment

Eligibility for the program is determined by healthcare providers during routine outpatient clinic visits. Patients are eligible for a Food Prescription Program prescription if they: (1) screen positive for food insecurity using the validated two-item Hunger Vital Sign™ (HVS) and (2) are identified as having uncontrolled hypertension (systolic blood pressure greater than 140 mmHg *or* diastolic blood pressure greater than 90 mmHg during the last measure taken) or uncontrolled diabetes Type 1 or 2 (last hemoglobin A1c reading greater than 9.0). Notably, the HVS™ identifies risk for food insecurity; therefore, individuals who are living with marginal food security may screen as "at-risk" for food insecurity using the HVS™. Studies in clinical settings show that the HVS shows high sensitivity and specificity with the Household Food Security Survey Module (32, 33), which the Food Prescription Program staff uses to assess food insecurity. Grady Health System began screening for Social Determinants of Health (SDOH), including food insecurity, in 2019. The SDOH screening occurred in a phased process, such that 11 primary care and diabetes clinics conducted screening between August 2020 and August 2022; however, Grady has since expanded SDOH screening to all outpatient clinics as of June 2023.

To simplify referral, the team developed a Best Practice Alert (BPA) within Epic (electronic medical record system) which prompts providers to sign a referral (i.e., prescription) to the Food Prescription Program. As a feature of the electronic medical record, referral to the Food Prescription Program is a staff-led intervention, offering nurses and certified medical assistants the ability to respond to the BPA. In the period between August 2020 and August 2022, each month an average of 236 BPAs were prompted, 122 referrals were made, and 42 enrollments occurred. Once enrolled, food prescriptions provide patients access to the Food Prescription Program for a 3-month "episode" of care which can be renewed up to 3 times (i.e., 1 year of access to the Food Prescription Program). During each episode, patients are invited to pick up fresh produce boxes biweekly, attend cooking classes in Jesse Hill Market's on-site Teaching Kitchen, participate in nutrition education sessions (one-on-one, group, or telehealth) with a registered dietitian, and continue to follow-up with their primary healthcare provider. The food prescription process is documented within the electronic medical record (EMR) system, including the referral and enrollment for eligible and participating

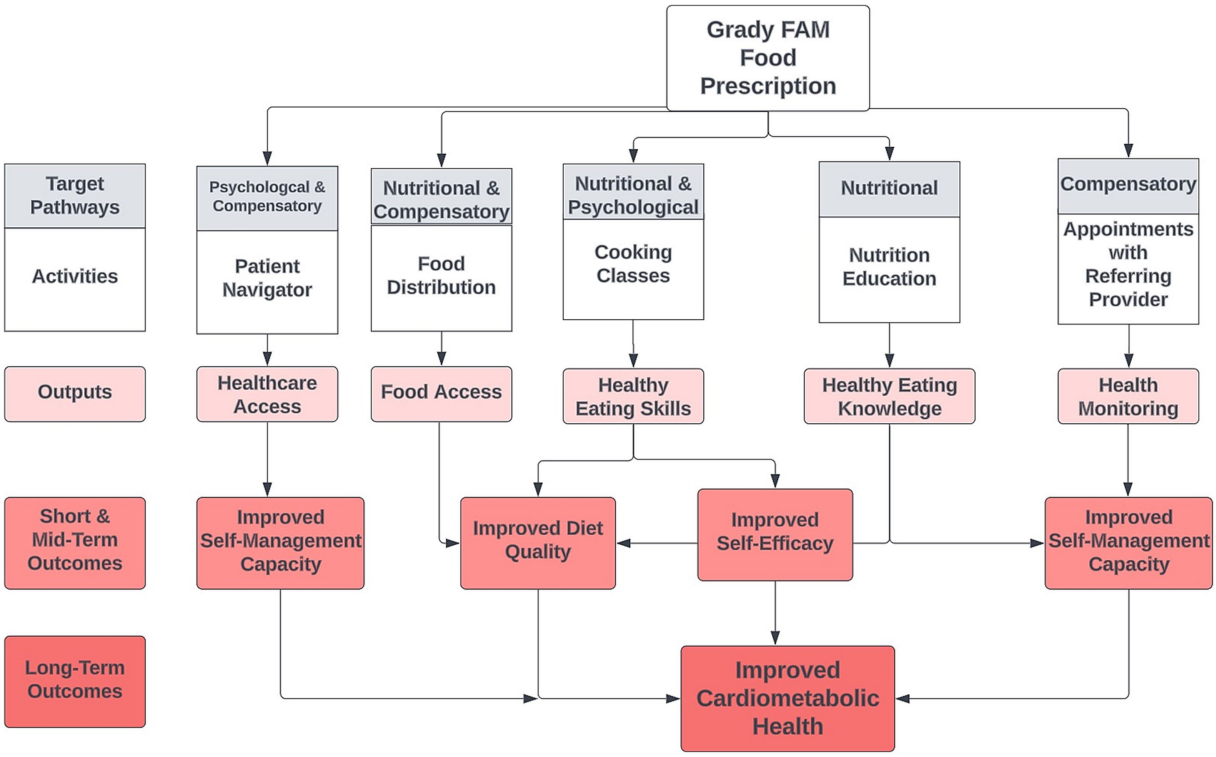

FIGURE 1
Grady food prescription program conceptual model.

patients, documentation of visits to the Food Prescription Program, Teaching Kitchen and nutrition education sessions, and health records. At their first Food Prescription Program visit, patients complete a standardized survey that further assesses social determinants of health using validated instruments. Specifically, patients complete the 6-item Household Food Security Survey Module (HFSSM), the Center for Disease Control Healthy Days Core Module (34), a one-item screening for housing insecurity, and information on household composition and utilization of food assistance. In addition to data from the survey instrument, a qualitative phone-based survey was conducted in April 2022 among a subset of participants to query barriers to program engagement and retention. To explore how these sociodemographic and health characteristics vary by loss to follow-up and re-enrollment, we divide descriptive tables into columns, as follows: the first column displays data on patients who did not renew the prescription after their first 3-month episode (those lost to follow-up), the second column displays data on those who renewed their prescription, the third column displays data from all patients who enrolled in the Food Prescription Program and were eligible for renewal, and the final column displays test statistics and *p*-values for statistical tests comparing patients who did not renew their prescription to those who renewed their prescription. Chi-square tests were used to assess differences across categorical variables and independent samples t-tests were used for continuous variables. We use an alpha level of 0.05 to determine statistical significance. To our knowledge, this is one of few Food is Medicine programs to be fully integrated as a clinical service line within the EMR in a US healthcare system.

Results

Patient characteristics and engagement

Between August 2020 and August 2022, 1,012 patients visited the Food Prescription Program at least once. Of those, 863 were eligible to renew their prescription by August 2022 based on their initial start date. During this period, the Food Prescription Program distributed over 142,000 pounds of food to patients enrolled in FAM. Overall, approximately 42.6% of patients renewed their prescription. Reflecting the demographics of the hospital, the majority of enrolled these patients identify as Black or African American (93%) and female (60%). Notably, 20% of these patients experienced housing insecurity in the previous 12 months, illustrating the influence of multiple social determinants on the health of this community. Similarly, using the Household Food Security Survey Module, nearly 70% of all enrollees experienced low or very low food security in the past month. Enrollees ranged in age from 19 to 90 years, with an average age of 56 years. Approximately one-third of all enrollees reported living in a household with at least one child, while almost half reported living in a household with at least one adult over age 60. Most enrollees reported preparing their own meals at home, which indicates capacity to implement lessons from the cooking and nutrition education components of the Food Prescription Program.

As shown in Table 1 significantly greater proportion of participants who renewed the initial prescription were female and had older adults living in their household compared to participants who did not renew the initial prescription. As shown in Table 1,

10.3389/fpubh.2023.1251912

TABLE 1 Sociodemographic characteristics at baseline.

	Initial prescription not renewed (*N* = 495)	Initial prescription renewed (*N* = 368)	Overall eligible (*N* = 863)	Test statistic, *P*
Gender				8.87, 0.003
Female	276 (55.8%)	243 (66.0%)	519 (60.1%)	
Male	219 (44.2%)	125 (34.0%)	344 (39.9%)	
Age (in years)				−4.12, <0.001
Mean (SD)	54 (± 11)	57 (± 9.9)	56 (± 11)	
Race				7.01, 0.072
Black or African American	456 (92.1%)	348 (94.6%)	804 (93.2%)	
Hispanic	14 (2.8%)	4 (1.1%)	18 (2.1%)	
Multi-Racial, Other, or Unknown	8 (1.6%)	10 (2.7%)	18 (2.1%)	
White	17 (3.4%)	6 (1.6%)	23 (2.7%)	
Ethnicity				0.052
Hispanic	18 (3.6%)	6 (1.6%)	24 (2.8%)	
Non-Hispanic	475 (96.0%)	356 (96.7%)	831 (96.3%)	
Unknown	2 (0.4%)	4 (1.1%)	6 (0.7%)	
Patient refused	0 (0%)	2 (0.5%)	2 (0.2%)	
Household demographics				
Any children (yes)	168 (33.9%)	107 (29.1%)	275 (31.9%)	2.56, 0.11
Missing	37 (7.5%)	23 (6.3%)	60 (7.0%)	
Any older adults (yes)	217 (43.8%)	191 (51.9%)	408 (47.3%)	4.10, 0.043
Missing	29 (5.9%)	14 (3.8%)	43 (5.0%)	
Food insecurity status				1.63, 0.44
High or marginal food security	117 (23.6%)	92 (25.0%)	209 (24.2%)	
Low food security	165 (33.3%)	110 (29.9%)	275 (31.9%)	
Very low food security	172 (34.7%)	141 (38.3%)	313 (36.3%)	
Missing	41 (8.3%)	25 (6.8%)	66 (7.6%)	
Was there a time in the last 12 months when you did not have your own place to stay were homeless or stayed in a shelter?				2.61, 0.11
Yes	112 (22.6%)	66 (17.9%)	178 (20.6%)	
Missing	18 (3.6%)	13 (3.5%)	31 (3.6%)	
When you eat at home who usually prepares meals?				2.59, 0.11
Other	71 (14.3%)	39 (10.6%)	110 (12.7%)	
Self	391 (79.0%)	309 (84.0%)	700 (81.1%)	
Missing	33 (6.7%)	20 (5.4%)	53 (6.1%)	

significantly more men did not renew the initial prescription compared to those who did renew the initial prescription. Additionally, mean age was significantly lower among those who did not renew the initial prescription compared to patients who renewed. Similarly, those with at least one older adult in the household were significantly more likely to renew their prescription compared to those without older adults in the household. However, there were no other significant demographic or household composition differences observed between those who renewed their prescription completed the program and those who were lost to follow-up.

Table 2 displays baseline biometrics of those who did not renew their prescription, those who renewed their prescription, and all eligible enrollees. Of those who enrolled in the food prescription, 88% had elevated or hypertensive blood pressure (systolic blood pressure greater than 140 mmHg *or* diastolic blood pressure greater than 90 mmHg), and 48% had a baseline HbA1c greater than or equal to 9.0%. Approximately 58% of patients had hypertensive blood pressure readings *and* HbA1c values of greater than or equal to nine, suggestive of a high prevalence of comorbidity relative to the general population. Those lost to follow-up had significantly smaller baseline waist circumference, but significantly greater diastolic blood pressure and A1C levels compared to than those who renewed prescriptions. There were no other differences in baseline physical or perceived health measures between the groups, suggesting that program retention may not be affected by

10.3389/fpubh.2023.1251912

TABLE 2 Biomarker health characteristics at baseline.

	Initial prescription not renewed (*N* = 495)	Initial prescription renewed (*N* = 368)	Overall eligible (*N* = 863)	Test statistic, *P*
Waist circumference (ins)				−2.12, 0.035
Mean (SD)	41 (± 8.1)	42 (± 8.0)	41 (± 8.1)	
Missing	122 (24.6%)	79 (21.5%)	201 (23.3%)	
Body mass index (kgm^2)				−1.36, 0.17
Mean (SD)	32 (± 8.6)	33 (± 8.7)	33 (± 8.7)	
Missing	7 (1.4%)	8 (2.2%)	15 (1.7%)	
Systolic blood pressure (mmHg)[1]				0.11, 0.92
Mean (SD)	140 (± 20)	140 (± 20)	140 (± 20)	
Missing	5 (1.0%)	11 (3.0%)	16 (1.9%)	
Diastolic blood pressure (mmHg)				3.04, 0.002
Mean (SD)	82 (± 12)	79 (± 12)	81 (± 12)	
Missing	5 (1.0%)	11 (3.0%)	16 (1.9%)	
A1C (%)				2.57, 0.010
Mean (SD)	9.4 (± 3.2)	8.9 (± 2.9)	9.2 (± 3.1)	
Missing	16 (3.2%)	17 (4.6%)	33 (3.8%)	

[1]Individuals with systolic blood pressure greater than 140 mmHg or diastolic blood pressure greater than 90 mmHg were classified as having hypertension. Individuals with A1C greater than or equal to 9.0% were classified as having uncontrolled diabetes.

differences in morbidity status or baseline health condition. As shown in Table 3, most enrollees (48%) rated their perceived health as "fair," with less than 10% of enrollees rating their health as "excellent" or "very good" (2 and 5%, respectively) at baseline. Using the CDC Healthy Days Tools, enrollees reported 11 days of poor physical health, 8 days of poor mental health, and 8 days during which mental or physical health prevented usual activities during the last month, on average.

Barriers to engagement

Of the 863 individuals who attended the Food Prescription Program at least once were eligible to renew their prescription, 495 (57.4%) did not renew their prescription to re-enroll in the Food Prescription Program. Noting that many participants enrolled had not met the participation requirements to re-enroll in an additional episode, a qualitative phone-based survey was conducted to query barriers to program engagement in April 2022. We identified 62 participants who would have been eligible for re-enrollment at this point had they met requirements and were able survey 25 (40% response rate). Barriers to engagement identified were highly individual but were often related to competing priorities and overlapping social determinants of health such as lack of transportation, caregiver responsibilities, work hours, and physical health challenges. Some responses were not able to be categorized but generally discussed the time commitment involved in meeting program requirements within the 3-month episode window (24% of responses discussed the time commitment as a barrier) (Table 4).

Discussion

Following principles of the Food is Medicine movement, this study of the Grady Food as Medicine program development and delivery is shared here for the purposes of transparency, replicability and transferability, and the enhancement of public health impact by integrating resources to alleviate social determinants of health directly within a health system. During the first 2 years of a Food Prescription program, Grady Health System engaged 1,012 patients living with diabetes or hypertension and at-risk for food insecurity, retaining approximately 42.6% of those eligible for future iterations of the program. The significantly greater loss to follow-up among individuals who identified as male warrants further investigation. In a recent study, Sauder and colleagues report similar findings from the Diabetes Prevention Program, in which older men and younger men were significantly less likely to complete one or more sessions than older women and younger women (35). Analyses of trends in home cooking demonstrate that a greater proportion of females report cooking at home. Furthermore, while the percentage of males who report cooking at home has increased overall in recent years, changes vary by educational attainment. Specifically, Taillie reports that the percentage of males with less than a high school education who cook has remained stagnant over the past decade (36). It is possible that documented gender norms surrounding cooking and feeding responsibilities explain the greater loss to follow-up among men, though gendered themes did not emerge from our qualitative investigation. In this vein, sociologists, including Fielding-Singh and Oleschuk propose that nutrition disparities between the sexes may, in part, derive from these gendered norms of "foodwork"—the practices that support and facilitate eating within households (37). As has elsewhere been argued, these structural and societal dimensions must be attended to in the design, implementation, and evaluation of nutrition interventions, including Food is Medicine programs (38). Akin to our findings, qualitative research on similar programs suggests that economic and structural barriers, such as limited income, caregiver responsibilities, and medical concerns associated with disease management may hinder program engagement. In addition to

TABLE 3 Perceived health characteristics at baseline.

	Initial prescription not renewed (*N* = 495)	Initial prescription renewed (*N* = 368)	Overall eligible (*N* = 863)	Test statistic, *P*
In general, how would you describe your health?				1.66, 0.80
Excellent	11 (2.2%)	7 (1.9%)	18 (2.1%)	
Very good	23 (4.6%)	24 (6.5%)	47 (5.4%)	
Good	121 (24.4%)	91 (24.7%)	212 (24.6%)	
Fair	240 (48.5%)	171 (46.5%)	411 (47.6%)	
Poor	89 (18.0%)	65 (17.7%)	154 (17.8%)	
Missing	11 (2.2%)	10 (2.7%)	21 (2.4%)	
How many days did poor mental or physical health prevent you from doing your usual activities?				−1.76, 0.08
Mean (SD)	7.8 (± 11)	9.2 (± 11)	8.4 (± 11)	
Missing	27 (5.5%)	18 (4.9%)	45 (5.2%)	
How many days during the last 30 days was your physical health poor?				−0.61, 0.54
Mean (SD)	11 (± 12)	11 (± 12)	11 (± 12)	
Missing	30 (6.1%)	19 (5.2%)	49 (5.7%)	
How many days during the last 30 days was your mental health poor?				−0.38, 0.70
Mean (SD)	8.4 (± 11)	9.2 (± 11)	8.5 (± 11)	
Missing	31 (6.1%)	18 (4.9%)	50 (5.8%)	

TABLE 4 Summarized barriers to engagement.

Theme	Frequency n (%)	Illustrative quote
Transportation issues	11 (44%)	"Just availability at the times they wanted to do certain things, like the times they wanted to do the cooking classes, I did not have a way to get there."
Caregiver responsibilities	4 (16%)	"I have a disabled daughter and she has been having complications and it was hard for me to participate and take her back and forth from the clinic."
Work hours	1 (4%)	"Because of the simple fact that I had to work."
Physical health challenges	3 (12%)	"I was having [2 chronic health conditions] … I'm talking fatigue that hits you like no other. I'll be shopping and feel like I'm 'bout to pass out. I'm trying to learn everything I can though."

these key findings, program strengths, lessons learned, and additional recommendations for other healthcare systems are highlighted below.

Strengths

The intervention development process strived to build upon effective research-community partnerships, incorporating community organizations working in the local food system sector for several decades and leveraging research expertise through academic partnerships with local universities. These organizations afforded the FAM partnership access to valuable networks and funding, without which this program would not be possible. The BPA alerts within the electronic medical record and nurse-led protocols facilitate easy identification of eligible participants, timely referral, and clinical integration of this program within the health system. Integrating referral in the electronic medical record also enables data sharing across clinical and intervention spaces. Moreover, the Food as Medicine program attempts to address the four major pillars of food insecurity: availability, access, stability, and utilization. While concerted efforts to address issues of availability and access are evident in intervention approaches, the cooking classes work to also improve utilization and patients' ability to re-enroll for up to 1 year aims to improve stability. Furthermore, the Food as Medicine program acts as a vital "one-stop-shop," for healthcare and food. The physical infrastructure and proximity of the Food Prescription Program in relation to the hospital alleviates some barriers to enrollment. FAM also enables patients to visit the Food Prescription Program on the same day as their initial referral, enabling patients to access food immediately. Nevertheless, as is evident in the proportion of people who do not return for a second visit, there remains space for growth regarding engagement and retention.

Lessons learned and future directions

In the future, Grady aims to further develop the Food Prescription Program and the overarching FAM program, with a particular emphasis on improving referrals and alleviating barriers to program participation. Based on our preliminary evaluation, engagement with the program appears to be representative of the patient population at Grady, though a fraction of those eligible enroll

in the FAM program. Further research is needed to understand barriers to engagement across each level of programmatic implementation. In this regard, more work should focus on barriers within the referral system, including variability across healthcare provider and clinical referral practices. Similarly, challenges or resistance to program enrollment among those referred warrants further attention. Among those who enroll in FAM, re-enrollment for additional three-month increments remains low. This begs the critical question: Why do people not remain engaged? And What additional supports can health systems implement to reduce barriers to engagement? Preliminary findings from brief interviews with enrollees suggest that transportation assistance may improve engagement and retention. Critically, program design anticipated that lack of access to transportation would pose a barrier for patients, particularly for bi-weekly food pick-ups. To address this barrier, Grady has piloted two transportation support programs in conjunction with the FAM program: home delivered boxes directly from the Atlanta Community Food Bank and car share rides for FAM participants funded by a health plan partner. In that regard, ongoing research with academic partners seeks to understand the added value of transportation assistance and incentives.

Other healthcare systems interested in developing Food is Medicine partnerships should prioritize the early establishment of cross-sector partnerships spanning nongovernmental and academic organizations with vested interest in the community. Additionally, programs should consider funding sources and funding sustainability. Program costs will vary depending on established partnerships and target patient engagement; at present, funding for Food is Medicine programs may incorporate governmental and private funds. As noted in our limitations section, patient engagement may present unique and contextually dependent challenges to program success. The pre-existence of social determinants of health screening facilitated recruitment for FAM at Grady and may provide a useful scaffold for enrollment in food and nutrition security programming within other healthcare systems. Finally, health systems and advocates alike must work toward a paradigm shift in how food and nutrition are treated and covered. More specifically, by viewing healthy foods, including fruits and vegetables, as fundamental to well-being and preventative care, health systems may promote increased coverage of these programs by insurance payors.

Global perspectives

Though Food is Medicine programs are most prominent in North America, the lessons learned have global relevance. A Food is Medicine program offers insight into how a more holistic approach to food and eating can sustainably improve well-being. The program emphasizes dietary quality in addition to quantity in a manner that seeks to address each of the pillars of food insecurity, including those often unaddressed in other programs, such as utilization and stability. One of the future directions of this program—increasing emphasis on culturally preferred and culturally relevant foods derives from the premise that celebrating foodways is essential for combatting the often-racialized stigmatization of certain foodways and for generating more sustainable dietary change. From the standpoint of sustainability and resilience, it is also important to reference and incorporate produce and cultural foods grown locally, sustainably. Relatedly, programs that adopt more multifaceted approaches, including access to community gardens and arable land, which can foster physical activity and social connection—both shown to reduce rates of mood disorders (39, 40)—can be replicated across many nutrition interventions in many global contexts. With growing concern over the impact of climate change on global food security, the future of resilient communities may depend on these integrated and more localized approaches.

Conclusion/broader impacts

In response to the disproportionate burden of food insecurity affecting the patient population at a large safety-net health system in the Atlanta MSA, Grady collaboratively developed a healthcare-integrated Food as Medicine program to improve food access and patient well-being. This case study details the development, refinement, and initial findings regarding patient engagement. In so doing, it aims to facilitate the replication or transferability of Food as Medicine interventions toward improving food security and human well-being for patients nationwide.

Data availability statement

The datasets presented in this article are not readily available because they include public health information. Requests to access the datasets should be directed to lhmarshburn@gmh.edu.

Ethics statement

The studies involving humans were approved by the Emory University Institutional Review Board; Grady Health Research Oversight Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because this study was deemed quality improvement and program evaluation.

Author contributions

CO: conceptualization, writing-original draft, and analysis. MC: analysis. JG: implementation. LM and KT: project administration. SS and JB-J: resources and supervision. RC: conceptualization, resources, and supervision. All authors contributed to review and editing of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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frontiers | Frontiers in Public Health

TYPE Brief Research Report
PUBLISHED 31 October 2023
DOI 10.3389/fpubh.2023.1286094

OPEN ACCESS

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RECEIVED 30 August 2023
ACCEPTED 13 October 2023
PUBLISHED 31 October 2023

CITATION
Bangham C, Zack RM, Nelson E, Liu X, Codner A, Hicks JM and Greece JA (2023) Assessing the effect of adverse economic events on severity of hunger among food pantry clients.
Front. Public Health 11:1286094.
doi: 10.3389/fpubh.2023.1286094

Assessing the effect of adverse economic events on severity of hunger among food pantry clients

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This study assessed relationship between adverse economic events (AEE) and hunger level (i.e., little to no, moderate, severe). A cross-sectional survey was conducted from June to August 2018 in 10 food pantries with 616 food pantry users. Hunger level was assessed by the Household Hunger Scale. AEE were evaluated over the past 3 months. Participants (60.55%) experienced unexpected or increased medical expenses (17.69%), job loss (13.64%), pay reduction (11.85%), and death of a family member (9.09%). Pay reduction (OR = 1.87, 95% CI: 1.12, 3.14) and increased debt (OR = 2.71, 95% CI: 1.92, 3.84) were associated with moderate hunger; death of a family member (OR = 2.43, 95% CI: 1.21, 4.90), pay reduction (OR = 2.95, 95% CI: 1.24, 7.04), and increased debt (OR = 3.46, 95% CI: 1.98, 6.04) were associated with severe hunger. Awareness of AEE can inform public health programs and policies for people in need of additional resources, which is essential in times of increased economic instability.

KEYWORDS

hunger, food insecurity, adverse economic events, food pantry, economic instability

1. Introduction

Adverse economic events, including job loss, changes in family structure, and poor health can frequently lead to economic instability (1–4). The COVID-19 pandemic has prompted many Americans to experience increased adverse economic events (5, 6) in particular job loss (7), income loss (8), and emotional strain and financial worry (9), which all have the potential to increase risk of food insecurity (6). While national efforts have been underway for some time to alleviate the impact of adverse economic events on well-being, particularly related to housing and food access, a more thorough understanding of the economic risk factors that contribute to food insecurity allows for more targeted policy and program efforts, particularly in times of emergency that require rapid response.

Food insecurity, which is defined as having limited access to adequate food due to a lack of money or other resources (6), is categorized into 4 levels – very low food security ("at times during the year, eating patterns of one or more household members were disrupted and food intake reduced because the household lacked money and other resources for food"), low food security ("households reduced the quality, variety, and desirability of their diets, but the quantity of food intake and normal eating patterns were not substantially" disrupted), marginal food security ("households had problems at times, or anxiety about, accessing adequate food, but the quality, variety, and quantity of their food intake were not substantially reduced"), and high food

security ("households had no problems, or anxiety about, consistently accessing adequate food") (10, 11). Hunger is defined as a physical feeling of discomfort due to lack of food intake (12). While food insecurity and hunger are distinct concepts, they are closely related; some may feel hungry because they took too long to eat their meal, and others cannot fulfil their hunger feeling because they do not have food to eat due to financial constraints (12).

Food assistance programs such as food pantries provide food to help relieve hunger in populations that are in need. This results in allowing people access to resources to be better prepared to address the root causes of food insecurity. In 2020, 10.5% of U.S. households were food insecure and 3.9% experienced very low food security (13). Food insecurity is associated with a higher prevalence of chronic diseases (14–17) and is associated with a lower diet quality in people across the lifespan (18, 19) further contributing to the detrimental effects of food insecurity on long-term health outcomes. Addressing food insecurity through policy efforts and targeted programs could result in reduced costs to the larger health care system (20). There are a number of U.S. federal food assistance programs that target low-income populations (21, 22) and range in coverage from food assistance programs [i.e., Supplemental Nutrition Assistance Program (SNAP), Special Supplemental Nutrition Program for Women, Infants, and Children (WIC)] to child nutrition programs [i.e., School Breakfast Program (SBP), National School Lunch Program (NSLP), Summer Food Service Program (SFSP)] to food distribution programs [i.e., Commodity Supplemental Food Program (CSFP), The Emergency Food Assistance Program (TEFAP)]. While these programs offer huge benefit to populations experiencing food insecurity there is room for improvement and expansion (23), particularly at a time when shifting environmental conditions have impacted the existence and severity of food insecurity for certain populations (24).

Recent research indicates that certain sociodemographic determinants are associated with hunger in food pantry users such as marital status (being single, divorced, or separated): education (having less than high school education); work status (working part-time, unemployed, or retired); and, income (earning less than $1,000 per month) (25). Research is limited, however, on the individual and joint effects of specific types of adverse economic events on the existence and severity of food insecurity and hunger, such as unemployment, increased medical expenses, eviction, and experiencing the death of a family member. As such, this study, resulting from a broader examination of hunger in food pantry clients (25), aimed to understand which aspects of adverse economic events were most strongly associated with hunger among food pantry users in Massachusetts in 2018 and the extent to which these events affected the severity of hunger. In Massachusetts, food insecurity increased by 58% from 19% in 2019 pre-pandemic to 30% in 2020 during the start of the pandemic (26). This marked increase allows an examination of a state that would benefit from broader recommendations.

Although this study occurred pre-pandemic, many of the adverse economic events investigated during this study, occurred with increased frequency during the COVID-19 pandemic. Some adverse economic events, including job loss, increased medical expenses, and eviction, were exacerbated especially for populations already utilizing resources (13), such as those accessing food pantries, but in need of additional supports. The examination of adverse economic events and hunger, particularly in a population already struggling, helps to understand not only these relationships in non-pandemic times, but also allows exploration of effects of changes in economic events during pandemics or other emergency situations such as natural disasters (27) that require prioritization of public health efforts, re-allocation of resources, re-examination of policies, and targeted environmental approaches. Accordingly, the goal of this study was to examine the relationship between adverse economic events and hunger to gain a better understanding of the types of adverse economic events that most affect hunger and in populations already accessing supports but who are in need of more.

2. Methods

2.1. Participants and recruitment

This study, described elsewhere (25), conducted in partnership with The Greater Boston Food Bank (GBFB), recruited food pantry users visiting one of 10 selected food pantries between June 2018 and August 2018 to complete a survey. The 10 food pantries were selected based on high food pantry user volume, which was defined as serving at least 1,000 households per month in 2017. Study participants were required to: (1) be at least 18 years old or older; (2) be mentally and physically capable of completing the entire survey (as evidenced by their acknowledgement and participation in the informed consent process); (3) speak English or Spanish; and (4) be not planning on moving within the next three months. Recruitment occurred at each food pantry on multiple days and times of the week in an effort to capture a more representative sample of clients who visit that food pantry. Of the 1,444 participants that met these criteria on the days of recruitment at the food pantries occurred, 825 (57.1%) agreed to participate: reasons for refusal included lack of time; being in a rush; not speaking English or Spanish; and not understanding the study. The majority of respondents were not first-time food pantry users; they reported visiting a food pantry within the past 30 days (this was not part of the inclusion criteria of the study).

The 15-min survey was administered at the food pantry. Participants chose whether to complete the survey via self-administration on an iPad tablet (34.1%) or interview administration (65.9%) and provided oral informed consent. A majority (79.0%) of surveys were completed in English with 21.0% in Spanish. Participants received a $10 gift card as compensation for their time. This study was approved by Boston University's Institutional Review Board (IRB # H-37567) as an exempt study with oral consent.

2.2. Measures

Hunger level, the outcome, was measured using a modified version of the validated Household Hunger Scale (HHS). This scale has been previously used for hunger monitoring and evaluation (28–31) and was used in this study as a proxy for the more traditional food insecurity assessments. The HHS was chosen for this study given it measures insufficient food quantity, is efficient in the food pantry setting, has been validated for use in a wide variety of cultures, and is appropriate for a population with a high level of food insecurity (25). Given the logistical and time considerations of conducting this study in a fast-paced food pantry setting, the HHS was modified for practical

use in this study limiting the validity of the instrument. The modified HHS is composed of the following questions: (1) "In the past 30 days, how often was there ever no food to eat of any kind in your house because of lack of resources to get food?"; (2) "In the past 30 days, how often did you or any household member go to sleep at night hungry because there was not enough food?"; and (3) "In the past 30 days, how often did you or any household member go a whole day and night without eating anything at all because there was not enough food?." Question response options include never (0 times), rarely (1–2 times), sometimes (3–10 times), and often (10+ times). Response options of "sometimes" and "often" were scored with 2, "rarely" was scored with 1, and "never" was scored 0 for each question (28–31). Per HHS protocol, the scores were then summed (range score 0 to 6) to create a hunger indicator score that was then categorized into ordinal and binary hunger variables. Ordinal hunger was defined as: little to no hunger (score = 0,1); moderate hunger (score = 2–3); and, severe hunger (score = 4–6). The binary hunger variable was defined as presence of moderate or severe hunger (score ≥ 2).

The exposure, adverse economic events (5), was evaluated by asking participants to select from a list the adverse economic event they or members of their household had experienced in the past 3 months. Participants could select all that apply from the following 10 options (variable labels in tables are provided in parentheses): (1) experienced significant (as determined subjectively by the respondent) out-of-pocket medical expenses (medical expenses); (2) lost a job (job loss); (3) had work hours and/or pay reduced (pay reduction); (4) were divorced (divorce); (5) received a foreclosure or eviction notice (eviction); (6) experienced the death of primary breadwinner or other family member (death of family member); (7) had loan repayment or interest/late fees from loans (debt); (8) had home repairs and increased cost of utilities (home-related expenses); (9) incurred legal expenses (legal expenses); and (10) other with a write-in option. Written responses for "other" were coded and recategorized into existing or new hardship categories (Table 1). Adverse economic events were quantified in three ways: (1) a binary variable defined as experience of any adverse economic events (i.e., at least one event reported); (2) an ordinal variable defined as total number of adverse economic events experienced (range of 0 to 6 with subsequent categories of none, 1 event, or 2 or more events); and (3) 10 binary variables defined as experience of each specific adverse economic events.

Data collected on covariates included self-report of participant's age, gender, educational attainment, race/ethnicity, marital status, occupational status, monthly household income, household size, and household composition [i.e., presence of children (<18 years old) or seniors (≥65 years old) in the household].

2.3. Data analysis

Participant characteristics were described overall and by hunger category with frequencies and percentages; Pearson's chi-square test of independence were used to test for differences in characteristics by hunger category. Mixed effects models were employed because demographics of pantry users differed greatly by food pantry site, specifically by educational attainment level, race, and age. These models adjusted for food pantry site as a random effect while all other covariates were controlled for as fixed effects (25). Multivariable mixed effects models were used to estimate associations between economic instability and hunger category. Separate models were run defining the exposure in slightly different ways: experience with; number; and type of adverse economic events. These models all controlled for food pantry site as a random effect and all other covariates as fixed effects and in accordance with the approaches previously described (25). Analyses confirmed that missing data occurred at random. Analyses were performed using SAS® (SAS® version 9.4, SAS Institute Inc., Cary, NC, United States, 2013) with level of significance at 0.05.

3. Results

3.1. Participant characteristics

Of the 616 participants, the majority were female (72.6%), aged 50 years or older (60.6%), did not have children (57.5%) or seniors (70%) in their household, were non-Hispanic Black (26.5%) or Hispanic (28.3%), had high school or some college education (60.1%), were unmarried (63.2%), lived in a household with 2 or more people (71.1%), did not work full-time (84.8%), and in households that earned less than $1,500 per month (72.4%) (Table 2). Hunger level, assessed by responses to the modified HHS for this study, differed by age, educational attainment, race/ethnicity, household size, marital status, seniors, number of children in the household, household income, occupation, and food pantry site but did not change by pantry user status (new or existing) (25). Over half of participants had experienced an adverse economic event in the past 3 months (60.6%) with nearly one-quarter (23.4%) experiencing 2 or more instabilities. The most common adverse economic events were unexpected or increase in medical expenses (17.7%), job loss (13.7%), and reduction in pay (11.9%). Adverse economic events were more common in those with higher levels of hunger (51.8%) in participants with little to no hunger, 65.3% in participants with moderate hunger, 82.6% in participants with severe hunger.

3.2. Multivariable mixed effect models

The results of multivariable mixed effect models examining the effect of adverse economic events on hunger level, adjusted for the food pantry attended, marital status, education status, age categories, income categories, seniors in the household, children in the household, race/ethnicity, occupation, and household size are shown in Table 1. Experience and number of adverse economic events were associated with higher odds of both moderate and severe hunger with severe hunger having higher odds than moderate hunger. Experience of any adverse economic event, compared to none, was associated with higher odds of moderate hunger (OR = 2.03, 95% CI: 1.07, 3.85) and severe hunger (OR = 5.39, 95% CI: 2.78, 10.48). Food pantry users that had 2 or more adverse economic events had higher odds of moderate hunger and severe hunger compared to having no adverse economic events (OR = 2.09, 95% CI: 1.11, 3.92 and OR = 4.16, 95% CI: 2.39, 7.26, respectively).

Reduction in pay and experiencing an increase in debt were both significantly associated with higher odds of moderate and severe hunger (reduction in pay – OR = 1.87, 95% CI: 1.11, 3.14 and OR = 2.95, 95% CI: 1.24, 7.04, respectively and debt – OR = 2.71, 95%

TABLE 1 Hunger Category by adverse economic event adjusted for food pantry and covariates, food pantry users in 10 food pantries in eastern Massachusetts, June 2018 – August 2018, $n = 616$.

	Moderate hunger[a], $n = 124$		Severe hunger[a], $n = 121$	
	Odds ratio (95% CI)	p-value[b]	Odds ratio (95% CI)	p-value[b]
Experience of adverse economic event[c]				
No	Ref		Ref	
Yes	2.03 (1.07, 3.85)	0.03	5.39 (2.78, 10.48)	<0.0001
Number of adverse economic events[d]				
0	Ref		Ref	
1	1.20 (0.83, 1.74)	0.33	0.74 (0.52, 1.06)	0.10
2+	2.09 (1.11, 3.92)	0.02	4.16 (2.39, 7.26)	<0.0001
Type of adverse economic events[e]				
Death of a family member	1.59 (0.75, 3.37)	0.23	2.43 (1.21, 4.90)	0.01
Divorce	1.31 (0.61, 2.83)	0.49	0.38 (0.02, 8.75)	0.55
Pay reduction	1.87 (1.12, 3.14)	0.02	2.95 (1.24, 7.04)	0.01
Legal expenses	0.21 (0.03, 1.67)	0.14	1.28 (0.66, 2.49)	0.46
Debt	2.71 (1.92, 3.84)	<0.0001	3.46 (1.98, 6.04)	<0.0001
Job loss	1.34 (0.80, 2.25)	0.26	1.77 (0.83, 3.79)	0.14
Home-related expenses	1.01 (0.34, 2.98)	0.9863	1.77 (0.60, 5.26)	0.3020
Eviction	4.19 (0.95, 18.50)	0.0587	4.19 (0.78, 22.51)	0.0947
Medical expenses	1.48 (0.75, 2.91)	0.2529	1.84 (0.84, 4.00)	0.1252
Other	1.56 (1.07, 2.27)	0.0218	1.64 (0.99, 2.72)	0.0541

[a]Hunger categories were defined as little to no hunger in the household (HHS score = 0–1), moderate hunger in the household (HHS score = 2–3), and severe hunger in the household (HHS 4–6) according to the HHS score. Both groups are compared to the no/little hunger group.
[b]Analyses were conducted using mixed effects modeling. The covariates included in the mixed-effects model are marital status, education status, age categories, income categories, seniors in the household, children in the household, race/ethnicity, occupation, and household size.
[c]Economic hardship was defined as experiencing at least one of the listed hardships in the past three months: medical expenses, job loss, reduced pay/h, divorce, home-related expenses, foreclosure/eviction notice, death of a family member or breadwinner, debt, legal expenses, or other hardship.
[d]Number of adverse economic events was determined based on the number selected by each participant.
[e]Types of adverse economic events were coded as separate variables.

CI: 1.92, 3.84 and OR = 3.46, 95% CI: 1.98, 6.04, respectively), with severe hunger having higher odds than moderate hunger for both types of instabilities. Death of a family member was associated with higher odds of severe hunger (OR = 2.44, 95% CI: 1.21, 4.90).

4. Discussion

This study documents that among food pantry users, experience with and number of certain adverse economic events resulted in increased odds of both moderate and severe hunger. In particular, experience with debt, reduction in pay, and eviction were significantly associated with moderate and severe hunger. Death of a family member was also significantly associated with severe hunger. Food pantry users that experienced two or more adverse economic events compared to no adverse economic events had significantly higher odds for moderate and severe hunger suggesting that compounded adverse economic events results in increased vulnerability to hunger. The most common economic household instabilities across all hunger categories (low, moderate, and severe) were unexpected or increased medical expenses, job loss, and reduction in pay in the past 3 months.

The findings of this study are consistent with the literature that shows adverse economic events impact food insecurity (32–34). Measures are in place, such as government assistance programs and economic relief payments, to address specific adverse economic events (6, 33, 35) and even with additional support during the pandemic, food insecurity and adverse economic events persist (6). The American Rescue Plan was enacted in March 2021 to address the hardships faced by many Americans as a result of the pandemic, which resulted in a 5% decline in the number of adults in the U.S. who reported not having enough to eat in the past 7 days in August 2021 (6). As these benefits expired, so did the relief Americans experienced (6) even though the economic instabilities or the impacts of them remain for many.

While this data was collected prior to the pandemic, adverse economic events highlighted in the findings of this study, have been exacerbated during the pandemic (13). For example, the unemployment rate in the U.S. increased from 4.4% in 2019 to 14.7% in April of 2020, during the height of the pandemic (36). While some lost work due to the economic repercussions of the pandemic, work status was directly impacted by the pandemic for some who contracted the virus; contracting the virus meant they were often unable to work. Those who suffered from job and income loss due to the pandemic had a harder time affording food for their households (7). In addition, loss of a family member also resulted in extra hardship. People who lost a household member due to COVID-19 may have lost a primary source of income, which led to further adverse economic events and impacted food security (37) including for children who are at

10.3389/fpubh.2023.1286094

TABLE 2 Hunger study participant characteristics by hunger level, food pantry users in 10 food pantries in eastern Massachusetts, June 2018 – August 2018, *n* = 616.

Variable	Overall (*N* = 616) *n* (%)	Little to no Hunger[a] (*N* = 371) *n* (%)	Moderate Hunger[a] (*N* = 124) *n* (%)	Severe Hunger[a] (*N* = 121) *n* (%)	*p*-value[b]
Age, years[c]					
18 – < 30	50 (8.12%)	19 (5.12%)	14 (11.29%)	17 (14.05%)	0.0018
30 – < 40	88 (14.29%)	53 (14.29%)	18 (14.52%)	17 (14.05%)	
40 – < 50	105 (17.05%)	58 (15.63%)	22 (17.74%)	25 (20.66%)	
50 – < 60	178 (28.90%)	100 (26.95%)	38 (30.65%)	40 (33.06%)	
60 – < 65	70 (11.36%)	47 (12.67%)	14 (11.29%)	9 (7.44%)	
≥ 65	125 (20.29%)	94 (25.34%)	18 (14.52%)	13 (10.74%)	
Sex					
Female	447 (72.56%)	268 (72.24%)	99 (79.84%)	80 (66.12%)	0.0538
Male	169 (27.44%)	103 (27.76%)	25 (20.16%)	41 (33.88%)	
Educational attainment					
Less than high school	153 (24.84%)	85 (22.91%)	38 (30.65%)	30 (24.79%)	0.0325
High school or some college	370 (60.06%)	217 (58.49%)	74 (59.68%)	79 (65.29%)	
College graduate (4 years) or more	93 (15.10%)	70 (18.60%)	12 (9.68%)	12 (9.92%)	
Race/ethnicity					
Non-Hispanic White	230 (37.34%)	156 (42.05%)	36 (29.03%)	35 (28.93%)	0.0707
Non-Hispanic Black	163 (26.46%)	90 (24.26%)	38 (30.65%)	42 (34.71%)	
Non-Hispanic other	49 (7.95%)	23 (6.20%)	12 (9.68%)	27 (22.31%)	
Hispanic	174 (28.25%)	102 (27.49%)	38 (30.65%)	17 (14.05%)	
Household size[d]					
0–1 people	178 (28.90%)	117 (31.54%)	26 (20.97%)	35 (28.93%)	0.0398
2–3 people	235 (38.15%)	147 (39.62%)	46 (36.10%)	42 (34.71%)	
4–5 people	145 (23.54%)	79 (21.29%)	39 (31.45%)	27 (22.31%)	
≥ 5 people	58 (9.42%)	28 (7.55%)	13 (10.48%)	17 (14.05%)	
Marital status					
Single, never married	219 (35.55%)	110 (29.65%)	52 (41.94%)	57 (47.11%)	0.0018
Married, living with partner	227 (36.85%)	142 (38.27%)	45 (36.29%)	40 (33.06%)	
Separated, divorced, or widowed	170 (27.60%)	119 (32.08%)	27 (21.77%)	24(19.83%)	
Senior (≥ 65 years old) in household[e]	185 (30.03%)	127 (34.23%)	343(27.61%)	25 (20.66%)	0.0133
Child (<18 years old) in household[e]	262 (42.53%)	147 (39.30%)	66 (52.80%)	52 (42.98%)	0.0338
Monthly income[f]					
Less than $500	112 (18.18%)	61 (16.44%)	24 (19.35%)	27 (22.31%)	0.0067
$500 to $999	183 (29.71%)	93 (25.07%)	49 (39.52%)	41 (33.88%)	
$1,000 to $1499	151 (24.51%)	98 (26.15%)	24 (19.35%)	30 (24.79%)	
$1500 to $1999	89 (14.45%)	58 (15.63%)	16 (12.90%)	15 (12.40%)	
$2000 or more	81 (13.15%)	62 (16.71%)	11 (8.87%)	8 (6.61%)	
Occupation					
Disabled	152 (24.68%)	84 (22.64%)	31 (25.00%)	37 (30.58%)	0.0218
Homemaker	50 (8.12%)	33 (8.89%)	11 (8.87%)	6 (4.96%)	
Other	9 (1.46%)	4 (1.08%)	3 (2.42%)	2 (1.65%)	
Retired	94 (15.26%)	71 (19.14%)	15 (12.10%)	8 (6.61%)	
Unemployed	96 (15.58%)	52 (14.02%)	21 (16.94%)	23 (19.01%)	
Working full time (> = 35 h/week)	94 (15.26%)	63 (16.98%)	12 (9.68%)	19 (15.70%)	
Working part time (<35 h/week)	121 (19.64%)	64 (17.25%)	31 (25.00%)	26 (21.49%)	

(Continued)

10.3389/fpubh.2023.1286094

TABLE 2 (Continued)

Variable	Overall (*N* = 616) *n* (%)	Little to no Hunger[a] (*N* = 371) *n* (%)	Moderate Hunger[a] (*N* = 124) *n* (%)	Severe Hunger[a] (*N* = 121) *n* (%)	*p*-value[b]
Food pantry site					
Pantry 1	126 (20.45%)	69 (18.60%)	24 (19.35%)	33 (27.27%)	0.0337
Pantry 2	21 (3.41%)	15 (4.04%)	4 (3.23%)	2 (1.65%)	
Pantry 3	25 (4.06%)	13 (3.50%)	7 (5.65%)	5 (4.13%)	
Pantry 4	98 (15.91%)	55 (14.82%)	23 (18.55%)	20 (16.53%)	
Pantry 5	18 (2.92%)	8 (2.16%)	5 (4.03%)	5 (4.13%)	
Pantry 6	18 (2.92%)	11 (2.96%)	6 (4.84%)	1 (0.83%)	
Pantry 7	38 (6.17%)	18 (4.85%)	10 (8.06%)	10 (8.26%)	
Pantry 8	215 (34.90%)	151 (40.70%)	30 (24.19%)	34 (28.10%)	
Pantry 9	51 (8.28%)	30 (8.09%)	13 (10.48%)	8 (6.61%)	
Pantry 10	6 (0.97%)	1 (0.27%)	2 (1.61%)	3 (2.48%)	
Experience of adverse economic events[g]					
Yes	373 (60.55%)	192 (51.75%)	81 (65.32%)	100 (82.64%)	<0.0001
No	243 (39.45%)	179 (48.25%)	43 (34.68%)	21 (17.36%)	
Number of adverse economic events					
0	264 (42.84%)	188 (50.67%)	50 (40.32%)	26 (21.49%)	<0.0001
1	208 (33.77%)	110 (29.65%)	44 (35.48%)	54 (44.63%)	
2 or more	144 (23.38%)	73 (19.68%)	30 (24.19%)	41 (33.88%)	
Type of adverse economic event[h,i]					
Death of family member	56 (9.09%)	24 (6.47%)	13 (10.48%)	19 (15.70%)	
Divorce	11 (1.79%)	7 (1.89%)	3 (2.42%)	1 (0.83%)	
Pay reduction	73 (11.85%)	32 (8.63%)	17 (13.71%)	24 (19.83%)	
Legal expenses	26 (4.22%)	17 (4.58%)	2 (1.61%)	7 (5.79%)	
Debt	61 (9.90%)	27 (7.28%)	16 (12.90%)	18 (14.88%)	
Job Loss	84 (13.64%)	40 (10.78%)	19 (15.32%)	25 (20.66%)	
Home-related expenses	28 (4.55%)	17 (4.58%)	4 (3.23%)	7 (5.79%)	
Eviction	31 (5.03%)	8 (2.16%)	10 (8.06%)	13 (10.74%)	
Medical expenses	109 (17.69%)	62 (16.71%)	21 (17.94%)	26 (21.49%)	
Other	117 (18.99%)	66 (17.79%)	26 (20.97%)	25 (20.66%)	

[a]Hunger categories were defined as little to no hunger in the household (HHS score = 0–1), moderate hunger in the household (HHS score = 2–3), and severe hunger in the household (HHS 4–6) according to the HHS score.
[b]Analyses were conducted using frequencies and Pearson's chi-square statistical test significance = 0.05.
[c]Age categories were created based on pre-established age definitions from the US Census.
[d]Household size categories were created based on the open-ended responses of number of people in household.
[e]Household composition for both children and seniors in the household were defined as at least one or more in the household.
[f]Income categories were created based on open-ended responses for annual/monthly income.
[g]Adverse Economic Events was defined as experiencing at least one of the listed events in the past three months: medical expenses, job loss, reduced pay/h, divorce, home-related expenses, foreclosure/eviction notice, death of a family member or breadwinner, debt, legal expenses, or another event.
[h]This was a select more than one adverse economic event and therefore the probability may exceed 100%.
[i]Types of adverse economic events were coded as separate variables and therefore no tests of statistical significance are conducted on this overall variable but are conducted in later tables.

significantly greater risk for food insecurity and Adverse Childhood Experiences (37) when living in households with lower incomes than in households with higher income (38).

Given the associations found in this study and in particular the types and amount of adverse economic events that are associated with hunger, we can expect that the increased prevalence of adverse economic events experienced during the pandemic can lead to substantial increases in hunger and food insecurity, particularly in populations already accessing services and supports for hunger such as food pantry clients. This is important in considering efforts to address hunger and food insecurity in populations already at-risk and specifically during times that increase disadvantageous conditions for these populations such as during a pandemic, natural disasters, and other emergency situations (27).

There have been efforts to address adverse economic events throughout and since the pandemic. For example, the number of adult renters who reported that they were not caught up on rent declined after the disbursement of emergency aid funded via the December 2020 relief package and American Rescue Plan, however many adult renters still faced challenges in paying rent due to accumulated debt

from job disruption and late fees associated with inability to pay rent for multiple months (6). Specifically, people of color and households with children reported higher rates of rent hardship (i.e., not being caught up on rent, throughout 2020 and 2021) (6).

Job loss and unemployment skyrocketed during the pandemic to rates not previously seen since the Great Depression, with job losses concentrated in the lowest paying industries (3). Our findings indicate that, among food pantry users, job loss significantly increased the odds of being severely hungry even before the repercussions of the pandemic. During the pandemic, the country responded by funding new or expanding existing programs to reduce the financial burden to families and address hunger. For example, the Pandemic-Electronic Benefit Transfer (P-EBT) program provided funding for states to allocate resources directly to households with children who lost access to school meal programs during COVID-19 in an effort to reduce child food insecurity (39, 40). While these types of supports emerged due to the pandemic, this research indicates the necessity of continuation of them given associations that existed even before the pandemic.

Increasing the accessibility of and eligibility for long-standing federal nutrition assistance programs, such as SNAP, can also help mitigate potential hunger impacts of adverse economic events. States often have flexibility in how they implement federal programs, which can allow for increased accessibility and flexibility of federal nutrition assistance programs. For example, USDA regulations include asset limits for SNAP, which means that a low-income household might not be eligible for SNAP due to having assets. One method in which states can increase SNAP eligibility is through removing asset limits through a policy called broad-based eligibility (41). Additional states could remove asset limits to increase SNAP availability for low-income households who may have a small amount of assets, but still be only one adverse economic event away from experiencing hunger.

While prior to and during the pandemic safety net programs and policies existed to alleviate food insecurity, in order to continually address adverse economic events and hunger, multiple interventions are needed to address the issue of food insecurity particularly on those who have faced, and continue to face these challenges (40). While our study did not find an association between home expenses and food insecurity, there was an association between factors (i.e., increased debt, reduction in pay, and eviction) that could affect someone's ability to retain their housing. Research has shown that some government programs to address adverse economic events have reduced food insecurity during the pandemic (42). For example, the expanded Child Tax Credits, beginning in July of 2021, reduced household food insufficiency by 26% (42). However, this was a temporary solution. Community Information Exchanges (CIE), which compile information for many community organizations that address different, but interconnected, needs have also shown to be successful in addressing specific social determinants that impact food insecurity, housing instability, and other adverse economic events (32). Accordingly, efforts should focus on populations that use food assistance and who have compounded hardship due to experience of these adverse economic events.

A strength of this study was the ability to assess the population on hunger status using the modified Household Hunger Scale (HHS), which allowed for the ability to efficiently quantify hunger levels of food pantry clients from a wide variety of cultures (28–31) though also had some limitations as described below. The large sample size of food pantry users speaking English or Spanish from 10 food pantries allowed for examination of a population already accessing services to address hunger pre-pandemic. Participants in the study experienced a number of adverse economic events allowing for an in-depth analysis of the type and cumulative number of instabilities experienced. This study was conducted before the pandemic, which helps to see the existing associations between hunger and hardship absent before an event that caused exacerbated economic stressors.

Despite the strengths of this study, limitations should be considered. First, this study was conducted in eastern Massachusetts, which is a narrow geographic area, so the results are not necessarily representative of the U.S. population. The findings, however, can inform approaches for food pantry clients who would benefit from enhanced resources. Second, there may be differential misclassification as individuals who were more likely to report adverse economic events may have also been more likely to report experiencing hunger. Third, the sample represents the food pantry clients who were present at the pantry on the day of recruitment and may not represent all pantry clients at that particular food pantry, although, we recruited at the food pantries on multiple days and times of each week. Fourth, the scale used to assess hunger is a 3-item modification of a validated 6-item scale and was used to feasibly administer a survey in a fast-paced food pantry setting to encourage greater participation and response. While not ideal we were able to obtain high participation that would have otherwise been difficult with a longer survey. Still, results should be interpreted with caution given this scale was modified and was not validated and social desirability is likely to have influenced responses. Other researchers conducting similar research should consider this against the logistical constraints of a longer but validated survey in dynamic research settings. Finally, we were unable to control for other factors that may impact adverse economic events and hunger such as housing situation (i.e., temporary versus permanent) and homelessness.

Findings from this study can inform considerations for expansion and sustainability of efforts to address food insecurity, particularly those enacted during the pandemic. Adverse economic events such as debt, reduction in pay, eviction, increased medical expenses, job loss, and death of a family member were exacerbated during the pandemic with an increase in government assistance to address them. As public health considers areas for intervention in policy development and program expansion for populations facing hunger and food insecurity, these data support consideration of the types and quantity of adverse economic events most affecting populations already in need of resources to ensure the root causes of hunger are addressed by ongoing, sustained efforts and appropriate allocation of resources and prioritization of planning. Further investigation of the impact of adverse economic events on use of food assistance programs (e.g., food pantries, SNAP), mental health disorders, and other adverse health outcomes could be beneficial to understanding the full cost of the economic repercussions of the pandemic. Additionally, future research to understand whether adverse economic events disproportionately increase hunger among certain demographic groups (e.g., race/ethnicity, immigration status, gender, households with children, seniors, etc.) is important when ensuring that programs and policies designed to address adverse economic events work to diminish, rather than increase, inequities (43).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Boston University's Institutional Review Board (IRB #H-37567) as an exempt study with oral consent. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because oral informed consent was obtained per IRB guidance.

Author contributions

CB: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. RZ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing. EN: Writing – original draft, Writing – review & editing. XL: Data curation, Formal analysis, Methodology, Writing – review & editing. AC: Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. JH: Conceptualization, Formal analysis, Methodology, Resources, Supervision, Writing – review & editing. JG: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers | Frontiers in Nutrition

TYPE Perspective
PUBLISHED 16 November 2023
DOI 10.3389/fnut.2023.1297214

OPEN ACCESS

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RECEIVED 20 September 2023
ACCEPTED 02 November 2023
PUBLISHED 16 November 2023

CITATION
Dietz WH and Fanzo J (2023) Mitigation of the U.S. agrifood sector's contribution to human and planetary health: a case study.
Front. Nutr. 10:1297214.
doi: 10.3389/fnut.2023.1297214

Mitigation of the U.S. agrifood sector's contribution to human and planetary health: a case study

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The relationship of the United States (U.S.) agrifood sector to climate change is bidirectional; cattle production for beef consumption generates methane and nitrous oxide, both of which are potent greenhouse gases (GHGs). These gases contribute to global warming which in turn increase the frequency and strength of adverse catastrophic events, which compromise the food supply. Increased GHGs also affect crop yields and the micronutrient content of crops, which adversely affect the prevalence of food and nutrition insecurity, particularly in low- and middle-income countries. Because the U.S. is a major contributor to global warming, we have a special responsibility to reduce our contribution to the generation of GHGs. The dilemma is that beef is a highly nutritious and desirable food, with excess consumption in the U.S. and under consumption in other parts of the world, but a desirable source of nutrients in low- and middle-income countries (LMICs). Reductions in fossil fuels have been a major focus of concern, and the agrifood system has been largely ignored. Policy changes to reduce beef consumption have been resisted at the highest levels of government. Furthermore, shifts to more plant-based diets have been contentious. Successful reductions in beef consumption will require individual, institutional, municipal, and state initiatives. Building the political will for change will require a compelling communication campaign that emphasizes the unsustainable contribution of beef consumption to climate change and land and water use.

KEYWORDS

climate change, agrifood, beef, political will, policy, communication

The food system and climate change

Climate change and climate-related extreme weather events (droughts, floods, fires, heat, and cold snap spells) adversely impact a whole host of societal systems and the lives that humans are used to (1). Food systems, in particular, are increasingly vulnerable to the effects of climate change. The natural resources – soils, water, biodiversity – and ecosystems essential to producing a wide range of food commodities are threatened or in decline. Extreme weather events have immediate and sometimes devastating consequences on the ability to farm and for farmers and laborers to cultivate food. Longer-term implications of a warmer planet could devastate the ability to grow key crop commodities in the southern latitudes (2). With more carbon dioxide (the main greenhouse gas emitted) in the atmosphere, some micronutrient content of C4 crops will decrease (3). Models suggest that climate change could also spur a phenomenon known as multiple breadbasket failures – in which extreme events could happen simultaneously worldwide, devastating large-scale breadbasket countries meant to feed large swaths of the global population (4).

At the same time, how we manage and govern food systems profoundly impacts the acceleration of climate change and natural resource degradation. In their totality, global food systems generate approximately 30% of total greenhouse gas emissions, much of which comes from the agricultural production of certain commodities with significant environmental footprints (5). While there is disagreement on how much other parts of the food supply chain, such as transport, packaging, and storage, contribute to that total greenhouse gas emission accumulation, it is clear that production and the consumption of foods derived from ruminants (mainly beef and lamb) are significant contributors to global warming (6, 7) with significant variations in those emissions depending on how those foods were grown. Food systems are also heavily dependent on fossil fuels. Producing, trading, moving, and selling food requires significant energy use – from fertilizers to transport to cold chain storage.

While there is a range of foods, including plant-based foods, that have variable environmental footprints across water and land use and greenhouse gas emissions, depending on where they grow, how they are grown and processed, and the practices taken by producers, some groups of foods are more intensive on natural resources and emit more greenhouse gases (8). Cattle production for meat and dairy is the largest emitter of greenhouse gases from the agrifood sector, particularly methane (9). Methane is one of three major greenhouse gases and is one of the most toxic because it traps more heat in the atmosphere than carbon dioxide. In comparing animal source foods, 1 kg of beef from cows generates 99.48 kilograms of carbon dioxide equivalent (kg CO2eq) as compared to 10 kg CO2eq for 1 kg of chicken. Also, 1 kg of soybeans, a high-protein plant-based food, generates 0.8 kg CO2eq.

Those who consume an omnivorous diet have a much higher greenhouse gas footprint than those who consume a plant-rich Mediterranean, vegetarian, or vegan dietary pattern (10). For the world's agriculture system to produce such a diet, the cattle sector alone would need to contract by 60% (10). The use of the land would also need to be altered significantly. Examining more broadly the use of global land, 40% of the earth's land is arable, and 77% of that land is used to raise a broad range of animals and the crops to feed them. The remaining 23% of land is used to grow plants. However, animals only generate 18% of the global calories for energy and 37% of calories for protein needs (11). Plants make up the rest. When examining the U.S., cattle (beef) production requires 28 times more land and 11 times more irrigated water compared to poultry, pork and eggs (12). These statistics emphasize that the current use of land and other natural resources is not the most efficient way to grow food for a growing population with significant variations in their environmental intensity depending on the livestock system. Instead, there is significant extensification into biodiversity hotspots.

It is not only the greenhouse gases that are an enormous challenge for the livestock sector. Raising cattle is also a major driver of tropical deforestation (13). This is an issue not only because of the profound and irreversible loss of biodiversity found in forestscapes but also because trees act as a mitigation strategy due to their functionality as carbon sinks (14). Biodiverse-rich sub- and tropical forests such as the Amazon have seen significant deforestation due to agriculture extensification largely due to livestock (and soy).

However, the demand for animal source foods is growing in many parts of the world with income growth. In China, the demand for pork increased from 10 kg per person in 1980 to 45 kg per person in 2022 (15). Brazil and some African countries, such as Ethiopia, are trying to meet that demand by growing their livestock sector. While low- and middle-income countries' demands are dynamic, there are a set of high-income countries that still consume more meat than is necessary to meet basic nutrient needs, such as the United States, Australia, Brazil, and Argentina, as some examples.

The need and challenge of reducing beef consumption to mitigate climate change in the U.S.

Because the US is second only to China in the generation of GHGs, and is fourth *per capita* in GHG generation, we bear a moral obligation to lead the way in terms of reducing GHGs. The agrifood sector, with a particular focus on beef consumption, represents one of the most important but neglected target to mitigate climate change. The US agrifood sector generates 10% of GHGs in the U.S. and a total of 85% of those GHGs are generated by cattle production. Cattle produce methane (CH_2) by enteric digestion of fodder; the overwhelming amount of methane comes from cattle, and almost 75% of that methane comes from beef cattle; the remainder comes from dairy cattle (16). Methane is approximately 80 times more powerful than CO_2 but has a relatively short atmospheric half-life. An additional source of GHG production related to cattle production comes from the fertilizer used to grow the fodder consumed by cattle. Fertilizer that is not used by plants is converted to nitrous oxide (N_2O), a GHG that is 265 times more powerful than CO_2, and has a long atmospheric half-life. In terms of their contribution to GHGs, nitrous oxide emissions are roughly equivalent to methane emissions (16).

Meat production and consumption go hand in hand with human and planetary health on an acute and chronic basis. Increased GHGs contribute to catastrophic weather events that immediately affect the food supply. On a longer term basis, increased GHGs reduce crop yields. Together with decreased crop yields, the decreased micronutrient of food causes food and nutrition insecurity, and increased beef consumption contributes to cardiovascular disease, colon cancer, diabetes, and obesity (17–19). Together, these interactions contribute to the global syndemic, but also point to the possibility of triple duty solutions that promote human and planetary health.

A recent study examined the environmental and health impact of four dietary indices based on the alternative healthy eating index 2010 (HEI-2010) (18). Higher (healthier) AHEI-2010 scores were associated with a decreased risk of cardiovascular disease (CVD) and a lower environmental impact. Red and processed meat was the biggest factor affecting both the AHEI score and more adverse environmental impacts. Beef consumption also was the biggest contributor to GHGs, cropland use (59%), irrigation water (26%) and fertilizer (8.5%) (18). As shown in the Table 1, as beef consumption decreases and consumption of more plant-based diets increases, GHGs, land and water use, and biodiversity improve (20). Even a modest 10% decrease in beef consumption will have positive effects (21).

The challenge is how to reduce meat intake. In the U.S., Men consume more beef/capita than women (86 vs. 48 lbs./capita/y), and ground beef (burgers) constitutes 42% of beef consumed (22). Consumption has somewhat decreased recently, but the sex dichotomy

TABLE 1 Environmental impact of dietary choices.

Group	CH_4 Kg/d	N_2O Kg/d	Land use m^2/d	H_2O use m^3/d
Vegans	4.4	0.7	4.4	0.4
Vegetarians	20.	1.0	6.0	0.5
Low meat-eaters (28g/d)	29.0	1.3	8.3	0.7
Medium meat eaters (50–99 g/d)	40.8	1.7	11.3	0.8
High meat eaters (140g/d)	65.4	2.6	16.8	0.9

Decreased meat consumption and increased plant-based diets are associated with reduced GHG emissions, and land and water use. Adapted from Scarborough et al. (20).

has persisted. Twenty eight percent of ground beef is consumed at restaurants, and most of the restaurants are likely fast food restaurants.

Despite the beneficial effects of reducing beef consumption, its importance as a target for mitigating climate change has largely been ignored. For example, the 2022 Policy Brief for the United States of America – Lancet Countdown on Health and Climate Change (23) failed to acknowledge the importance of the agrifood system and offered no strategies to reduce beef production. Furthermore, the role of beef production has received only limited attention from mainstream media. In a survey of 1,000 articles related to the causes of climate change in ten major media sources, such as the Wall Street Journal or the New York Times, animal agriculture was cited in only 7% of articles as a contributor to climate change (24). Therefore, it is not a surprise that only 3% of US consumers rank industrial meat compared to 21% of US consumers that rank fossil fuels as the major contributor.

Federal responses to efforts to reduce beef consumption in the U.S.

The U.S. Dietary Guidelines for Americans (DGAs) provide the most comprehensive nutritional recommendations for federal programs and the general public. However, efforts to address beef consumption in the context of sustainability have met resistance at the highest levels of government. The most egregious example occurred in response to the recommendations of the 2015–2020 DGA Advisory Committee. One of their recommendations was that sustainability, which clearly included reductions in beef consumption, be considered in the DGAs (25). In response, the meat industry conducted a vigorous and successful lobbying effort that prompted the Secretaries of Health and Human Services and the Department of Agriculture to announce that sustainability would not be included as a DGA criterion (26). That stance has continued with the 2020–2025 DGAs.

The response of the Trump administration to the closure of meat packing plants during the COVID-19 pandemic provides another example of the power and politicization of the beef industry. In response to packing plant closures, President Trump declared that packing plants for beef and poultry were "critical infrastructure" (27) and issued an Executive Order declaring that operations in these packing plants continue, despite the high rates of Covid-19 infections and deaths among meat packing workers (28, 29). In effect, disruptions of the beef supply chain were considered a national emergency.

The absence of policies to reduce beef consumption have not fared much better under the Biden-Harris administration. In 2022, the report of the White House Conference on Hunger Nutrition and Health made only one reference to climate change, and that focused on research rather than actionable strategies to increase the consumption of sustainable foods (30).

A number of federal policy initiatives for the reduction of beef consumption have been proposed (31, 32). These include strengthening dietary guidelines, taxes on GHG emissions, removal of agricultural subsidies that maintain low beef prices, and communication campaigns. Federal policy changes in the U.S. are unlikely, given the vocal but influential minority that denies the existence of climate change and refuses to support changes that mitigate it. Suggestions to reduce beef consumption are met with similarly polarized attitudes in the public domain that split along all or nothing lines – either vegan or vegetarian diets versus beef consumers. The latter argue that the adverse effects of beef on health lack scientific evidence, impair individual freedom, and characterize vegans of plotting a near vegan diet for the world's population (31). Resistance to policy changes directed at reducing beef consumption are characterized by highly polarized responses. For example, the "war on meat" has been described as "the devil is a shapeshifter…he takes the form of demonic foods. In response the armies of the righteous have already waged war on sugar, and now red meat is in their sights."

The need for local strategies to build political will in the U.S.

These observations emphasize the need to move from a focus on federal policy to one which builds on individual, institutional, municipal and state policy to generate political will from the ground up. Increased awareness of the adverse effects of beef consumption on human and planetary health can lead to changes at the individual level that extend to family and friends. At the institutional level, procurement policies, like those based on the federal food service guidelines, can be used to reduce the purchases of beef and increase the availability of plant-based options. A default strategy, which made plant-based main dishes the default option in cafeterias effectively changed food choices in university settings (33).

Effective communication efforts will be essential. These efforts should emphasize that the nutritional benefits of beef in the provision of protein, iron, zinc and vitamin B_{12} can readily be achieved at levels of intake below the current excess intakes that are consumed. Significant efforts will be required to identify the most cogent arguments that appeal to men. Communication strategies need to be adequately tested but could include the following (31).

- Focus on reduction, not elimination
- Acknowledge the positive health effects of beef consumption in HICs and LMICs
- Emphasize that beef consumption in North America and Eurasia exceed recommended consumption by 6 and 3 times, respectively (6)
- Present the case that both planetary and human health are adversely affected by beef production and consumption

- Emphasize the effects that reduced beef consumption/production will have on land, water, fertiliser, and GHGs
- Provide compelling examples: GHGs from 1 serving beef = GHGs from 20 servings of vegetables; land that produces 100gm plant protein produces only 4 gm beef protein

Two relevant experimental studies have assessed the impact of messaging on discouraging red meat consumption. An online study compared the impact of messages related to animal welfare, health or the effects of red meat production on climate change with a neutral non-red meat control in a survey of 2,773 non-vegetarian and non-vegan adults. Adults who received the message regarding the effects of red meat consumption on climate change were significantly more likely to indicate that they would reduce their red meat consumption at full service restaurants than those who received the messages about health and animal welfare (34). A second study of college students found that students ranked reduced meat intake as less effective than other measures to address climate change, such as recycling and using less plastic. However, among students who reported that making food choices that were good for the environment, consuming foods that reduced climate impact, or that eating less red meat was an effective way to reduce climate change reported a 10%–25% lower frequency of red meat consumption (35).

The dilemma

Reductions in beef consumption pose a dilemma. In the U.S., beef is a highly desirable and valued food that is over-consumed compared to nutritional requirements (6). Beef is also a rich source of protein, vitamin B12, iron and folic acid lacking in the diets of the global south, making it a valuable source of nutrients. The dilemma is how to reduce beef consumption in the U.S. to reduce climate change and simultaneously increase beef consumption in lower- and middle-income countries without increasing GHG production. One of the unanticipated adverse consequences of reduction in beef consumption in the US is that beef exports could increase without a reduction in production. This possibility emphasizes the need for global efforts to achieve an overall reduction in beef consumption while achieving a redistribution that meets the nutrient needs of LMICs.

Summary

The need to reduce GHGs is urgent. Fifteen percent of fossil fuel use is attributable to the transportation sector, most of which is attributable to car use. The agrifood system generates 10% of GHGs, 85% of which is attributable to the production and consumption of meat. The product of GHGs from fossil fuels is CO_2 which has a half-life of over 100 years, whereas the GHG products of beef production are methane and nitrous oxide. Methane is 80 times more powerful than CO_2 and its half life is approximately 10 years. Therefore, reductions in meat consumption and their consequent effect on meat production promises a much more rapid effect on GHGs. The challenge is how to reduce beef consumption in the U.S. We suggest that federal policy initiatives are unlikely to succeed given the polarization in Congress, and that change needs to start with individuals, their families, social networks, and institutions, and municipalities to generate the political will necessary to accomplish reductions in beef consumption. An effective communication strategy will be essential. Rapid change is essential for the health of humans and the planet.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

WD: Conceptualization, Writing – original draft, Writing – review & editing. JF: Conceptualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 23 November 2023
DOI 10.3389/fpubh.2023.1269857

OPEN ACCESS

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RECEIVED 31 July 2023
ACCEPTED 23 October 2023
PUBLISHED 23 November 2023

CITATION
Martinez-Brockman JL, Hromi-Fiedler A, Galusha D, Oladele C, Acosta L, Adams OP, Maharaj RG, Nazario CM, Nunez M, Nunez-Smith M and Pérez-Escamilla R (2023) Risk factors for household food insecurity in the Eastern Caribbean Health Outcomes Research Network cohort study. *Front. Public Health* 11:1269857. doi: 10.3389/fpubh.2023.1269857

Risk factors for household food insecurity in the Eastern Caribbean Health Outcomes Research Network cohort study

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Background: Globally, 1.3 billion people were considered food insecure as of 2022. In the Caribbean region, the prevalence of moderate or severe food insecurity was 71.3% as of 2020, the highest of all subregions in Latin America. Experienced based measurement scales, like the Latin American and Caribbean Food Security Scale, are efficient measurement tools of food insecurity used globally. The Eastern Caribbean Health Outcomes Research Network (ECHORN) Cohort Study is a population-based longitudinal cohort study in the two Caribbean U.S. territories of Puerto Rico and the U.S. Virgin Islands, as well as in Barbados and Trinidad & Tobago. The purpose of this research was to examine the demographic, psychosocial, behavioral, and environmental risk factors associated with household food insecurity (HFI) among adults ≥40years of age in the ECHORN cohort.

Methods: A cross-sectional analysis of baseline ECHORN cohort study data was conducted. The primary outcome was household food insecurity (none, mild, moderate/severe). A total of 16 known and potential risk factors were examined for their association with HFI. The ANOVA and chi-square statistics were used in bivariate analysis. Ordinal logistic regression was used for the multivariable and sex stratified analyses.

Results: More than one-quarter of the sample (27.3%) experienced HFI. In bivariate analyses, all risk factors examined except for sex, were significantly associated with HFI status. In the multivariable analysis, all variables except sex, education, marital status, smoking status, and residing in Puerto Rico were significant predictors of HFI in the adjusted model. In sex stratified analysis, depression, food availability, self-rated physical health, and island site were significantly associated with increased odds of worsening HFI for women, but not for men. Source of potable water was an important risk factor for both men and women.

Discussion: The prevalence of HFI in the ECHORN cohort study is comparable to other studies conducted in the region. While women did not have an increased risk of HFI compared to men, a different set of risk factors affected their vulnerability to HFI. More research is needed to understand how water and food security are interrelated in the ECHORN cohort.

KEYWORDS

food insecurity, household food insecurity, Caribbean region, U.S. territories, ELCSA

1 Introduction

The World Health Organization (WHO) defines food security as "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (1). Globally, 1.3 billion people were considered food insecure as of 2022, with an increase of nearly 119 million people due to the pandemic in 2021 (2). Measuring food insecurity through household food insecurity (HFI) experience-based measurement scales continues to be the method of choice to assess food insecurity globally, compared to other methods like household expenditure surveys or dietary intake assessments (3). In adults worldwide, HFI has been associated with chronic diseases such as diabetes (4–6), hypertension (7) and overweight (8). In women and adults in low-income households, there is robust evidence of an association between HFI and malnutrition globally (8–13). Among children, HFI has been associated with childhood obesity (4, 14), stunting (15), malnutrition (15–18) as well as disability and/or injury (4).

In the Caribbean region, the prevalence of moderate or severe food insecurity was 71.3 percent in 2020, the highest of all subregions in Latin America when measured using the Food Insecurity Experience Scale (19). In this region, HFI has been associated with HIV/AIDS in Haitian adults (20, 21), HIV in adults in the Dominican Republic (22), and malnutrition in adults from both the Dominican Republic and Haiti (6, 22). HFI is associated with lower household income, physical disability, and having an underweight body mass index among adults in Trinidad & Tobago (23, 24). In Barbados, HFI is associated with disability and/or injury (4), and in Puerto Rico the Covid-19 pandemic worsened food insecurity in many households (24). In children in the Caribbean, HFI has been associated with child disability, family divorce or separation, and increased child healthcare needs in Caribbean households with children in the Eastern Caribbean Child Vulnerability Study (4). Among adolescents in a five-country study that included Trinidad & Tobago, HFI was associated with negative psychological and behavioral outcomes (25). In rural Haiti, HFI was associated with childhood malaria (26).

Household food insecurity must be considered in the context of water security (27–29). There is a consistent relationship between water and food insecurity. Indeed, in a study conducted in 27 sites in 21 low-and middle-income countries, the Household Water Insecurity Experiences (HWISE) Scale revealed an association between increasing rates of household water insecurity and decreasing availability and quality of food in the household (27, 28, 30). HFI is exacerbated by water insecurity through the direct limitation of food options that can be prepared due to a lack of potable water (31) and by directly limiting the budget for household food items due to the need to pay for treatment of potable water (28). Water insecurity is also associated with non-communicable diseases such as malaria, obesity, diabetes, and hypertension (32).

Existing cross-sectional and prospective epidemiologic studies that have examined risk factors for food insecurity are primarily focused on the United States or other high resource settings. In the U.S. these risk factors include having a lower level of education, never being married or being divorced/separated, being young, renting, or being African American or Hispanic (33, 34). Few epidemiologic studies exist that examine risk factors for food insecurity in the Caribbean region. The Eastern Caribbean Health Outcomes Research Network (ECHORN) Cohort Study is an ongoing population-based longitudinal cohort study designed to follow adults 40 years of age and older in the two Caribbean U.S. territories of Puerto Rico and the U.S. Virgin Islands, as well as in the nations of Barbados and Trinidad & Tobago. Its primary purpose is to measure the prevalence and incidence of diabetes, cancer, and heart disease as well as known and potential risk factors including food insecurity. The Caribbean region has the highest burden of non-communicable diseases, compared to Latin America, the U.S., and Canada. In fact, the U.S. Caribbean territories of Puerto Rico and the U.S. Virgin Islands are home to nearly 3.4 million Americans, yet we know very little regarding the risk factors for HFI and the relationship between HFI and non-communicable diseases on these islands. ECHORN is the first multi-country, intergenerational cohort study in the region designed to examine non-communicable disease outcomes and their known and potential risk factors. The purpose of this research was to examine the demographic, psychosocial, behavioral, and environmental risk factors associated with household food insecurity among adults ≥40 years of age in the ECHORN cohort.

2 Methods

The ECHORN study protocol was reviewed and approved by the Institutional Review Boards at Yale University, the University of Puerto Rico Medical Sciences Campus, the University of the Virgin Islands, the University of the West Indies – Cave Hill, and St. Augustine (Trinidad) campuses, and the Ministry of Health of Trinidad and Tobago. All participants provided their fully informed consent prior to initiating study procedures. The current analysis was approved by the Data Access and Scientific Review committee of the ECHORN Cohort Study.

2.1 Sample

Eligible participants at baseline were 40 years of age and older, English or Spanish speaking, able to provide informed consent, non-institutionalized at the time of data collection, had reliable contact/residential information, were semi-permanent or permanent residents of the island for 10 or more years, and had no plans to permanently relocate in the next 5 years.

The sampling methodology for the baseline ECHORN cohort ($n = 2{,}961$) has been described in detail elsewhere (35). Briefly, in

Trinidad, Puerto Rico, and Barbados, stratified multistage probability sampling was used to empanel the baseline cohort between 2013 and 2018. In the US Virgin Islands simple random sampling was used across the islands of St. Thomas St. Croix and Saint John. Participants visited a community assessment center, centrally located on each island site, for their baseline assessment. After informed consent was obtained, participants were asked to complete a health survey, a clinical assessment, and provide a blood sample for immediate testing to identify markers of disease. The health survey consisted of questions pertaining to health status and chronic disease history, health behaviors, diet, household food insecurity, access to health care, migration history, social support, health networks, neighborhood factors, and demographic information. The cross-sectional sample used in this analysis included all participants with household food insecurity data at baseline and non-missing values for the examined risk factors ($n = 1{,}939$).

2.2 Primary outcome

The primary outcome was household food insecurity as measured by the Latin American and Caribbean Food Security Scale (or ELCSA by its Spanish acronym) (34). The 9-item ELCSA scale for adults (Table 1) is a household-level experiential food security scale and is scored by assigning 1-point to each affirmatively answered yes/no question. Next, responses are divided into the following categories: food secure (score of 0), mild food insecurity (score of 1–3), moderate (4–6), and severe food insecurity (score of 7–9). Respondents with moderate and severe food insecurity scores (4–9) were grouped into a single category.

TABLE 1 Latin American and Caribbean household food security scale items.

Item #	Question During the last 3 months, because of lack of money or other resources:
1	Were you worried about running out of food?
2	Did your home run out of food at any time?
3	Were you or any other adult in your home unable to eat the kinds of nutritious foods that make people healthy?
4	Did you or any other adult in your home usually have to eat the same foods almost every day?
5	Was there any day that you or any other adult in your home skipped a meal because of lack of food?
6	Did any adult in your home eat less food than what they needed because there wasn't enough food?
7	Was there any day when you or any other adult in your home felt hungry but did not eat because there wasn't enough food?
8	Was there any day when you or any other adult in your home did not eat for a whole day or just ate once during the day because there wasn't enough food?
9	Did you do things that you would have preferred not to do, such as begging or sending children to work, to get food?

2.3 Independent variables

Sixteen risk factors were chosen and examined based on existing literature and potential risk factors specific to this population, based on experience working in the region. Demographic factors included age at baseline interview (continuous), sex, level of education, perceived economic status, marital status, island site (Puerto Rico, USVI, Trinidad, or Barbados), home ownership status (Yes/No), and whether the participant had moved in the past year (Yes/No). Sex was measured on the baseline survey using the following question, "What sex were you at birth?" Educational attainment was measured using the question, "What is the highest year of school that you completed?" Responses were categorized into less than high school (or secondary school), high school graduate, some college, and college and higher. Perceived economic status was measured using an adapted version of the World Gallup Poll® question: "Please look at this figure, with steps numbered from 1 at the bottom to 10 at the top. Suppose the top of the ladder represents the richest people of this island and the bottom represents the poorest people of this island. Taking into consideration your current personal situation, what is the number of the step on which you would place yourself?" Responses ranged from 1 poor to 10 high and were categorized into bottom, middle, and top quantiles. Marital status was measured by asking "What is your current relationship status" and responses categorized into married, single, separated/divorced, or widowed.

Psychosocial factors included were emotional support, and depression. Emotional support was measured using the PROMIS Emotional Support short form (36). Responses were dichotomized (Yes/No) as to whether each participant had a low emotional support score, meaning less than 12. Depression (Yes/No) was measured by the Patient Health Questionnaire (PHQ-2) (37, 38).

Behavioral factors included current smoking and self-reported physical health scores. Current smoking status (Yes/No) was measured using two variables: "Have you EVER smoked any tobacco product, such as cigarettes, cigars, or tobacco pipe? Yes/No. Those that answered Yes were asked "Do you still smoke cigarettes, cigars, or tobacco pipe regularly? By regularly we mean at least 20 cigarettes or 1 cigar or half an ounce sachet of loose tobacco per month." The PROMIS Global Physical Health score was used to assess participant reported physical health (39, 40). The score ranges from 4 to 20, with 4 being poor health and 20 excellent health. The score was created using 4 items (Table 2).

Environmental factors included fruit and vegetable availability and quality, mode of transportation to the grocery store, and water source as a proxy for water security. Fruit and vegetable availability and quality were measured as follows: "Thinking about food resources in your neighborhood, how often are a large selection of fresh fruits and vegetables, excluding provisions, available in my neighborhood?" and "Thinking about food resources in your neighborhood, how often are the fresh fruits and vegetables in your neighborhood of high quality?" Responses were dichotomized into never/rarely/sometimes *or* usually/always. Mode of transportation to the grocery store was measured with a single item: "What is the most typical way you travel to the store for your groceries?" and responses were dichotomized: drive own car/ride with friend/family *or* take the bus/taxi/bike/walk. Water insecurity was measured by a single item asking about source of potable water: "What is the main source of water supply for members of your household? This item was used as a proxy for water

TABLE 2 PROMIS Global Physical Health score (40, 41).

Item	Response options
1. In general, how would you rate your physical health? (Choose one)	Excellent (1), very good (2), good (3), fair (4), poor (5)
2. To what extent are you able to carry out your everyday physical activities such as walking, climbing stairs, carrying groceries, or moving a chair? (Choose one)	Completely (1), mostly (2), moderately (3), a little (4), not at all (5)
3. In the past 7 days, how would you rate your pain on average? (Reverse scored and categorized as follows: (0 = 5; 1,2,3 = 4; 4,5,6 = 3; 7,8 = 2; 9 = 1)	0 no pain to 9 worst pain imaginable
4. In the past 7 days, how would you rate your fatigue on average? (Choose one) (Reverse scored from numbers shown in parenthesis to the right)	Very severe (1), severe (2), moderate (3), mild (4), none (5)

insecurity. Responses were dichotomized as water secure (water piped into dwelling) and water insecure (water not piped into dwelling).

2.4 Analysis

Rasch modeling was used to assess the ELCSA scale's psychometric properties since this was the first time the scale was being used in the ECHORN Cohort. The Rasch model is a 1-parameter item response model, a modeling technique that is consistently applied in studies using the ELCSA and other food insecurity scales (26, 41–43). RASCH modeling was completed using the full data set ($n = 2{,}961$). The model was run in the following ways: (1) On the full sample using all 9 ELCSA items; (2) on the full sample using 8 of 9 ELCSA items (removing number 9—begging); (3) on the sample from each island (using all 9 items and 8 items as above); (4) removing individual participants identified as outliers—both on the full sample using all 9 items and for each island site using the 9-item scale. Unidimensionality of the scale by island was further assessed using Differential Item Functioning (DIF). DIF analysis was performed to compare scale performance for each island to the full sample. Measure, Infit values, and differences in item performance were assessed by island site. A detailed description of the RASCH results can be found in Supplementary material.

Next, univariate and bivariate analyses were conducted to determine the prevalence of household food insecurity, describe the overall sample by each risk factor, and to examine the association between household food insecurity and each risk factor. Study variables were summarized using means and standard deviations or frequency distributions for the total sample and by level of household food insecurity. The analysis of variance and the chi-square test were used to examine the association between potential risk factor variables and household food insecurity. Tetrachoric and polychoric correlation coefficients were also examined to determine whether collinearity existed between specific study variables: education, perceived economic status, water supply (which may be a marker for economic status in the Caribbean region), and home ownership. Finally, multivariable ordinal logistic regression was then used to determine the association between household food insecurity (mild to moderate/severe) and each risk factor holding all other variables constant. The analysis was first conducted for the full sample, then stratified by sex as women are more likely to experience HFI than men (44).

3 Results

3.1 Rasch modeling results

Rasch modeling of the ELCSA scale in the ECHORN sample indicated that the full 9-item scale for adults used with the full cohort (rather than by island site) was the best fit. The Cronbach's Alpha for the scale was 0.90. Figure 1 shows the ELCSA scale item infit values. Each item is shown along the X-axis and the item infit value on the Y-axis. Infit is a fit statistic that is less sensitive to outliers and more sensitive to observations near the respondent's ability level (45). Acceptable infit values range from 0.7 to 1.3 (46). All 9-items of the ELCSA scale had acceptable infit values in the ECHORN sample. This means that the infit values demonstrate that the items measure the same construct and are independent of one another. Further information on the psychometric validity of the scale—as demonstrated through item prevalence, item severity, and differential item functioning by island site—is presented in Supplementary material.

3.2 Univariate and bivariate analysis

The final sample size consisted of 1,939 individuals with a baseline household food insecurity score and non-missing data for the examined risk factors. More than one-quarter of the sample (27.3%) experienced some level of household food insecurity (17.0% mild, 10.3% moderate or severe). Respondents were on average 57 years of age (S.D. 10.5) and nearly two-thirds were female. Nearly one-third had no high school education, 41% were married, nearly two-thirds owned their own home and 50% rated themselves in the middle economic quartile of their respective island. Nearly 15% of respondents did not have water piped directly into their homes (Table 3, total column). Correlation coefficients ranged from −0.04 to 0.23, indicating that collinearity was not present between education, perceived economic status, water supply, and home ownership.

In bivariate analyses, all risk factors examined, except for sex were significantly associated with household food security status (Table 3). Those who were food secure were 4.8–6.3 years older than those who had mild or moderate/severe food insecurity. Those who reported that they had not completed high school or college, were single, did not own a home, moved in the past year, or had a self-reported economic status in the bottom quantile were more likely to report food insecurity than their counterparts. Participants in Trinidad were more likely to report food insecurity compared to the other three island sites. The prevalence of water insecurity was 14.5% in this sample. A dose response relationship with water insecurity was found such that food insecurity worsened as the proportion of respondents who did not have potable water piped directly into their dwelling increased.

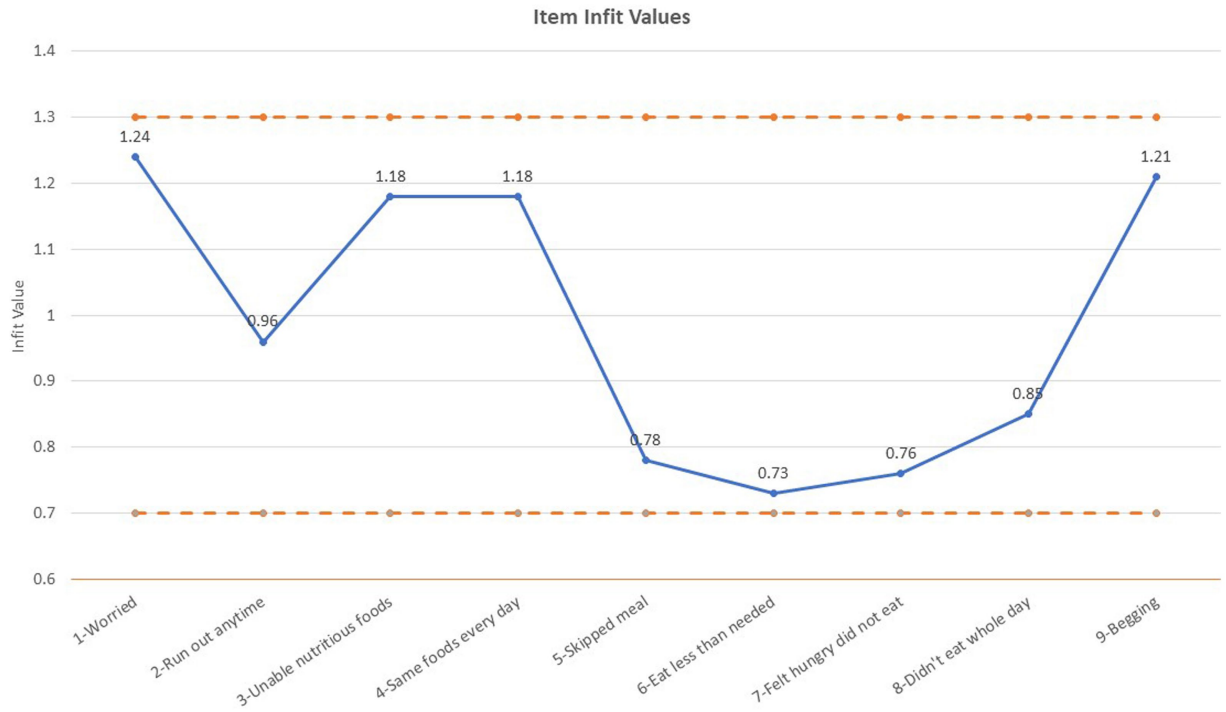

FIGURE 1
ELCSA item infit values.

3.3 Multivariable analysis

The multivariable analysis modeled the odds of worsening household food insecurity (mild to moderate/severe; Table 4). Increasing age was protective against experiencing worsening HFI in this sample. All variables except sex, education, marital status, smoking status, and residing in Puerto Rico (compared to Barbados) were significant predictors of HFI in the adjusted model. Sex was not associated with HFI in either the unadjusted or the adjusted model. In the adjusted model, those who were depressed had 71% increased odds (OR: 1.71; 95% CI: 1.28–2.28) of worsening HFI compared to those who were not depressed. Those who did not have water piped directly into their dwelling had 59% increased odds of worsening HFI compared to those with water piped directly into their home (OR 1.59; 95% CI: 1.17–2.17).

3.4 Sex stratified analysis

In the sex stratified analysis, age was a significant protective factor against worsening HFI; however, there was a greater protective effect for women compared to men (Table 5). For every 1-year increase in age, women were 6% less likely to experience worsening HFI, while men were 3% less likely. Self-reported economic status in the middle or bottom quantiles, not owning a home, having moved in the past year, low emotional support, lack of car or ride to get to the grocery store, and lack of water piped directly into the home were significantly associated with worsening HFI among both men and women. Education, marital status, current smoking status, and access to high quality foods were not associated with worsening HFI in men or women.

Depression, food availability, self-rated physical health, and island site were significantly associated with increased odds of worsening HFI for women, but not for men. Women who screened positive for depression had 72% increased odds of worsening HFI (OR: 1.72; CI: 1.22–2.44) compared to those without depressive symptoms. This is compared to 59% increased odds among men; however, this effect estimate was not statistically significant (OR: 1.59; CI: 0.92–2.74).

4 Discussion

This study aimed to examine demographic, psychosocial, behavioral, and environmental factors associated with HFI in a four-island Caribbean cohort. Identified demographic risk factors included younger age, lack of home ownership, and lack of stable housing. Psychosocial and behavioral risk factors included were depression, low emotional support, and poor self-rated physical health. Environmental risk factors included lack of food availability, lack of high-quality foods, and lack of water piped directly into the home. Our findings demonstrate that the prevalence of household food insecurity in the ECHORN Cohort is comparable to other studies that have been conducted in the region. A study of adults in Trinidad, showed a 25.0% prevalence of HFI and found that lower household income and physical disability were each independently associated with HFI (23). Another study conducted in households with children in three Eastern Caribbean countries (Barbados, St. Lucia, and St. Vincent and the Grenadines), that examined HFI as an exposure, showed a prevalence of HFI of 33.0% and found that food insecure households were more

TABLE 3 Risk factors for household food insecurity by HFI status ($n = 1,939$)[a].

Characteristic	Total ($n = 1,939$)[b]	Food secure ($n = 1,410$)	Mild ($n = 330$)	Moderate/Severe ($n = 199$)	p-value[c]
Demographic factors					
Age (years)	57.2 (10.5)	58.7 (10.7)	53.9 (9.4)	52.4 (8.0)	<0.0001
Sex					0.5290
Male	673 (34.7)	499 (35.4)	111 (33.6)	63 (31.7)	
Female	1,266 (65.3)	911 (64.6)	219 (66.4)	136 (68.3)	
Education					<0.0001
No HS	626 (32.3)	430 (30.5)	120 (36.4)	76 (38.2)	
Completed HS	474 (24.5)	348 (24.7)	79 (23.9)	47 (23.6)	
Some college	436 (22.5)	301 (21.4)	80 (24.2)	55 (27.6)	
University degree	403 (20.8)	331 (23.5)	51 (15.5)	21 (10.6)	
Marital status					<0.0001
Married	793 (40.9)	618 (43.8)	123 (37.3)	52 (26.1)	
Single	787 (40.6)	531 (37.7)	145 (43.9)	111 (55.8)	
Separated/Div.	214 (11)	152 (10.8)	40 (12.1)	22 (11.1)	
Widowed	145 (7.5)	109 (7.7)	22 (6.7)	14 (7)	
Economic status					<0.0001
Bottom quartile	491 (25.3)	299 (21.2)	102 (30.9)	90 (45.2)	
Middle	979 (50.5)	723 (51.3)	171 (51.8)	85 (42.7)	
Top quartile	469 (24.2)	388 (27.5)	57 (17.3)	24 (12.1)	
Home ownership					<0.0001
No	661 (34.1)	380 (27)	156 (47.3)	125 (62.8)	
Yes	1,278 (65.9)	1,030 (73.1)	174 (52.7)	74 (37.2)	
Moved past year					<0.0001
No	1811 (93.4)	1,359 (96.4)	292 (88.5)	160 (80.4)	
Yes	128 (6.6)	51 (3.6)	38 (11.5)	39 (19.6)	
Island site					<0.0001
Barbados	553 (28.5)	437 (31)	70 (21.2)	46 (23.1)	
Puerto Rico	685 (35.3)	537 (38.1)	86 (26.1)	62 (31.2)	
Trinidad & Tobago	564 (29.1)	345 (24.5)	141 (42.7)	78 (39.2)	
US VI	137 (7.1)	91 (6.5)	33 (10)	13 (6.5)	
Psychosocial, behavioral, and environmental factors					
Low emotional support score (<12)					<0.0001
No	1706 (88)	1,288 (91.4)	274 (83)	144 (72.4)	
Yes	233 (12)	122 (8.7)	56 (17)	55 (27.6)	
Current smoking					<0.0001
No	1765 (91)	1,301 (92.3)	300 (90.9)	164 (82.4)	
Yes	174 (9)	109 (7.7)	30 (9.1)	35 (17.6)	
Depression					<0.0001
No	1,653 (85.3)	1,258 (89.2)	267 (80.9)	128 (64.3)	
Yes	286 (14.8)	152 (10.8)	63 (19.1)	71 (35.7)	
Physical health—mean, sd	14.4 (2.83)	14.7 (2.76)	14.0 (2.88)	13.4 (2.86)	<0.0001
Food availability					<0.0001
Never/rarely/sometimes	708 (36.5)	463 (32.8)	141 (42.7)	104 (52.3)	
Usually/always	1,231 (63.5)	947 (67.2)	189 (57.3)	95 (47.7)	
Food high quality					<0.0001
Never/rarely/sometimes	744 (38.4)	479 (34)	160 (48.5)	105 (52.8)	
Usually/always	1,195 (61.6)	931 (66)	170 (51.5)	94 (47.2)	
Mode of transport to get groceries					<0.0001
Drive own car/ride with friend or family	527 (27.2)	311 (22.1)	105 (31.8)	111 (55.8)	
Take the bus/taxi/bike/walk	1,412 (72.8)	1,099 (77.9)	225 (68.2)	88 (44.2)	
Water supply					
Not piped into dwelling	283 (14.6)	150 (10.6)	79 (23.9)	54 (27.1)	<0.0001
Piped into dwelling	1,656 (85.4)	1,260 (89.4)	251 (76.1)	145 (72.9)	

[a]Table values are mean ± SD for continuous variables and n (column %) for categorical variables; HS = High School.
[b]Numbers may not sum to total due to missing data, and percentages may not sum to 100% due to rounding.
[c]*P*-value is for *t*-test (continuous variables) and chi-square test (categorical variables).

TABLE 4 Unadjusted and adjusted associations between risk factors and household food insecurity ($N = 1,939$)*.

Variable	Unadjusted models		Adjusted model	
	OR	95% CI	OR	95% CI
Age (years)	0.95	0.94–0.96	0.95	0.94–0.96
Sex				
Male	1.00 (Reference)		1.00 (Reference)	
Female	1.12	0.91–1.38	1.03	0.81–1.32
Education				
No HS	2.12	1.57–2.88	0.83	0.57–1.22
Completed HS	1.69	1.22–2.33	0.87	0.60–1.26
Some college	2.11	1.52–2.91	1.36	0.95–1.94
University degree	1.00 (Reference)		1.00 (Reference)	
Marital status				
Married	1.00 (Reference)		1.00 (Reference)	
Single	1.77	1.41–2.21	1.22	0.94–1.57
Separated/Div.	1.45	1.04–2.03	1.42	0.97–2.07
Widowed	1.20	0.79–1.8	1.48	0.91–2.4
Economic status				
Bottom quartile	3.22	2.39–4.33	2.93	2.09–4.1
Middle	1.69	1.28–2.24	1.90	1.39–2.58
Top quartile	1.00 (Reference)		1.00 (Reference)	
Home ownership				
No	3.17	2.58–3.88	1.90	1.49–2.41
Yes	1.00 (Reference)		1.00 (Reference)	
Moved past year				
No	1.00 (Reference)		1.00 (Reference)	
Yes	4.53	3.23–6.36	2.34	1.59–3.43
Island site				
Barbados	1.00 (Reference)		1.00 (Reference)	
Puerto Rico	1.05	0.8–1.37	1.35	0.93–1.95
Trinidad and Tobago	2.29	1.76–2.98	1.92	1.39–2.65
US VI	1.79	1.19–2.68	1.99	1.21–3.29
Low emotional support				
No	1.00 (Reference)		1.00 (Reference)	
Yes	2.94	2.25–3.84	1.86	1.38–2.53
Current smoking				
No	1.00 (Reference)		1.00 (Reference)	
Yes	1.81	1.33–2.48	1.04	0.72–1.5
Depression				
No	1.00 (Reference)		1.00 (Reference)	
Yes	3.06	2.39–3.92	1.71	1.28–2.28
Physical health score	0.88	0.85–0.92	0.93	0.89–0.97
Food availability				
Never/rarely/sometimes	1.80	1.48–2.2	1.42	1.04–1.95
Usually/always	1.00 (Reference)		1.00 (Reference)	
Food high quality				
Never/rarely/sometimes	1.95	1.59–2.38	1.38	1.02–1.88
Usually/always	1.00 (Reference)		1.00 (Reference)	
Mode of transport to get groceries				
Drive own car/ride with friend or family	1.00 (Reference)		1.00 (Reference)	
Take the bus/taxi/bike/walk	2.66	2.16–3.28	2.40	1.84–3.13
Water supply				
Not piped into dwelling	2.73	2.13–3.51	1.59	1.17–2.17
Piped into dwelling	1.00 (Reference)		1.00 (Reference)	

*The Score Test for the proportional odds assumption for the adjusted model was not statistically significant (chi-square: 34.5582 (23 df); $p = 0.06$).

TABLE 5 Adjusted associations between risk factors and household food insecurity, stratified by sex (n = 1,939)*.

Variable	Males (n = 673)		Females (n = 1,266)	
	OR	95% CI	OR	95% CI
Age (years)	0.97	0.95–0.99	0.94	0.93–0.96
Education				
No HS	0.93	0.49–1.77	0.78	0.48–1.26
Completed HS	0.95	0.50–1.83	0.82	0.51–1.31
Some college	1.65	0.89–3.06	1.18	0.76–1.85
University degree	1.00 (Reference)		1.00 (Reference)	
Marital status				
Married	1.00 (Reference)		1.00 (Reference)	
Single	1.28	0.83–1.99	1.22	0.88–1.68
Separated/Div.	1.33	0.70–2.55	1.46	0.91–2.35
Widowed	0.91	0.17–4.82	1.66	0.98–2.82
Economic status				
Bottom quartile	3.18	1.72–5.86	2.99	1.99–4.52
Middle	2.11	1.19–3.75	1.84	1.27–2.66
Top quartile	1.00 (Reference)		1.00 (Reference)	
Home ownership				
No	1.85	1.22–2.8	1.92	1.43–2.59
Yes	1.00 (Reference)		1.00 (Reference)	
Moved past year				
No	1.00 (Reference)		1.00 (Reference)	
Yes	3.52	1.77–7.02	1.96	1.23–3.13
Island site				
Barbados	1.00 (Reference)		1.00 (Reference)	
Puerto Rico	1.37	0.74–2.55	1.37	0.86–2.18
Trinidad	1.66	0.94–2.93	2.12	1.43–3.14
USVI	1.13	0.48–2.68	2.99	1.59–5.61
Low emotional support				
No	1.00 (Reference)		1.00 (Reference)	
Yes	2.41	1.48–3.94	1.62	1.09–2.4
Current smoking				
No	1.00 (Reference)		1.00 (Reference)	
Yes	1.04	0.61–1.76	1.03	0.62–1.73
Depression				
No	1.00 (Reference)		1.00 (Reference)	
Yes	1.59	0.92–2.74	1.72	1.22–2.44
Physical health score	0.94	0.88–1.02	0.92	0.87–0.97
Food availability				
Never/rarely/sometimes	1.04	0.61–1.79	1.73	1.17–2.56
Usually/always	1.00 (Reference)		1.00 (Reference)	
Food high quality				
Never/rarely/sometimes	1.61	0.94–2.74	1.25	0.86–1.84
Usually/always	1.00 (Reference)		1.00 (Reference)	
Mode of transport to grocery store				
Drive own car/ride with friend or family	1.00 (Reference)		1.00 (Reference)	
Take the bus/taxi/bike/walk	2.02	1.26–3.23	2.66	1.92–3.67
Water supply				
Not piped into dwelling	1.87	1.08–3.21	1.49	1.01–2.19
Piped into dwelling	1.00 (Reference)		1.00 (Reference)	

*The Score Test for the proportional odds assumptions of each model were not statistically significant: Males—chi-square = 31.3249 (22 df); p = 0.09; Females—chi-square = 25.55 (22df); p = 0.27.

likely to include a chronically ill parent, among other factors (4). With respect to populations living with infectious diseases, the prevalence of HFI is even higher. Fifty-eight percent of people living with HIV in the Dominican Republic reported experiencing severe HFI (22). Finally, in a study of women with young children in Haiti, 98% of the sample had some level of food insecurity. This study found that severe food insecurity was a significant risk factor for clinical malaria (26).

The findings presented above differ from the existing literature in important ways. First, women are more likely to experience HFI than men, globally (47); however, sex was not associated with HFI in our bivariate or multivariable analyses. Given that female sex is a known risk factor for HFI in other regions of the world, a sex stratified analysis was conducted to understand how risk factors for HFI might differ by sex in this sample. In stratified analyses we found that women who screened positive for depression, had poorer self-rated physical health, and who did not think fresh fruits and vegetables were readily available had increased odds of worsening HFI. The existing literature demonstrates an association between HFI and depressive symptoms, anxiety, poor coping strategies, and risky behavior among women (48). The directionality of the association between depression and HFI is undetermined and while these findings do not directly fill that gap, they add to the body of literature demonstrating an association between mental health and HFI. Furthermore, women with poor self-rated physical health may have both physical and economic limitations that contribute to their food insecurity status. Future research should explore longitudinal associations between depression, self-rated physical health, food availability and HFI.

Furthermore, this study adds to the growing body of literature examining the association between water and food insecurity. Source of potable water-a proxy for water insecurity-was a significant predictor of HFI for both men and women, such that those without water piped directly into their home had an increased odds of experiencing HFI. We did not find evidence of multicollinearity between water source and other indicators of socioeconomic status such as education, perceived economic status, and home ownership, suggesting that source of potable water is an independent risk factor for HFI in this sample. To our knowledge, this is the first multi-country study in the Caribbean region to examine the association between water security and HFI. Recent scholarship on water and food security suggests collecting more and better data on water insecurity, including prevalence data (49). We will continue to explore the relationship between water and food security and corresponding health outcomes in subsequent waves of data collection for the ECHORN cohort.

4.1 Study strengths and limitations

We used a validated and well-tested measure of household food insecurity for this research and confirmed its robust psychometric properties in the ECHORN cohort. We also examined known and potential risk factors for HFI (based on our knowledge of the region), which allowed us to identify important risk factors specific to the populations under study. This research fills a gap in the literature with respect to identifying and understanding risk factors for household food insecurity in the Caribbean region, and strongly calls for applying the lessons learned in these settings to the design of similar policy relevant studies in other regions of the world. Importantly, we present evidence of a link between source of potable water, a proxy for water security, and household food insecurity in the ECHORN cohort. These findings have important implications for understanding how to improve the governance of food and water security systems and the coordination needed between them.

With respect to study limitations, the cross-sectional nature of this analysis only allows us to draw conclusions about the association between the studied risk factors and household food insecurity in the region, without comment on causality. In addition, these findings pertain to the ECHORN cohort study sites only and cannot be extrapolated to other nations or territories in region.

5 Conclusion

This cross-sectional, multi-country study was designed to identify risk factors for household food insecurity in the Eastern Caribbean. The findings fill a gap in the literature with respect to understanding risk factors for HFI and have important implications for future research and policy in this area. Future research should examine these risk factors longitudinally, with a focus on understanding the transition from a food secure to a food insecure state over time in the ECHORN cohort. Additional work will examine whether household food insecurity is associated with specific cardiometabolic conditions in the cohort and what role water security also plays in these relationships.

Data availability statement

The datasets generated and analyzed for this study are available upon request to the ECHORN Data Access and Scientific Review committee (https://www.echorn.org/request-echorn-data).

Ethics statement

This study was approved by the Institutional Review Boards at Yale University, the University of Puerto Rico Medical Sciences Campus, the University of the Virgin Islands, the University of the West Indies – Cave Hill, and St. Augustine (Trinidad) campuses, and the Ministry of Health of Trinidad and Tobago. This study were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JM-B: Conceptualization, Formal analysis, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. AH-F: Formal analysis, Methodology, Software, Supervision, Writing – review & editing. DG: Data curation, Formal analysis, Methodology, Writing – review & editing. CO: Writing – review & editing. LA: Writing – original draft, Writing – review & editing. OA: Data curation, Funding acquisition, Resources, Writing – review & editing. RM: Data curation, Funding acquisition, Resources, Writing – review & editing. CN: Data curation, Funding acquisition, Resources, Writing – review & editing. MN: Data curation, Funding

acquisition, Resources, Writing – review & editing. MN-S: Data curation, Funding acquisition, Resources, Writing – review & editing. RP-E: Conceptualization, Methodology, Supervision, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This publication was supported by the National Institute on Minority Health and Health Disparities through the Eastern Caribbean Health Outcomes Research Network (ECHORN)-U24MD006939 and through the Yale Transdisciplinary Collaborative Center for Health Disparities Research focused on Precision Medicine (Yale-TCC)-U54MD010711. Support was also provided by CTSA Grant Number KL2 TR001862 and KL2 RR024138 from the National Center for Advancing Translational Science (NCATS), a component of the National Institutes of Health (NIH). The contents are solely the responsibility of the authors and do not necessarily represent the official view of NIH.

Acknowledgments

We would like to thank the ECHORN research teams on each island site for their tireless efforts in establishing and maintaining this cohort. We would also like to thank the ECHORN cohort study participants for entrusting us with their health information.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer AJ declared a shared affiliation, though no other collaboration, with one of the authors RM to the handling editor.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1269857/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 06 December 2023
DOI 10.3389/fpubh.2023.1215462

OPEN ACCESS

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RECEIVED 02 May 2023
ACCEPTED 30 October 2023
PUBLISHED 06 December 2023

CITATION
Madzorera I, Bliznashka L, Blakstad MM, Bellows AL, Canavan CR, Mosha D, Bromage S, Noor RA, Webb P, Ghosh S, Kinabo JL, Masanja H and Fawzi WW (2023) Women's input and decision-making in agriculture are associated with diet quality in rural Tanzania. *Front. Public Health* 11:1215462. doi: 10.3389/fpubh.2023.1215462

Women's input and decision-making in agriculture are associated with diet quality in rural Tanzania

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Background: Women's empowerment is one critical pathway through which agriculture can impact women's nutrition; however, empirical evidence is still limited. We evaluated the associations of women's participation, input, and decision-making in key agricultural and household activities with women's diet quality.

Methods: We analyzed data from a cross-sectional study of 870 women engaged in homestead agriculture. We used food frequency questionnaires to assess women's diets and computed women's diet quality using the Prime Diet Quality Score (PDQS) (range 0–42), which captures healthy and unhealthy foods. We evaluated women's decision-making in 8 activities, food crop farming, cash crop farming, livestock raising, non-farm economic activities, wage/salary employment, fishing, major household expenditures, and minor household expenditures. Generalized estimating equations (GEE) linear models were used to evaluate associations between (a) women's participation, (b) decision-making, (c) adequate input, (d) adequate extent of independence in decision-making in agriculture, and (e) adequate input in use of agricultural income with their PDQS. Adequate input was defined as input into some, most or all decisions compared to input into few decisions or none. Adequate extent of independence was defined as input to a medium or high extent compared to input to a small extent or none.

Findings: Median PDQS was 19 (IQR: 16–21). Women's adequate input in decision-making on wage and salary employment (estimate: 4.19, 95% CI: 2.80, 5.57) and minor expenditures were associated with higher PDQS vs. inadequate input. Women with independence in decision-making on livestock production (estimate: 0.97, 95% CI: 0.05, 1.90) and minor household expenditures, and women with adequate decision-making in the use of income from wages/salaries (estimate: 3.16, 95% CI: 2.44, 3.87) had higher PDQS. Participation in agricultural activities was positively associated with PDQS.

Conclusions: Women's participation and input in decision-making in wage and salary employment, livestock production, and minor household expenditures were strongly associated with the consumption of better-quality diets. Women participating in multiple farm activities were also likely to have better diet quality. This study adds to the growing evidence on the pathways through which women's empowerment may influence women's nutrition in rural Tanzania.

KEYWORDS

women's empowerment, diet quality, decision-making, women, women's participation, agriculture, sub-Saharan Africa

Background

Women's diet quality influences their nutrition and health, as well as that of their offspring. In many parts of Africa and Asia, women experience sub-optimal micronutrient intake and chronic energy deficiency because their diets consist primarily of staples with limited intake of nutrient-rich animal-source foods, vegetables and fruits (1). Recent transformations of global and local food systems have also contributed to the problems by increasing the availability of refined, processed, fast and unhealthy foods for women even in rural settings of low- and middle-income countries (LMICs) (2). It is not surprising that women in LMICs are increasingly facing a triple burden of malnutrition (persistent undernutrition, micronutrient deficiencies, and increasing overweight and obesity) (2, 3). In Tanzania, 10% of the women are underweight, 45% are anemic and overweight and obesity affect 18 and 10% of the women, respectively (4). Consumption of quality diets can address these key nutrition challenges among Tanzanian women.

For women involved in agriculture in Tanzania, access to resources and decision-making in agriculture may be important for their diets and nutrition. Literature suggests that for women involved in agriculture, empowerment may entail increasing their decision-making authority in relation to agricultural resources, management and production, and income (5). In Sub-Saharan Africa, women make up at least 40% of the agricultural labor, yet they face severe constraints, including a lack of access to inputs and other production resources required to meet their production potential (6). When women are not empowered, their access to the physical and human resources required to adopt optimal nutrition practices for their improved health is limited (7). Women tend to spend a greater proportion of household income on food purchases compared to men (5), and when they have more input in making decisions and have nutritional knowledge, they may act on that knowledge to provide higher quality diets for themselves and their families. Therefore, understanding the role of women's empowerment, input and decision-making in agriculture, and how that affects nutrition is important (8).

The empirical evidence linking women's empowerment with their nutrition outcomes has been increasing. Women's empowerment has been positively associated with women's diets and lower risk of maternal undernutrition (9–13). Constructs of women's empowerment such as empowerment in credit decisions, group membership and control over income have also been associated with women's dietary diversity (9, 10). However, most prior studies were cross-sectional and evaluated women's dietary diversity rather than overall diet quality. Dietary diversity represents only one dimension of diet quality, that is micronutrient adequacy (14), and does not consider the consumption of unhealthy foods and nutrients which have been increasing in LMICs and are linked to increased risk of non-communicable diseases (NCDs) such as diabetes and cardiovascular disease (2, 15–18). In a previous study, we assessed women's diet quality (including unhealthy foods) in urban Dar es Salaam using a novel tool, the Prime Diet Quality Score (PDQS) and found that women's diet quality was poor and associated with risk of low birth weight and preterm births (19). There is a need to further evaluate the risk factors for poor maternal diet quality in rural Tanzania, including the role of women's empowerment.

We believe that women's agency (including processes of decision-making) is an important component of women's empowerment and an important determinant of their nutrition. It reflects women's decision-making in intra-household resource allocation activities related to dietary intake, and their ability to act on their nutrition knowledge (20). Women also often have different preferences for allocating food and non-food resources compared to men, with benefits to their nutrition and health (5).

In this study, we evaluated associations of constructs of women's empowerment with their diet quality in rural Tanzania. Specifically, we evaluated the associations of (a) women's input in agriculture and household decision-making, (b) the extent to which women could provide input if they need to, and (c) women's decision-making on the use of income from agricultural activities, with women's diet quality, as measured by the PDQS in rural Tanzania. To our knowledge, no studies have evaluated the relationship between women's decision-making in agriculture and dietary quality.

Abbreviations: BMI, Body mass index; CI, Confidence interval; DD, Dietary diversity; FFQ, Food frequency questionnaire; HANU, Homestead Agriculture and Nutrition; HDSS, Health and Demographic Surveillance System; IQR, Inter quartile range; LMICs, Low- and middle-income countries; PDQS, Prime diet quality score; WEAI, Women's Empowerment in Agriculture Index.

Materials and methods

Study population

This study sample included participants enrolled in the Health and Demographic Surveillance System (HDSS) in Rufiji district, Tanzania. We used data from the Homestead Agriculture and Nutrition (HANU) project, a pair-matched cluster-randomized trial that sampled from participants from the HDSS and evaluated the effect of homestead gardening and nutrition and health education on women's diets. Details of the intervention have been published elsewhere (21, 22). The Rufiji HDSS is a repeated study and surveillance system that was established in 1998. It tracks households over time and collects data on the structural, behavioral, socio-economic and biological drivers of health and their impacts on the community (23). It generates information on longitudinal health and demographic indicators to guide national policy and decision-making (23).

Briefly, the HANU study selected 36 villages that were close to sources of water bodies for home gardening and to food markets as eligible for the study out of the 94 villages that are part of the Rufiji HDSS (24). From the 36 eligible villages, the study randomly selected and matched 10 eligible villages (5 pairs) from the HDSS and allocated them to the intervention (homestead gardening) or control groups (24). The study then enrolled 1,006 women of reproductive age (18–49 years), with at least one child aged 6–36 months and with access to pieces of land for vegetable production from the selected villages. The intervention was a homestead gardening intervention that provided seeds and training by agricultural extension officers to support the production of vegetables such as amaranthus, okra, and spinach by the study households, as well as nutrition education to promote the consumption of produced foods.

The study was implemented from August 2016 to December 2019 (25). The baseline conducted between August and October 2016 and a midline assessment from August-October 2017, 12 months after the intervention started. We used data from 880 women who participated in the midline assessment of the study for this analysis. We used data from the midline study only as it had allowed women to access the intervention that could impact the quality of their diets.

Research assistants collected data on household and women's socio-demographic characteristics, asset ownership and dietary intake. Maternal anthropometric measures of weight and height were also made. We collected data on household agricultural production and women's participation and decision-making in key agriculture activities. The interviews regarding women's decision-making were conducted where other members of the household or community could not overhear or contribute answers.

Exposure variables

Women's empowerment

Conceptual frameworks have shown complexities in relationships in food systems and nutrition, and have posited that women's empowerment is a key component of impact pathways through which food systems could affect women's nutrition (26–29). Women's empowerment (WE), however, is a multi-dimensional and complex construct that is difficult to define and measure. It has been defined as a process through which women who have been denied the ability to make strategic choices acquire the ability to do so, and it encompasses access, the capability to make choices, and control over resources (30, 31). It is from this construct that the empowerment of women in agriculture metrics have been developed.

There are multiple ways to measure WE but only the Women's Empowerment in Agriculture Index (WEAI) has been widely applied to agricultural contexts (32). The WEAI assesses the empowerment, agency and inclusion of women in agriculture, and focuses on 5 domains (1) decisions about agricultural production, (2) access to and decision-making power on productive resources, (3) control of the use of income, (4) leadership in the community, and (5) time allocation (32). However, the time demands for the WEAI are high and it is more suited to producing country-level estimates (33). A project-level WEIA (pro-WEIA) (33) has also been developed, however, it is also time intensive. Therefore, a gap exists for simpler tools for assessing WE that can be easily incorporated into agriculture programs to track progress.

We assessed women's participation and decision-making in agriculture and household activities using select questions adopted from the WEAI questionnaire [4]. Women's empowerment was determined based on their participation in the following agricultural and household activities: (1) food crop farming: crops grown primarily for household food consumption; (2) cash crop farming: crops grown primarily for sale in the market; (3) livestock raising; (4) non-farm economic activities: e.g., running a small business, self-employment, buy and sell businesses; (5) wage and salary employment: work that is paid for in cash or in-kind, including agriculture and other wage work; (6) fishing or fishpond culture; (7) major household expenditures (e.g., purchases of bicycles, land, and small motorcycles); and, (8) minor household expenditures (e.g., purchasing food for daily consumption or other household needs).

For each activity, women were asked five questions which we used to define our exposure variables. Supplementary Table 1 shows the questionnaire used for the assessment, which is an excerpt from the WEIA questionnaire. We selected several questions from the WEIA around women's decision-making and the extent of their input (including their scoring guidelines) in key agriculture related activities. We assessed the following:

(a) *Participation in agricultural activity*: Women were asked if they participated (alone or with others) in household activities in the past 12 months. We developed a binary score for women's participation in agriculture and household activities (yes/no).
(b) *Decision-making regarding activity*: We asked women if they reported participating in selected activities, did they make decisions around these activities individually or jointly with others in the households. We calculated a binary score for women's participation in decision-making (yes/no).
(c) *Adequate input in decision-making in agriculture activities:* If they reported participating in the selected activities,

we also asked women how much input they provided in decision-making in the 8 agricultural and household activities. We classified responses as "Yes" when they had input into some, most, or all decisions, or "No" if they had no input or input into a few decisions for each activity (adequate women's input, binary variable, yes/no).

(d) *Adequate extent of independence in decision-making in agriculture activities:* We asked women about the extent to which they could (hypothetically) provide input in decision-making in the eight agricultural and household activities. We classified responses as "Yes" when they had input to a medium or high extent, or "No" if they had no input or input to a small extent (adequate extent of independence in decision-making, binary variable, yes/no).

(e) *Adequate input in use of income from agriculture activities:* Finally, we asked women if they participated in decision-making on the use of income from agricultural activities, including for household expenditures. We defined responses as "Yes" when they provided input into some, most, or all decisions, or "No" when they provided no input or input into a few decisions (adequate decision-making on the use of income from agriculture, binary variable, yes/no).

We also summed up the total number of activities that women participated in (range 0–8), to calculate a participation score. We classified women's participation scores into tertiles.

Figure 1 shows our theory of change on how these factors could influence women's diets and nutrition outcomes. We hypothesized that different forms of women's participation in agriculture would impact women's diets and nutrition through their influence on their food security. We also hypothesized that women's participation in agricultural activities alone may not be sufficient to optimize their dietary intake. We posit that as we move from participation to decision-making this represents greater empowerment, as does independence in making decisions (if required) and control over financial resources; and as these improve, the impacts on women's diets and nutrition would be greater. Further, we also suggest that participation in some activities may be more important than others for women's diets.

Outcome variable

Women's dietary intake was assessed using a food frequency questionnaire (FFQ) which was administered by research assistants. A previously validated FFQ composed of a list of 79 common local foods was used (34). Women were asked to recall how often they consumed foods over the previous month. Frequency of food consumption was recorded as: 0 times in a month, 1–3 times per month, 1 time per week, 2–4 times per week, 5–6 times per week, 1 time per day, 2–3 times per day, 4–5 times per day, and 6 or more times per day.

Women's diet quality was assessed using the Prime Diet Quality Score (PDQS). The PDQS has been used as a measure of diet quality in urban Tanzania where it was shown to be associated with low birth weight and preterm births (19), and has been shown to predict gestational diabetes, hypertension diabetes, and coronary heart disease among women in high-income contexts (16–18). The PDQS is a measure of overall diet quality, capturing the diversity of healthy and unhealthy food consumption (15).

We classified foods consumed by women in the previous month into 21 food groups for the PDQS as follows, 14 healthy food groups (dark green leafy vegetables; other vitamin A rich vegetables; cruciferous vegetables; other vegetables; whole citrus fruits; other fruits; fish; poultry; legumes; nuts; low-fat dairy; whole grains; eggs; and, liquid vegetable oils) and 7 unhealthy food group (red meat; processed meats; refined grains and baked goods; sugar-sweetened beverages; desserts and ice cream; fried foods obtained away from home and potatoes) based on criteria determined by previous studies (16, 17). We included roots and tubers in the potatoes group, and maize flour-based products including ugali as refined grains. Based on the frequency of consumption, we assigned points for healthy foods as follows: 0–1 serving/week (0 points), 2–3 servings/week (1 point) and $\geq$4 servings/week (2 points). For unhealthy food groups we assigned points as: 0–1 serving/week (2 points), 2–3 servings/week (1 point) and $\geq$4 servings/week (0 points) (16).

Processed meat intake, low-fat dairy, liquid vegetable oil consumption were not measured in the study, therefore all women were assigned low intake for these groups, that is 2 points for processed meats and 0 points for the others. We summed the healthy and unhealthy foods scores to compute the overall PDQS for each woman (range 0–42).

Ethics

Written informed consent was obtained from all enrolled women. Ethical approval for the study was provided by the Ifakara Health Institute (IHI) independent research board, the Medical Research Council Committee of the National Institutes of Medical Research (NIMR) in Tanzania (NIMR/HQ/R. 8 a/Vol. IX/2262), and the Harvard T. H. Chan School of Public Health institutional review board. The trial was registered with clinicaltrials.gov (ClinicalTrials.gov NCT03311698).

Statistical analysis

We described the background characteristics of the women included in our study. Chi square *p*-values were reported for categorical/binary variables and the Wilcoxon test for continuous variables was used to describe differences in background characteristics by tertile of participation in agricultural activities. We described the frequency of consumption of the PDQS food groups, and women's participation and input into agriculture decisions, the extent of their independent input in agriculture decisions and their decision-making in use of income from agriculture using counts and frequencies and means and standard deviations.

We used generalized estimating equation (GEE) linear models with exchangeable correlation and adjusting for clustering by village pair to evaluate univariate associations of (a) women's participation in agriculture activities, (b) women's decision-making, (c) women's adequate input into decision-making in

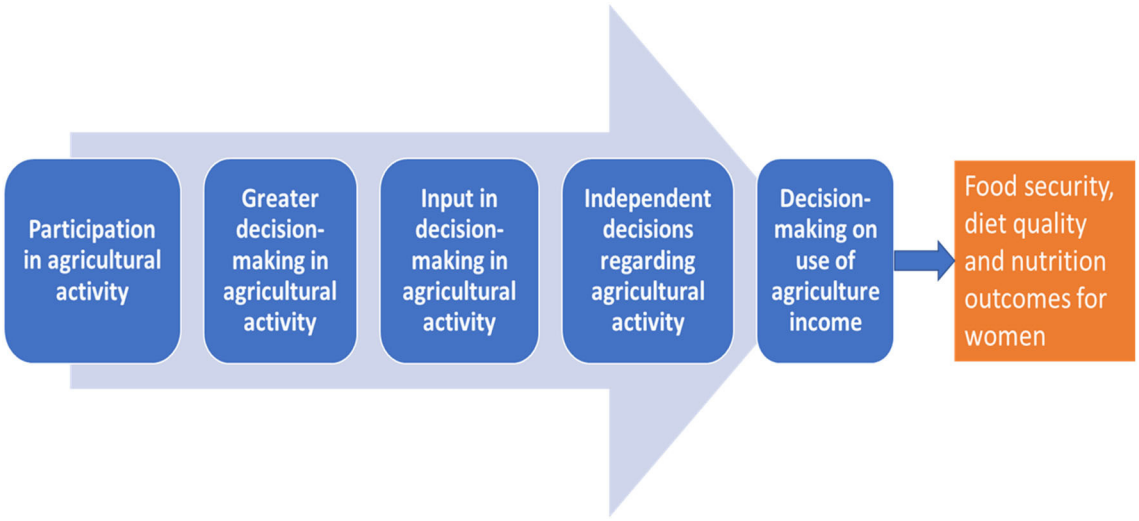

FIGURE 1
Theory of change.

agriculture, (d) women's adequate extent of independence in decision-making in agriculture activities, and (e) women's decision-making in the use of agricultural income with women's diet quality (PDQS).

We also estimated adjusted models, selecting confounders based on univariate associations between potential confounders and PDQS at levels of $p < 0.20$. We adjusted for participation in the homestead gardening intervention (intervention vs. control). We considered the following potential confounders: women's age (18–24, 25–34, 35–49 years), women's education (none, primary, secondary, or higher), marital status (married/not married), women's body mass index (underweight: BMI $<$ 18.5, normal weight: BMI 18.5–24.9, and overweight and obesity: BMI $\geq$ 25 kg/m^2), parity (0–1, $\geq$2), family size, wealth index (calculated using factor analysis of nine items for asset ownership and housing quality), land size (acres), weekly income (log), food expenditure (log), and distance to market (km). Multivariable associations were considered statistically significant at $p < 0.05$. We used the missing indicator method to account for missing covariate data (35). Analysis was conducted using SAS 9.4 program.

Results

We analyzed data from 870 women (excluding 10 women $\leq$18years or older than 50 years). The mean age of study women was 31($\pm$8) years. At least 77% of the women were married, 34% had no primary school education, and 57% had only primary school education. On average, women reported participating in 3 ($\pm$2) agricultural activities out of a possible 8 activities. Women in the highest tertile of the agriculture participation score were older, and more likely to have more than 2 children (Table 1). They also lived further from markets. In addition, women participating in more agricultural activities had access to larger pieces of land (4.1 $\pm$ 3.9 vs. 2.8 $\pm$ 2.5 acres) and were more likely to have sold at least 1 food crop in the previous year (68.9% vs. 31.5%) compared to women participation in a few activities. However, they spent less money on food purchases compared to women in the lowest tertile. Women who reported participating in $\geq$3 agricultural activities (median) were more likely to be older, married, and less educated, compared to women who participated in 2 or fewer activities. Overweight and obesity were high affecting 24.3% and 13.1% of women, and underweight affected 6.8% of the women, respectively. Women's PDQS was low (median 19, IQR: 16–21, maximum score 42).

Among the healthy food groups, women consumed other vegetables (97.1%), fish (89.4%), legumes (81.6%), and dark green vegetables (62.3%; Table 2) at least 4 times each week. The most frequently consumed unhealthy food groups (where consumption in moderation is preferred) were refined grains (100%) and potatoes, roots, and tubers (82.7%) which were consumed at least 4 times per week on average. Median PDQS was 19 (IQR: 17–21).

Most of the women in our study reported participating in food crop farming (77.7%) and minor household expenditures (69.4%) (Supplementary Table 2). Women's participation in the other activities we assessed was low (<36%). Women's reported participation was lowest for fishing (1.4%), wage and salaried employment (15.7%), and livestock raising (18.7%). When we only considered women who reported participating in the activity, more than 80% reported making decisions in minor household expenditures, non-farm economic activities, cash crop farming and livestock raising (Supplementary Table 2). Figure 2 shows women's input in decision-making in agriculture and household activities. On average, among women reporting participating in each activity, most reported providing input into some decisions (Figure 2A), the ability (hypothetical) to participate in decision-making to a medium extent (Figure 2B), and participating in decision-making and providing input into some decisions on the use of income (Figure 2C).

In adjusted models, women's participation in non-farm economic activities (estimate: 0.62, 95% CI: 0.14, 1.10) and wage and salaried employment (estimate: 1.15, 95% CI: 0.25, 2.04) were positively associated with PDQS (Table 3). Women who reported participating in decision-making alone or jointly with

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TABLE 1 Socio-economic and demographic characteristics of study women in Tanzania by participation in agricultural activities ($N = 870$).

	Number of agricultural and household activities women participate in		
	Tertile 1 (0–1)	Tertile 2 (2, 3)	Tertile 3 (4–8)
	$N = 203$	$N = 408$	$N = 257$
Maternal age (years)	29.8 ± 7.7	31.0 ± 7.5	33.5 ± 7.6***
18–24	65 (32.0)	97 (23.8)	38 (14.8)***
25–34	76 (37.4)	184 (45.1)	94 (36.6)***
35+	62 (30.5)	127 (31.1)	125 (48.6)***
Marital Status			
Married	151 (74.3)	303 (74.3)	218 (84.8)*
Body mass index (BMI kg/m2)			
Underweight (BMI < 18.5)	12 (5.9)	24 (5.9)	23 (9.1)
Normal weight (BMI 18.5–24.99)	113 (55.9)	236 (58.0)	132 (52.2)
Overweight (BMI 25–29.99)	54 (26.7)	93 (22.9)	62 (24.5)
Obese (BMI ≥ 30)	23 (11.4)	54 (13.3)	36 (14.2)
Maternal education			
None	52 (25.6)	145 (35.5)	96 (37.4)
Primary school	129 (63.6)	226 (55.4)	144 (56.0)
Secondary school or higher	22 (10.8)	37 (9.1)	17 (6.6)
Paternal education			
None	38 (23.8)	83 (27.0)	48 (21.7)
Primary school	93 (58.1)	182 (59.1)	146 (66.1)
Secondary school or higher	29 (18.1)	43 (14.0)	27 (12.2)
Parity			
1 child or none	56 (27.6)	86 (21.1)	24 (9.3)***
2 or more children	147 (72.4)	322 (78.9)	233 (90.7)***
Family size	6.5 ± 3.0	6.4 ± 2.5	6.7 ± 2.4
Household wealth quintile			
First (lowest)	32 (15.8)	81 (19.9)	60 (23.4)
Second	45 (22.2)	112 (27.5)	74 (28.8)
Third	29 (14.3)	51 (12.5)	29 (11.3)
Fourth	48 (23.7)	84 (20.6)	50 (19.5)
Fifth (highest)	49 (24.1)	80 (19.6)	44 (17.1)
Household food expenditure (Tanzanian shillings)	7,639 ± 4,076	7,297 ± 3,440	7,141 ± 5,137***
HANU assignment			
Treatment	87 (42.9)	205 (50.3)	155 (60.3)**
Control	116 (57.1)	203 (49.8)	102 (39.7)**
Plot size (acres)	2.8 ± 2.5	3.1 ± 3.8	4.1 ± 3.9***
Livestock ownership, mean (± SD)			
Chickens	9.7 ± 8.2	9.2 ± 15.2	9.3 ± 15.1
Goats	1.2 ± 4.6	1.2 ± 4.2	0.8 ± 2.7
Sold at least 1 crop in the previous year	64 (31.5)	201 (49.3)	177 (68.9)***
Distance to market (km) Median (IQR)	0.9 [0.6–1.3]	1.1 [0.8–1.5]	1.4 [0.9–5.7]***
PDQS Median (IQR)	19.0 [(16.0–21.0)]	19.0 [(17.0–21.0)]	19.0 [(16.0–21.0)]

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Values are mean ± SD, median [IQR], or frequency (percent); PDQS, Prime Diet Quality Score. Chi-square p-values were reported for categorical/binary variables and the Wilcoxon test was for continuous variables. Exchange rate in November 2016: 2,200 Tanzanian shillings per $US1.

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TABLE 2 Proportion of women reporting consumption of PDQS food groups in rural Tanzania.

Healthy foods			
Servings and points	0–1 serving/wk (0 points)	2–3 servings/wk (1 point)	≥4 servings/wk (2 points)
Cruciferous vegetables	706 (81.3)	133 (15.3)	29 (3.3)
Dark leafy green vegetables	137 (15.8)	190 (21.9)	541 (62.3)
Eggs	839 (96.7)	26 (3.0)	3 (0.4)
Fish	5 (0.6)	87 (10.0)	776 (89.4)
Legumes	46 (5.3)	114 (13.1)	708 (81.6)
Liquid vegetable oils[d]	870 (100)	0 (0)	0 (0)
Low-fat dairy[d]	870 (100)	0 (0)	0 (0)
Nuts	793 (91.4)	61 (7.0)	14 (1.6)
Other vegetables	5 (0.6)	20 (2.3)	853 (97.1)
Other vitamin A-rich vegetables (incl. carrots)	469 (54.0)	208 (24.0)	191 (22.0)
Other whole fruits	397 (45.7)	244 (28.1)	227 (26.2)
Poultry	818 (94.2)	40 (4.6)	10 (1.2)
Whole citrus fruits	324 (37.3)	295 (34.0)	249 (28.7)
Whole grains	532 (61.3)	209 (24.1)	127 (14.6)
Unhealthy foods			
Servings and points	0–1 serving/wk (2 points)	2–3 servings/wk (1 point)	≥4 servings/wk (0 points)
Desserts and ice cream[a]	190 (21.9)	307 (35.4)	371 (42.7)
Fried foods away from home	830 (95.6)	33 (3.8)	5 (0.6)
Potatoes[b]	29 (3.3)	121 (13.9)	718 (82.7)
Processed meats[d]	870 (100)	0 (0)	0 (0)
Red meats	777 (89.5)	83 (9.6)	8 (0.9)
Refined grains, baked goods[c]	0 (0)	0 (0)	868 (100)
Sugar-sweetened beverages	566 (65.2)	193 (22.2)	109 (12.6)

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, wk, week. Values are mean ± SD, median [IQR], or frequency (percent); PDQS, Prime Diet Quality Score. [a]The desserts and ice cream group includes cakes, doughnuts, rice cake, honey, and ice cream. [b]A roots and tubers group was used in place of a "potatoes" group in the original score. This category includes potatoes, sweet potatoes, and taro. [c]Maize flour-based products are classified as refined grains. [d]Processed meat intake, low-fat dairy, liquid vegetable oil, and were not measured in the study, therefore all women were assigned low intake for these groups, that is 2 points for processed meats and 0 points for the others.

other household members in food crop farming (estimate: 0.67, 95% CI: 0.10, 1.23), cash crop farming (estimate: 1.05, 95% CI: 0.16, 1.95), livestock farming (estimate: 1.33, 95% CI: 0.95, 1.72), wage and salaried employment (estimate: 0.87, 95% CI: 0.64, 1.10), major (estimate: 0.44, 95% CI: 0.17, 0.72) and minor household expenditures (estimate: 0.96, 95% CI: 0.50, 1.43) had higher PDQS.

With respect to adequate input in decision-making, we found that women with adequate input in decision-making on wage and salary employment had 4.19 (95% CI: 2.80, 5.57) points higher PDQS compared to women with inadequate input (Table 4). In addition, women with adequate input in minor expenditures had 1.12 (95% CI: 0.78, 1.45) points higher PDQS compared to women without adequate input. However, women reporting adequate input in major household expenditures had lower PDQS (estimate −1.25, 95% CI: −2.39, −0.11), compared to women without adequate input.

Women with adequate independence in decision-making in livestock production had 0.97 (95% CI: 0.05, 1.90) points higher PDQS and women with adequate independence in decision-making in minor household expenditures had 1.35 (95% CI: 0.54, 2.15) points higher PDQS compared to those with inadequate independence. Further, women's adequate decision-making in the use of income from wage and salary employment was associated with a 3.16-point higher PDQS (95% CI: 2.44, 3.87) in adjusted models. Finally, women who participated in more agricultural activities had higher PDQS (tertile 3 vs. 1: estimate: 0.78, 95% CI: 0.38, 1.18) in adjusted models (Table 5).

Discussion

We assessed the associations between women's participation in decision-making in agricultural and household activities and

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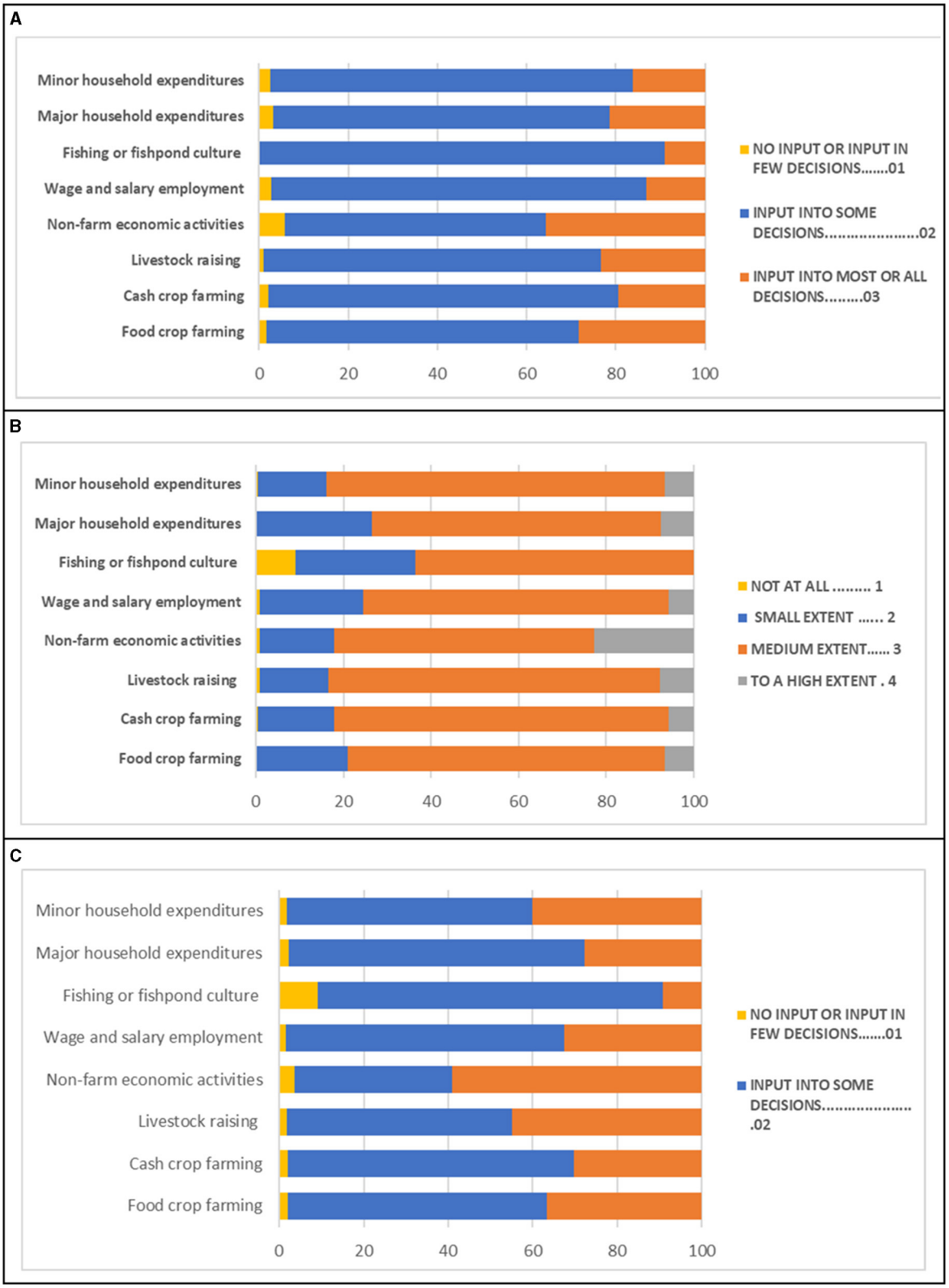

FIGURE 2
Prevalence of **(A)** women's input in decision-making in agricultural activities **(B)** women's extent of independence in decision-making in agricultural activities, and **(C)** women's input in decision-making on the use of income from agricultural activities and for household expenditures in rural Tanzania.

TABLE 3 Associations of women's participation in agricultural and household activities and decisions-making on household life with women's PDQS.

Activity	Woman participates in activity[a]			Woman contributes to decision-making regarding activity[b]		
	n/N	Univariate estimate	Adjusted estimate[c]	*n/N*	Univariate estimate	Adjusted estimate[c]
Food crop farming	674/868	0.15 (0.03, 0.28)*	0.11 (−0.03, 0.24)	528/672	−0.11 (−1.03, 0.81)	0.67 (0.10,1.23)*
Cash crop farming	308/868	0.29 (−0.14, 0.72)	0.11 (−0.27, 0.48)	250/306	0.18 (−0.60, 0.96)	1.05 (0.16, 1.95)*
Livestock raising	162/868	0.40 (0.06, 0.74)*	0.61 (−0.33, 1.55)	132/162	0.18 (−0.31, 0.67)	1.33 (0.95, 1.72)***
Non-farm economic activities	252/868	0.60 (0.22, 0.98)**	0.62 (0.14, 1.10)*	212/252	0.49 (0.13, 0.84)*	0.92 (−0.37, 2.21)
Wage and salary employment	136/868	0.87 (0.43, 1.32)***	1.15 (0.25, 2.04)*	103/136	0.46 (−0.17, 1.10)	0.87 (0.64, 1.10)***
Major household expenditures	190/868	0.86 (0.55, 1.17)***	0.46 (−0.05, 0.97)	130/190	0.50 (−0.58, 1.58)	0.44 (0.17, 0.72)**
Minor household expenditures	602/868	0.31 (−0.33, 0.95)	−0.27 (−1.34, 0.80)	508/602	1.43 (1.04, 1.82)***	0.96 (0.50, 1.43)***

PDQS, Prime Diet Quality Score, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. Generalized estimating equation (GEE) linear models with exchangeable correlation and adjusting for clustering by village pair were used to evaluate the association of women's empowerment with women's diet quality. [a]Woman decision-making in activity alone or jointly with other household members—(see Question 1 of questionnaire in Supplementary Table 1). [b]See Question 2 of questionnaire in Supplementary Table 1). [c]Adjusted models control for treatment assignment (treatment/control), woman's age (18–24 years, 25–34 years, 35–49 years), woman's education (none, primary, secondary and higher), parity (0–1, 2+), wealth index (quintiles), land size (acres), livestock diversity, weekly income (log), household food expenditure (log), and distance to market. Models for fishing are not shown due to non-convergence of models.

TABLE 4 Associations of adequate input in decision-making, extent of decision-making, and adequate input in use of agricultural income with women's PDQS.

Activity	*n/N*	Woman has substantial input in decision-making related to activity[a,d]		Woman can make her own personal decisions regarding activity[b,d]		Woman has substantial decision-making on use of income generated from activity[c,d]	
		Univariate estimate	Adjusted estimate	Univariate estimate	Adjusted estimate	Univariate estimate	Adjusted estimate
Food crop farming	674/868	−0.06 (−0.62, 0.51)	−0.30 (−1.37, 0.77)	0.26 (−0.61, 1.13)	0.65 (−0.07, 1.37)	0.16 (−0.51, 0.83)	−0.14 (−0.72, 0.45)
Cash crop farming	308/868	1.02 (0.25, 1.79)*	0.57 (−1.18, 2.33)	−0.49 (−1.05, 0.07)	−0.87 (−1.88, 0.15)	0.65 (−0.49, 1.79)	0.96 (−1.27, 3.20)
Livestock raising	162/868	1.75 (1.40, 2.09)***	0.11 (−1.17, 1.39)	−0.54 (−2.14, 1.06)	0.97 (0.05, 1.90)*	0.03 (−1.63, 1.69)	1.14 (−0.76, 3.05)
Non-farm economic activities	252/868	0.68 (0.50, 0.87)***	1.08 (−0.04, 2.20)	0.37 (−0.56, 1.31)	1.01 (−1.54, 3.56)	0.37 (−0.50, 1.24)	0.72 (−0.53, 1.97)
Wage and salary employment	136/868	2.66 (2.65, 2.67)***	4.19 (2.80, 5.57)***	−0.22 (−1.94, 1.49)	−0.54 (−2.57, 1.49)	2.63 (2.62, 2.64)**	3.16 (2.44, 3.87)***
Major household expenditures	190/868	0.79 (0.50, 1.07)***	−1.25 (−2.39, −0.11)*	0.97 (0.00, 1.95)*	0.80 (−0.15, 1.75)	1.56 (1.14, 1.98)**	0.81 (−0.81, 2.43)
Minor household expenditures	602/868	0.15 (−0.08, 0.37)	1.12 (0.78, 1.45)**	1.20 (0.53, 1.87)**	1.35 (0.54, 2.15)**	−0.15 (−1.99, 1.69)	0.93 (−0.85, 2.71)

PDQS, Prime Diet Quality Score; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. Generalized estimating equation (GEE) models with exchangeable correlation and adjusting for clustering by village pair were used to evaluate the association of women's empowerment with diet quality. [a]Binary variables for adequate input in decision-making used. Adequate input is defined as input into some, most or all decisions, compared to no input or input into few decisions. A binary variable is used (Y/N) (see Question 3 of questionnaire in Supplementary Table 1). [b]Binary variables for adequate extent of independence in decision-making in agriculture activities used. Adequate extent of decision-making is defined as input to a medium or high extent, compared to no input or input to a small extent. A binary variable is used (Y/N) (see Question 4 of questionnaire in Supplementary Table 1). [c]Binary variables for adequate decision-making on use of income used. Adequate decision-making on use of income from agriculture is defined as input into some, most or all decisions compared to no input or input into few decisions. A binary variable is used (Y/N) (see Question 5 of questionnaire in Supplementary Table 1). [d]Adjusted models control for treatment assignment (intervention vs. control), woman's age (18–24 years, 25–34 years, 35–49 years), women's education (none, primary, secondary, and higher), parity (0–2, 3+), wealth index (quintiles), land size (acres), weekly income (log), food expenditure (log), and distance to market. Model for livestock excludes food expenditure to enable convergence of model. [e]Models for fish farming are excluded due to non-convergence.

TABLE 5 Associations of women's participation in agricultural and household activities with women's PDQS.

	Women's participation in agriculture score[a]			
	Tertile 1 (0–1)	Tertile 2 (2, 3)	Tertile 3 (4–8)	
	$N = 203$	$N = 408$	$N = 257$	P for trend
PDQS, Mean (SD)	18.51 ± 2.78	18.86 ± 2.68	18.93 ± 2.98	
Univariate	ref	0.57 (0.19, 0.94)*	1.16 (0.72, 1.59)***	<0.001
Multivariate[b]	ref	0.35 (−0.47, 1.17)	0.78 (0.38, 1.18)***	<0.001

PDQS, Prime Diet Quality Score, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Generalized estimating equation (GEE) linear models with exchangeable correlation, controlling for clustering by village pair, were used to evaluate the association of women's empowerment with maternal diet quality. [a]Women's participation is calculated as the number of agricultural activities that women participate in. Classified as tertiles. [b]Adjusted models control for treatment assignment (interventions vs. control), woman's age (18–24 years, 25–34 years, 35–49 years), woman's education (none, primary, secondary and higher), parity (0–2, 3+), wealth index (quintiles), land size (acres), weekly income (log), food expenditure (log), and distance to market.

how they related to their diet quality in rural Tanzania. We found that women's participation in non-farm-economic activities and paid employment and their adequate input and decision-making in the use of income were associated with better diet quality. Women's decision-making and ability to make decisions regarding livestock rearing were also associated with better-quality diets. Finally, women who participated in more agricultural activities were more likely to have better diet quality.

Overall, our study's findings of associations between various dimensions of women's empowerment with diet quality are consistent with previous studies that have shown that women's empowerment is associated with women's diversity. A study in Uganda, Rwanda, Malawi, Zambia, and Mozambique found that women's greater input in production decisions was associated with the higher consumption of dairy products, fruits, and vitamin A-rich vegetables (36). Findings relating women's empowerment in economic domains and better diet quality are consistent with previous studies showing that women's empowerment in credit decisions in Ghana (10), and control over income in Nepal (9), were positively associated with women's dietary diversity. Studies have also shown associations between off-farm income and diets. In India, household access to non-farm income was associated with a lower likelihood of the household consuming poor quality diets (37), and in Nigeria, off-farm income improved household calorie supply (38).

Women's income-based empowerment likely works to enhance diet quality by increasing food purchases for her and her household and also influencing other non-food household expenditures (28). However, we lacked data on food purchases and were unable to empirically confirm this hypothesis. A systematic review found that women's share of household income-earned and share of land owned did not increase household food budgets (39). However, it is plausible that women with greater agency are either able to re-allocate the household budget (shifting it toward themselves rather than increasing it) or were able to start their own food budget (and thus purchase healthier foods for themselves). Future studies should collect detailed data on household and individual food purchases to help unpack the pathways through which income-based empowerment influences diet quality.

Previous studies have also shown associations between women's empowerment with women's diet diversity in Kenya, Ghana, Nepal, India, and Timor Leste (9, 10, 12, 13, 40, 41), as well as women's nutrition status in Benin (42).

We found that when women could make more independent decisions regarding livestock, their diet quality was better. This may be because women view decision-making power as being key to increasing their independence in livestock rearing (43). Livestock can play an important role in providing food and income, as well as increasing women's bargaining power (44). This is particularly true for small livestock that tend to be considered a women's responsibility in many LMICs. It is important to note that merely owning livestock is not sufficient for women to benefit, as they often have limited ownership rights pertaining to livestock, have restricted decision-making power and control over income, and are not often prioritized for access to livestock products (45). Therefore, control of resources related to livestock and decision-making around livestock may be crucial for women's diets, as well as, for their children (44). In our study, most households owned chickens and goats and we hypothesized that women may have benefitted from consuming poultry and other related products and from derived income from the sale of the livestock and their products.

The finding that participation in more agricultural activities was associated with better quality diets was contrary to some studies. One study in Bhutan suggested that the relationship between women's participation in decision-making in agricultural activities with household dietary diversity may be non-linear, with high levels of participation associated with less diverse household diets (46). Additionally, there is often the concern that participating in numerous agricultural activities increases women's time use burden, and takes away time for nutrition practices, to the detriment of women's nutrition (47). Further, additional energy expenditure by women for example during cultivating periods can adversely affect their nutrition and health (28). We hypothesized that participating in more agriculture activities can be a valuable coping strategy for the most vulnerable households as it helps diversify income and food sources. Higher and more stable income earned from these agricultural activities can then be used by women to procure more nutritious foods. Other studies have also indicated that resources and agency are important to ensure that women optimize their livelihoods and health outcomes (48). In our study, women who participated in more activities had access to larger plots of land and were more likely to sell crops in the previous season. Thus, diversification of agricultural activities could have benefitted women.

The strengths of this study include that it is one of the first studies to relate women's empowerment to the overall quality of diets consumed by women in Tanzania. The limitations of the study include the cross-sectional study design. Further, our paper seeks to investigate dimensions of women's participation in agriculture and how they relate to their diets. However, the limited number of papers on this topic and varying definitions of WE make comparability with other projects and approaches difficult. Finally, the questions that are used for the analysis (and their scoring) are part of the WEIA questionnaire which has been extensively validated (32). However, the independent evaluation of the sub-components has been limited thus far. However, in this study, we are doing construct validation of these sub-components against diet quality for women and this provides valuable information.

Despite these limitations, our findings have important research and policy implications. First, our findings are consistent with prior work using more comprehensive measures of women's empowerment. Thus, we believe that our approach of using simpler, proxy measures for women's empowerment, an approach also used by other scholars, has great promise (9, 10, 36, 49). Adopting simpler measures will make it easier for researchers and programs to evaluate and track progress in women's empowerment. Our findings that women's empowerment was associated with better quality diets suggest that interventions aiming to improve women's diets should explicitly promote women's empowerment. In Tanzania, interventions to promote women's empowerment in livestock rearing, participation in non-farm activities, and decision-making in the use of agricultural and non-agricultural income may be effective at improving women's diet quality. The study findings could be extrapolated to similar rural locations in Tanzania and other LMIC countries in Africa where similar conditions prevail such as limited access to water for vegetable gardening.

In conclusion, we assessed the associations between women's empowerment and diet quality in rural Tanzania. We found that women's input in decision-making about paid employment, women's decision-making in livestock production and minor household expenditures, and decision-making in the use of income from wages and salaried employment were associated with the consumption of better-quality diets. Increasing women's participation and decision-making in these key activities may be an important consideration for agriculture programs and policies that seek to improve women's diets and nutrition.

Data availability statement

The datasets presented in this article are not readily available because of a data transfer agreement between the Harvard T. H. Chan School of Public Health and the Ifakara Health Institute. Requests to access the datasets should be directed to ghp@hsph.harvard.edu.

Ethics statement

The studies involving humans were approved by Ethical approval for the study was provided by the Ifakara Health Institute (IHI) independent research board, the Medical Research Council Committee of the National Institutes of Medical Research (NIMR) in Tanzania (NIMR/HQ/R. 8 a/Vol. IX/2262), and the Harvard T. H. Chan School of Public Health institutional review board. The trial was registered with clinicaltrials.gov (ClinicalTrials.gov NCT03311698). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

IM conceived and designed the study, analyzed the data, and drafted the manuscript. WF was the principal investigator for the parent study, conceived the study, designed the study, interpreted the data, and guided revisions of the manuscript. LB, MB, AB, CC, DM, SB, RN, PW, and SG designed the study, interpreted the data, and guided revisions of the draft manuscript. JK and HM were co-investigators for the study and participated in the study implementation, interpreted the data, and guided revisions of the manuscript. All authors read and approved the final manuscript.

Funding

This study was funded by the IZUMI Foundation. IM was supported by the Feed the Future Innovation Lab for Nutrition at Tufts University in Boston, MA, funded by the United States Agency for International Development, award AID-OAA-L-10-00006. DM was supported by the Fogarty International Center of the National Institutes of Health under award number D43 TW007886/TW/FIC NIH HHS/United States.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1215462/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Review
PUBLISHED 14 March 2024
DOI 10.3389/fpubh.2024.1340149

OPEN ACCESS

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RECEIVED 17 November 2023
ACCEPTED 19 February 2024
PUBLISHED 14 March 2024

CITATION
Pérez-Escamilla R (2024) Food and nutrition security definitions, constructs, frameworks, measurements, and applications: global lessons.
Front. Public Health 12:1340149.
doi: 10.3389/fpubh.2024.1340149

Food and nutrition security definitions, constructs, frameworks, measurements, and applications: global lessons

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Food security (FS) is a powerful social determinant of health (SDOH) and is crucial for human and planetary health. The objectives of this article are to (i) provide clarity on the definitions of FS and nutrition security; (ii) provide a framework that clearly explains the links between the two constructs; (iii) summarize measurement approaches, and (iv) illustrate applications to monitoring and surveillance, policy and program design and evaluation, and research, mainly based on the ongoing rich experience with food insecurity (FI) scales. A clear and concise definition of FI and corresponding frameworks are available. There are different methods for directly or indirectly assessing FI. The best method(s) of choice need to be selected based on the questions asked, resources, and time frames available. Experience-based FI measures disseminated from the United States to the rest of the world in the early 2000s became a game changer for advancing FI research, policy, program evaluation, and governance. The success with experience FI scales is informing the dissemination, adaptation, and validation of water insecurity scales globally. The many lessons learned across countries on how to advance policy and program design and evaluation through improved FS conceptualization and measurement should be systematically shared through networks of researchers and practitioners.

KEYWORDS

food security, nutrition policy, dietary quality, measurement, nutrition security, food access

Introduction

Food security (FS) is a powerful social determinant of health (SDOH) and is crucial for human and planetary health (1). FS is indeed crucial for nations to meet the Sustainable Development Goals (SDGs) and, in turn, the SDGs need to be met to achieve food and nutrition security for all (1). Unfortunately, there are still many misunderstandings and misconceptions about the definition of the construct of FS, how it relates to nutrition security, and which sound frameworks are needed to guide the research and practice work in this field (2). Hence, the objectives of this article are to (i) provide clarity on the definitions of FS and nutrition security; (ii) provide a framework that clearly explains the links between the two constructs; (iii) summarize measurement approaches, and (iv) illustrate applications to monitoring and surveillance, policy and program design and evaluation, and research, mainly based on the ongoing rich experience with food insecurity (FI) scales.

Based on the 1996 World Summit in Rome hosted by the United Nations Food and Agriculture Organization (3), the United Nations World Food Security Committee

defines FS as a condition that exists when "…people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (4).

Consistent with the United Nations World Food Security definition, the U.S. Department of Agriculture (USDA) has defined FS as "access by all people at all times to enough food for an active, healthy life" (5) and specified that "Food security includes at a minimum: (i) the ready availability of nutritionally adequate and safe foods, and (ii) the assured ability to acquire acceptable foods in socially acceptable ways (e.g., without resorting to emergency food supplies, scavenging, stealing, or other coping strategies)," hence endorsing the dimension of social acceptability as a core component of the FS construct (5). Furthermore, the US has expressed that an active, healthy life depends on both adequate amounts of food and the proper mix of nutrient-rich food to meet an individual's nutrition and health needs (ERS-USDA). As a corollary, FI has been defined as a condition that occurs "whenever the availability of nutritionally adequate and safe foods, or the ability to acquire acceptable foods in socially acceptable ways is limited or uncertain" (5).

The definition of FS that has been in place for over three decades has made it clear that FS is a multidimensional construct that includes the following dimensions: *Quantity,* enough calories; Dietary *Quality,* nutritional value of foods; *Food Safety*, foods free of harmful microorganisms or other environmental contaminants; *Suitability,* culturally acceptable; *Psycho-emotional,* anxiety and feelings of deprivation; and *Social Acceptability,* socially acceptable methods for acquiring foods (1, 6, 7).

These definitions of FS were strongly informed by the development of FS experience-based scales based on mixed-methods research conducted with people in the US experiencing FI and hunger (the most extreme form of FI) (8), and led to the development, validation, and launch of the US Household Food Security Survey (USHFSSM) module in 1995 (5) and its subsequent dissemination, adaptation, and validation globally (7, 9, 10).

Nutrition status has been defined as "the assimilation and utilization of nutrients by the body plus interactions of environmental factors such as those that affect food consumption and food security" (11). Hence, it is a construct that needs to be assessed and understood by researchers, program evaluators, and policymakers at the level of the individual's organism. Indeed, Smith presented a clear food and nutrition security multilevel framework (12) adapted from Frankenberger (13) and UNICEF (14), ranging from the global to the individual level to understand the strong relationship between FS and nutrition security and their distinct characteristics (Figure 1).

Extensive research involving experience-based FS scales has shown that in human societies, FS needs to be understood at the household level, and that it is a SDOH that, in turn, is strongly determined by socio-economic status and social class (7). FS relies on stable economic, physical, and social access to diverse, healthy, and nutritious foods that are culturally acceptable in the communities where the households are located. This access, in turn, depends on regional, national, and global availability of such foods. Currently, the global availability of these foods is constantly threatened by climate change and armed conflicts across the globe (1).

Nutrition security among individuals is determined by FS in combination with other SDOH, including healthcare access,

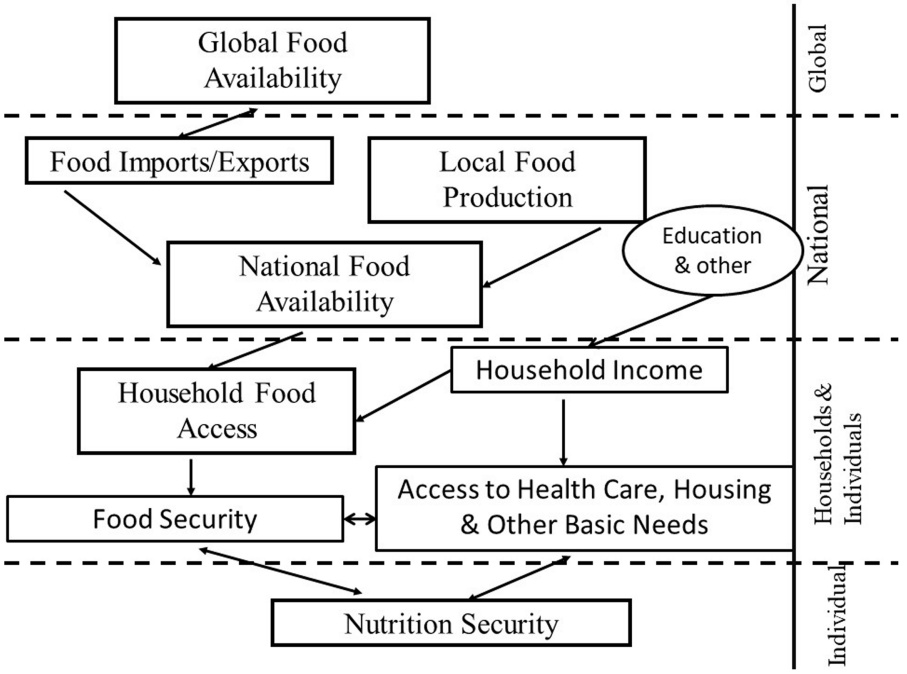

FIGURE 1
The relationships between global food security, household food security, and nutrition security. Adapted with permission from Smith (12), Frankenberger et al. (13), and UNICEF (14).

housing, and other basic human needs such as water security (3, 4, 15).

Food and nutrition security sits right at the intersection of public health and human rights, as reflected in articles from the UN Charter on the Right to Adequate Food (16). For instance, *Articles 11 and 12* of the *International Covenant on Economic, Social, and Cultural Rights (ICESCR)* along with children's rights to food, health, care, survival, and development; *Articles 6, 24, and 27 of the Convention on the Civil Rights of the Child (CRC)* detailing the rights of mothers to adequate nutrition during pregnancy and lactation; and Article *12.2 of the Convention on the Elimination of all forms of Discrimination Against Women (CEDAW)* highlight this intersection. These articles reflect the universal, indivisible, interrelated, and interdependence of the human right to food.

The definition of food and nutrition security in Brazil is an example of how a country can incorporate the domains of human rights, taking the SDOH and environmental sustainability into account. Specifically, the Brazilian Government defines food and nutrition security based on its Organic Law on Food and Nutritional Security (LOSAN—Law No. 11.346, issued on 15 September 2006) as "the realization of everyone's right to regular and permanent access to quality food, in sufficient quantity, without compromising access to other essential needs, based on health-promoting food practices that respect cultural diversity and are environmentally, culturally, economically and socially sustainable" (17).

It is clear from the definitions of FS used internationally and within countries that the construct of FS has four interrelated dimensions: food availability, access, utilization, and stability (4). Since access to food is key for food and nutrition security, it is important to understand what this construct means and its domains. Food access centers on the stable availability of nourishing, affordable, and suitable food access, shaped by diverse economic, social, commercial, and political structural factors. Physical and economic access to nutritious foods coming from sustainable food production systems are important elements of the food access construct. Hence, the construct of food access has five dimensions: food availability, proximity, affordability, acceptability, and accommodation to cultural preferences (18).

Food and nutrition security can only be attained with stable access to healthy, nutritious, and sustainable diets. These diets should avoid or strongly minimize the inclusion of ultra-processed foods and beverages and maximize the intake of unprocessed or minimally processed foods such as fresh fruits and vegetables, whole grains, and sustainable protein sources, prepared in healthy ways, as well as water (19–21).

Food security assessment methods

There are different methods to assess different dimensions of FS, including aggregated availability to adequate calories and FAO balance sheets; individual-level dietary intake with 24-h recalls, Food Frequency Questionnaires, and/or food records; anthropometry; and biomarkers such as blood levels of iron and other micronutrients (6). However, the only method currently available to directly assess household FS is through experience-based scales, almost all of which are derived from the USHFSSM (6, 22). All the methods have strengths and weaknesses related to specificity, ease of application, data collection speed, cost, and measurement errors, they complement each other, and the choice of method(s) depends on the question(s) being asked (22). For example, a comprehensive assessment of the nutritional status of individuals requires evaluation of their food consumption patterns and FI status as well as examining biochemical, clinical, and anthropometric indices of their nutritional status (11).

Given the rapid dissemination and utilization of experience-based scales globally, the following subsection focuses on them.

Experience-based food security scales

The origin of experience-based scales dates back to the 1980s when ethnographic research conducted in upstate New York with people who had experienced hunger and FI suggested that FI could be understood as a stepwise process that starts with household members worrying about food running out followed by sacrificing dietary quality and eventually calories are first reduced among adults and last among children living in the household (6). Subsequently, FS experience-based scales were developed by researchers to capture this sequence of events as reported by a household informant. The strong validity of the scale provided a strong impetus for the US Government to bring together a group of experts to develop what became the USHFSSM, which was heavily influenced by the Radimer/Cornell Hunger scale (23) and the Community Childhood Hunger Identification Project (CCHIP) scale (5, 24, 25). As a result, the USHFSSM has been incorporated since 1995 in the US Census Bureau Continuous Population Survey (CPS) (5) and became incorporated in nationally representative surveys such as the National Health and Nutrition Examination Survey (NHANES) (25) (Table 1).

The specific, measurable, achievable, relevant, and time-bound (SMART) properties of the indicators derived from the USHFSSM led to the global dissemination, adaptation, and validation of the USHFSSM across world regions (26). In Latin America, the experience of the Brazilian Food Insecurity Scale (EBIA) (27, 28), a scale from Colombia (9), and the Household Food Insecurity Access Scale (HFIAS) (29) led to the development of the Latin American Food Security Scale (ELCSA) in strong partnership with FAO's Latin American regional office in Chile (9) (Table 2).

ELCSA was subsequently adopted in additional countries, including Mexico and Guatemala, and it eventually provided the impetus for the development of the Food Insecurity Experience Scale (FIES) that is being used by FAO to track the Sustainable Development Goal 2.1.2 (10) (Table 3).

FS experience scales yield an additive score that allows households to be classified according to their level of severity of FI (mild, moderate, and severe), which has allowed for a better understanding of how to design and target FS policies and programs (6). This is because different levels of severity of FI represent different issues ranging from psycho-emotional stress to poor dietary quality all the way to excessive hunger, which requires different solutions (30) (Figure 2).

Application of food security experience scales across world regions

FS experience scales have allowed countries, regions, and the world to have better estimates of the burden of FI in the world. Based on FIES, in 2022, 29.6% of the global population, or 2.4 billion people,

TABLE 1 The US Household Food Security Survey Module.[a,b]

#	Question	Response options
Items in reference to the whole household[c]		
1	The first statement is "(I/We) worried whether (my/our) food would run out before (I/we) got money to buy more." Was that often true, sometimes true, or never true for (you/your household) in the last 12 months?	Often true Sometimes true Never true DK or Refused
2	The food that (I/we) bought just did not last, and (I/we) did not have money to get more. Was that often, sometimes, or never true for (you/your household) in the last 12 months?	Often true Sometimes true Never true DK or Refused
3	(I/we) could not afford to eat balanced meals. Was that often, sometimes, or never true for (you/your household) in the last 12 months?	Often true Sometimes true Never true DK or Refused
Items in reference to adults in the household In the last 12 months…		
4	Did (you/you or other adults in your household) ever cut the size of your meals or skip meals because there was not enough money for food?	
4a	How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?	Almost every month Some months but not every month Only 1 or 2 months DK
5	Did you ever eat less than you felt you should because there was not enough money for food?	Yes No DK
6	Were you ever hungry but did not eat because there was not enough money for food?	Yes No DK
7	Did you lose weight because there was not enough money for food?	Yes No DK
8	Did (you/you or other adults in your household) ever not eat for a whole day because there was not enough money for food?	Yes No DK
8a	How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?	Almost every month Some months but not every month Only 1 or 2 months DK
Items in reference to children in the household In the last 12 months…		
9	(I/we) relied on only a few kinds of low-cost food to feed (my/our) (child/the children) because (I was/we were) running out of money to buy food in the last 12 months?	Often true Sometimes true Never true DK or Refused
10	Could not feed (my/our) (child/the children) a balanced meal, because (I/we) could not afford that in the last 12 months?	Often true Sometimes true Never true DK or Refused
11	(My/Our child was/The children were) not eating enough because (I/we) just could not afford enough food in the last 12 months?	Often true Sometimes true Never true DK or Refused
12	Did you ever cut the size of (your child's/any of the children's) meals because there was not enough money for food?	Yes No DK

(Continued)

TABLE 1 (Continued)

#	Question	Response options
13	Did (CHILD'S NAME/any of the children) ever skip meals because there was not enough money for food?	Yes No DK
13a	How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months?	Almost every month Some months but not every month Only 1 or 2 months DK
14	(Was your child/were the children) ever hungry but you just could not afford more food?	Yes No DK
15	Did (your child/any of the children) ever not eat for a whole day because there was not enough money for food?	Yes No DK

[a]Adapted from: https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-u-s/survey-tools/#household.
[b]Questions 1 through 15 (including 1a, 4a, and 13a) comprise the 18-item U.S. Household Food Security Scale (questions 1 through 8a for households with no child present). Specification of food security status depends on the raw score and whether there are children in the household (i.e., whether responses to child-referenced questions are included in the raw score).
[c]If single adult in the household, use "I," "My," and "You" in Parentheticals; otherwise, use "we," "our," and "your household". For households with one or more children: Raw score zero—High food security; 1-2—Marginal food security; 3-7—Low food security; 8-18—Very low food security. For households with no child present: Raw score zero—High food security; 1-2—Marginal food security; 3-5—Low food security 6-10—Very low food security. Households with high or marginal food security are classified as food secure. Those with low or very low food security are classified as food insecure. Questions 1 through 8a (including 4a) comprise the U.S. Adult Food Security Scale. Raw score zero—High food security among adults; 1-2—Marginal food security among adults; 3-5—Low food security among adults; 6-10—Very low food security among adults. Questions 2 through 6 (including 4a) comprise the six-item Short Module from which the six-item Food Security Scale can be calculated. Raw score 0-1—High or marginal food security (raw score 1 may be considered marginal food security, but a large proportion of households that would be measured as having marginal food security using the household or adult scale will have a raw score of zero on the six-item scale); 2-4—Low food security; 5-6—Very low food security. Questions 9 through 15 (including 13a) comprise the U.S. Children's Food Security Scale. Raw score 0-1—High or marginal food security among children (raw score 1 may be considered marginal food security, but it is not certain that all households with a raw score of zero have high food security among children because the scale does not include an assessment of the anxiety component of food insecurity); 2-4—Low food security among children; 5-8—Very low food security among children.

TABLE 2 Latin American and Caribbean Food Security Scale (ELCSA).[1]

Questions referring to the household or adults living in the household[2]
During the last 3 months, because of lack of money or other resources…
1 Were you worried about running out of food?
2 Did your household run out of food at any time?
3 Was your household unable to eat a healthy and nutritious diet?
4 Did you or anybody else in your household usually have to eat the same kinds of foods almost every day?
5 Did any day, you or any other adult in your home skip breakfast, lunch, or dinner?
6 Did any adult in your home eat less food than what you think s/he needed because there was not enough food?
7 Was there any day when you or any other adult in your home felt hungry but did not eat because there was not enough food?
8 Was there any day when you or any other adult in your home did not eat for a whole day or just ate once during the day because there was not enough food during the last 3 months?
Questions for households with minors under 18 years of age[2]
During the last 3 months, because of lack of money or other resources…
9 Did any children/youth in your household unable to consume a healthy and nutritious diet?
10 Did any children/youth in your household usually have to eat the same kinds of foods almost every day?
11 Did any child/youth in your household eat less food than what s/he needs because there was not enough food?
13 Did any day you have to reduce the amount of food served to children/youth in your household?
14 Was there any day when any child/youth in your household felt hungry but could not be fed because there was not enough food?
15 Was there any day when any child/youth in your household did not eat for a whole day or just ate once during the day because there was not enough food?

[1]Adapted from Comité Científico de la ELCSA (9). Escala Latinoamericana Y Caribeña De Seguridad Alimentaria (ELCSA): Manual De Uso y Aplicaciones. FAO, Santiago, Chile. Available from http://www.fao.org/3/i3065s/i3065s.pdf. [2]Response options: Yes, No, Do not Know, Refuse. An additive score is computed based on the number of questions affirmed, Cutoff points for households with children/youth: 'household food secure' (score = 0), 'mild household food insecurity (score = 1–5), 'moderate household food insecurity' (score = 6–10), 'severe household food insecurity' (score = 11–15). Cutt-off points for households with members above the age of 18: 'household food secure' (score = 0), 'mild household food insecurity' (score = 1–3), 'moderate household food insecurity' (score = 4–6), 'severe household food insecurity' (score = 7–8).

were moderately or severely FI (31). This meant that there were 391 million more people experiencing moderate or severe FI in 2022 than in 2019, before the outbreak of the COVID-19 pandemic (31). Furthermore, significant inequities existed based on the economic development of countries, the area of residence (rural vs. peri-urban vs. urban), and sex (female vs. male) (31).

TABLE 3 Food Insecurity Experience Scale.[a,b]

Question	Response options	
Q1. During the last 12 months[c],**was there a time when you were worried you would not have enough food to eat because of a lack of money or other resources?**	0 No 1 Yes	98 DK 99 Refused
Q2. Still thinking about the last 12 months,**was there a time when you were unable to eat healthy and nutritious food because of a lack of money or other resources?**	0 No 1 Yes	98 DK 99 Refused
Q3. During the last 12 months,**was there a time when you ate only a few kinds of foods because of a lack of money or other resources?**	0 No 1 Yes	98 DK 99 Refused
Q4. During the last 12 months,**was there a time when you had to skip a meal because there was not enough money or other resources to get food?**	0 No 1 Yes	98 DK 99 Refused
Q5. Still thinking about the last 12 months,**was there a time when you ate less than you thought you should because of a lack of money or other resources?**	0 No 1 Yes	98 DK 99 Refused
Q6. In the past 12 months,**was there a time when your household ran out of food because of a lack of money or other resources?**	0 No 1 Yes	98 DK 99 Refused
Q7. In the past 12 months,**was there a time when you were hungry but did not eat because of a lack of money or other resources for food?**	0 No 1 Yes	98 DK 99 Refused
Q8. During the last 12 months,**was there a time when you went without eating for a whole day because of a lack of money or other resources?**	0 No 1 Yes	98 DK 99 Refused

[a]Adapted from https://www.fao.org/3/bl404e/bl404e.pdf.
[b]For household level (vs. individual level) FI assessment substitute 'was there a time when you…you' with 'was there a time when you or others in your household…' Raw additive scores are used to classify households into food secure, mildly FI, moderately FI, or severely FI.
[c]Time frame can also be the previous 4 weeks. In this case, if questions 6, 7, and 8 are affirmed, then each of them needs to be followed by 'How often did this happen in the past 4 weeks?' with response options: Rarely (1 or 2 times); Sometimes (3–10 times); Often (more than 10 times); Do not Know; Refused.

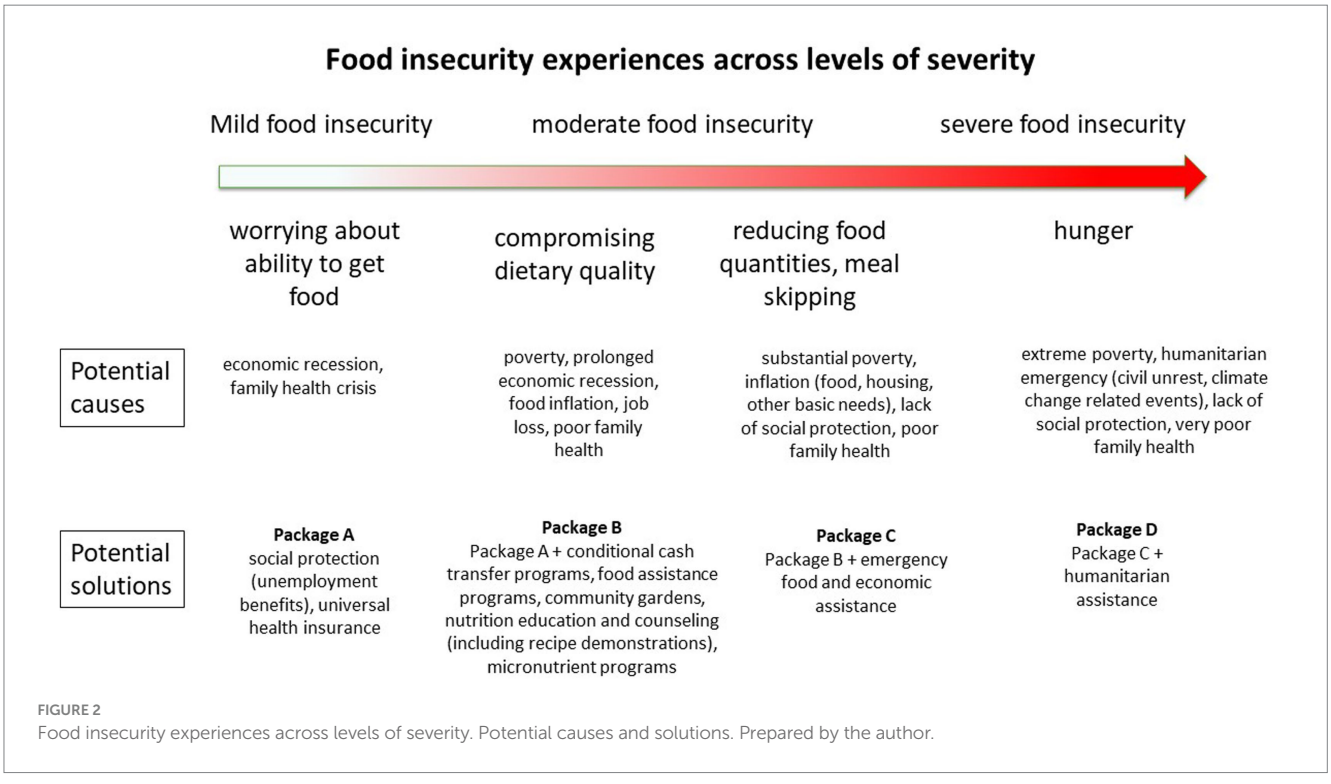

FIGURE 2
Food insecurity experiences across levels of severity. Potential causes and solutions. Prepared by the author.

FS experience scales have allowed researchers to better understand the links between FI and (i) the triple burden of malnutrition (undernutrition, obesity, and climate change) (32); (ii) infectious diseases including COVID-19, and common childhood communicable diseases in low- and middle-income countries; (iii) poor mental health across the life course; and (iv) poor early childhood development; (v) and poor medication adherence to treatments (1, 7, 30–39).

Furthermore, from a policy and programmatic perspective, FS experience scales have been useful for supporting equitable social policy investments (30, 31) across countries and for holding governments accountable when FI rates increase, as recently shown in Brazil, and the number of people affected by severe FI increased from 10 million to 30 million between 2018 and 2022 (40, 41). They have also been used to assess the impact of specific programs, including the

SNAP programs in the US (26) and conditional cash transfer programs in Mexico (42) and Brazil (40).

Food and water insecurity

The profound link between water and FI in a highly unstable world highlighted the need to consider the use of water insecurity experience scales such as the Household Water Insecurity Experiences (HWISE) alongside the FI scales (15). The 12-item HWISE scale yields an additive score that, combined with a pre-established cutoff point, allows households to be categorized as water-secure or insecure (43) (Table 4). HWISE assesses the frequency in the previous 4 weeks that anyone in the household experienced any of 12 negative emotions (e.g., worry, anger, and shame), disruptions in daily life (e.g., inability to wash clothes, hands, or take a bath), or even unsatisfied thirst due to water insecurity. Research using HWISE has shown that WI is strongly and consistently associated with FI all over the world (15, 44), as well as with physical and mental health outcomes (45–48). Similar to food, access to safe water is a human right recognized by the UN charter since 2010 (15, 43), and it is important to track it as part of the SDGs with an experience scale as it is done for FS (45).

Inspired by the experience with EBIA, Brazil recently applied the HWISE in a nationally representative sample to document the prevalence of WI during the COVID-19 pandemic and how strongly it relates to FI (41). Findings showed that 12% of households experienced WI in Brazil and that among those with WI, 42% experienced severe FI (vs. 12.1% in water-secure households) (43). Mexico has now also included HWISE and a water intermittency scale in nationally representative surveys. The application of HWISE in the National Health and Nutrition Survey (ENSANUT)-2021 demonstrated that HWISE has strong psychometric and predictive validity in the Mexican context (49), and its application through another nationally representative public opinion poll showed that 32% of Mexican households experienced water insecurity and that 68% of households experiencing severe FI were also experiencing WI (vs. 17% in FS households) (50). Furthermore, the application of a water intermittency scale in ENSANUT-2022 found that only 31.5% of Mexican households had water 7 days per week, and of these, only 17.4% did not experience water scarcity in the previous 12 months (51). As expected, water intermittency was more common in the poorest region of Mexico and among the poorest families, confirming that the distribution of WI follows the same social, economic, and demographic inequity patterns as FI.

Cross-border lessons learned

There are indeed key lessons learned that show how cross-border collaborations have advanced and can continue advancing FI solutions across borders and world regions.

The strong global consensus on the definition of FI and the development of sound conceptual frameworks explaining its determinants at multiple levels and how, together with other SDOH links with nutrition security, allowed for the development of FI measurement approaches that have helped understand the causes,

TABLE 4 Household Water Insecurity Experience Scale (HWISE).[a,b]

Dimension	Question
Worry	1 In the last 4 weeks, how frequently did you or anyone in your household worry you would not have enough water for all of your household needs?
Interrupt	2 In the last 4 weeks, how frequently has your main water source been interrupted or limited (e.g., water pressure, less water than expected, and river dried up)?
Clothes	3 In the last 4 weeks, how frequently have problems with water meant that clothes could not be washed?
Plans	4 In the last 4 weeks, how frequently have you or anyone in your household had to change schedules or plans due to problems with your water situation? (Activities that may have been interrupted include caring for others, doing household chores, agricultural work, income-generating activities, sleeping, etc.)
Food	5 In the last 4 weeks, how frequently have you or anyone in your household had to change what was being eaten because there were problems with water (e.g., for washing foods, cooking, etc.)?
Hands	6 In the last 4 weeks, how frequently have you or anyone in your household had to go without washing hands after dirty activities (e.g., defecating or changing diapers, cleaning animal dung) because of problems with water?
Body	7 In the last 4 weeks, how frequently have you or anyone in your household had to go without washing their body because of problems with water (e.g., not enough water, dirty, unsafe)?
Drink	8 In the last 4 weeks, how frequently has there not been as much water to drink as you would like for you or anyone in your household?
Angry	9 In the last 4 weeks, how frequently did you or anyone in your household feel angry about your water situation?
Sleep	10 In the last 4 weeks, how frequently have you or anyone in your household gone to sleep thirsty because there wasn't any water to drink?
None	11 In the last 4 weeks, how frequently has there been no useable or drinkable water whatsoever in your household?
Shame	12 In the last 4 weeks, how frequently have problems with water caused you or anyone in your household to feel ashamed/excluded/stigmatized?

[a]Adapted from https://arch.library.northwestern.edu/concern/generic_works/kk91fk74c.

[b]Each item is phrased to capture experiences that anyone in the household has had in the last 4 weeks. Responses to items are never (0 times), rarely (1–2 times), sometimes (3–10 times), often (11–20 times), and always (more than 20 times). Never is scored as 0, rarely is scored as 1, sometimes is scored as 2, and often/always is scored as 3. Households with a score > 12 are classified as water insecure.

consequences, and potential solution to FI across and within countries (1, 7, 9, 10, 26).

The capacity of countries, regions, and the world to track FI with SMART monitoring and surveillance systems on a continuous basis has been greatly facilitated by the dissemination, adaptation, and validation of the USHFSSM (1, 7, 9, 10, 26). In the US, this scale has been used through the CPS Food Security Supplement, NHANES, the National Health Interview Survey (NHIS), the Early Childhood Longitudinal Survey (ECLS), and other monitoring and surveillance systems across sectors. Latin American countries have included scales derived from the USHFSSM, such as EBIA (28) and ELCSA (9), as part of the countries' national health and nutrition surveys, household income expenditure surveys, public opinion polls, and state and local monitoring systems. At a global level, FIES is used to track SDG 2.1.2, and in fact, FIES was instrumental in the addition of this target to the SDGs. As previously mentioned in this article, all the methods for assessing FI complement each other. Hence, it is encouraging that comprehensive multi-methods monitoring systems have also been developed, such as the food systems dashboard (52) and a low-burden tool for collecting valid, comparable food group consumption data through the "What the World Eats" initiative (53, 54).

FI experience scales have been shown to be helpful for food and nutrition security policies and program designs, including program targeting and evaluation. A robust body of evidence confirms that FI experience scales yield SMART indicators that can help improve FS governance across countries and regions (17, 26, 40, 55).

Conclusion

A clear and concise global definition of FI and corresponding frameworks are in place. Countries such as Brazil have strengthened the definition of food and nutrition security by incorporating human rights and the sustainability dimension, which they have clearly operationalized through the country's progressive food and nutrition security policies and dietary guidelines (21). There are different methods for directly or indirectly assessing FI. The best method(s) of choice need to be selected based on questions asked, resources, and time frames available. Experience-based FI measures disseminated from the United States to the rest of the world in the early 2000s became a game changer for advancing FI research, policy, and program evaluation. The success of experience-based FI scales is informing the dissemination, adaptation, and validation of WI scales globally. The rich lessons learned across countries on how to advance policy and program design and evaluation through improved FS conceptualization and measurement should be systematically shared through networks of researchers and practitioners such as the recently established Water Insecurity Experiences-Latin America and the Caribbean (WISE-LAC) Network (56).

Author contributions

RP-E: Conceptualization, Investigation, Project administration, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. The author received funding support from the NIH Fogarty International Center. This work was also supported by the Cooperative Agreement Number 5 U48DP006380–02-00 funded by the Centers for Disease Control and Prevention, Prevention Research Center Program (PI. Rafael Pérez-Escamilla). The funders did not participate in the development of this manuscript. The contents of this article are solely the responsibility of the author and do not necessarily represent the official views of the Centers for Disease Control, the Department of Health and Human, or the NIH Fogarty International Center.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 20 March 2024
DOI 10.3389/fpubh.2024.1295291

OPEN ACCESS

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RECEIVED 15 September 2023
ACCEPTED 26 February 2024
PUBLISHED 20 March 2024

CITATION
Rhodes EC, Pérez-Escamilla R, Okoli N, Hromi-Fiedler A, Foster J, McAndrew J, Duran-Becerra B and Duffany KO (2024) Clients' experiences and satisfaction with produce prescription programs in California: a qualitative evaluation to inform person-centered and respectful program models. *Front. Public Health* 12:1295291. doi: 10.3389/fpubh.2024.1295291

Clients' experiences and satisfaction with produce prescription programs in California: a qualitative evaluation to inform person-centered and respectful program models

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Background: Produce prescription programs have strong potential to improve food security, fruit and vegetable consumption, and health across the life course. Understanding clients' experiences and satisfaction with produce prescription programs is critical for evaluating the person-centeredness and quality of these programs. The objectives of this study were to (1) describe client experiences and satisfaction with produce prescription programs, with an emphasis on the extent to which they felt they were treated with respect and dignity, and (2) identify recommendations for improving client experiences.

Methods: We conducted four focus group discussions with clients of produce prescription programs in two Federally Qualified Health Centers in California. We used a modified framework analysis approach and organized participants' experiences with programs into themes.

Results: Three themes captured participants' program experiences. First, *respectful produce prescription programming* encompassed interactions with individuals delivering the programs that felt respectful (e.g., program staff showing they cared about participants' health and offering timely assistance with financial incentives) and disrespectful (e.g., not receiving prompt responses to questions about incentives), as well as aspects of program design perceived to be respectful (e.g., provision of gift cards as financial incentives, which offered privacy when purchasing produce). Second, having *autonomy* to use gift cards to choose their preferred fresh fruits and vegetables was viewed as a positive experience, though participants desired greater autonomy to shop at stores other than the program designated stores. Third, participants frequently discussed *program usability*, with some reporting that joining the programs and using the cards was easy, and others describing difficulties activating cards and using them at stores due to cashiers' lack of awareness of the programs. Overall, participants were highly satisfied with the programs. To improve client experiences, they recommended increasing privacy (e.g., by educating cashiers

on the programs so that clients do not need to explain in public what the card is for) and autonomy (e.g., allowing cards to be used at other chain or local stores).

Discussion: Our findings inform efforts to make produce prescription programs more person-centered and respectful, which in turn may increase program demand, engagement, and impact.

KEYWORDS

person-centered, qualitative research, food security, produce prescription, United States

1 Introduction

The United States (US) is facing the large and growing threat of food insecurity, defined as a lack of continuous access through socially acceptable means to nutritious and safe foods in the amounts needed for a healthy and active life (1). Disproportionately affecting those living in poverty and low-resource settings, food insecurity drives health inequities through multiple pathways such as poor-quality diets, particularly high consumption of low-cost, energy-dense ultra-processed foods and sugar-sweetened beverages and low intake of water, fruits, vegetables, whole grains, and other healthy foods (2). Produce prescription programs have gained traction as a "Food is Medicine" intervention that can reduce food insecurity (3).

In these programs, health care providers "prescribe" fruits and vegetables at the same time that they provide patients with vouchers or debit cards that can be used at retail locations to purchase produce, and/or provide access to produce at healthcare facilities or by delivering at home (4, 5). Eligibility for participation commonly includes patients who have or are at risk for diet-related non-communicable diseases like type 2 diabetes and cardiovascular disease, and who experience food insecurity (4, 6). Produce prescription programs for pregnant women and children, adolescents, and their caregivers are also underway (7–10). Mounting evidence suggests that produce prescription programs can generate substantial health and economic benefits. Studies have found that these programs increase purchasing and consumption of fruits and vegetables, reduce food insecurity, and improve health indicators such as body mass index, hemoglobin A1C, and diastolic blood pressure (10–19). A microsimulation model estimated that produce prescription programs implemented nationally for US adults with diabetes and food insecurity could save $39.6 billion in health care costs and $4.8 billion in productivity costs (12). From a health perspective, the intervention was highly cost effective, with an incremental cost-effectiveness ratio of $18,100/quality-adjusted life years (12). It was also cost saving from a societal perspective (12).

As produce prescription programs are adapted to new contexts and scaled, making these programs person-centered is important; that is, they should be "respectful of and responsive to individual preferences, needs, and values" (20). It is now widely recognized that the provision of high-quality health services is essential for improving population health, and that a key element of high-quality services is that they are person-centered (7). Indeed, evidence links positive health service experiences with patient satisfaction, service utilization, and improved health outcomes (21).

Evaluating person-centeredness involves understanding both client experiences and satisfaction with programs (22). Client experiences of programs is a process indicator of person-centeredness, while client satisfaction is an outcome of client experiences of programs that reflects the extent to which the services provided meet their needs and expectations (22). Although a growing body of literature has explored client experiences and satisfaction with produce prescription programs (23–30), there is still a need to better understand whether program clients feel they are treated with respect and dignity, a key domain of positive client experiences (22, 31). Furthermore, more input and insights from clients on how produce prescription programs can promote positive experiences can be useful for informing the design and delivery of person-centered and respectful programs.

The two objectives of this qualitative research study were to (1) describe client experiences and satisfaction with produce prescription programs, with an emphasis on their perceptions of the extent to which they felt they were treated with respect and dignity, and (2) identify recommendations for improving client experiences. Our study can inform program co-design and person-centered implementation of produce prescription programs in similar contexts in the US.

2 Methods

2.1 Study team and reflexivity statement

This research was conducted through an equitable partnership between the Yale-Griffin Centers for Disease Control and Prevention (CDC) Prevention Research Center at Yale School of Public Health (Y-G PRC) and Wholesome Wave, a national organization dedicated to improving health equity by making fruits and vegetables more accessible and affordable. Wholesome Wave funds and supports the implementation of produce prescription programs, and Y-G PRC conducts evaluations of these programs in collaboration with a colleague at Emory University. As part of our collaborative work, we are also leading national efforts to promote person-centered and respectful produce prescription program models. For the present study, staff from Wholesome Wave worked jointly with the study team which included the Y-G PRC team and a colleague from Emory University to develop the research objectives, recruit participants, and develop data collection instruments. The study team members collected and analyzed the data, with Wholesome Wave staff providing contextual information about the produce prescription programs. Together, the authors have rich practice, policy, and/or research experience with food assistance programs, including produce prescription programs. Throughout the research process, the study team practiced reflexivity (32). During team discussions, we acknowledged our

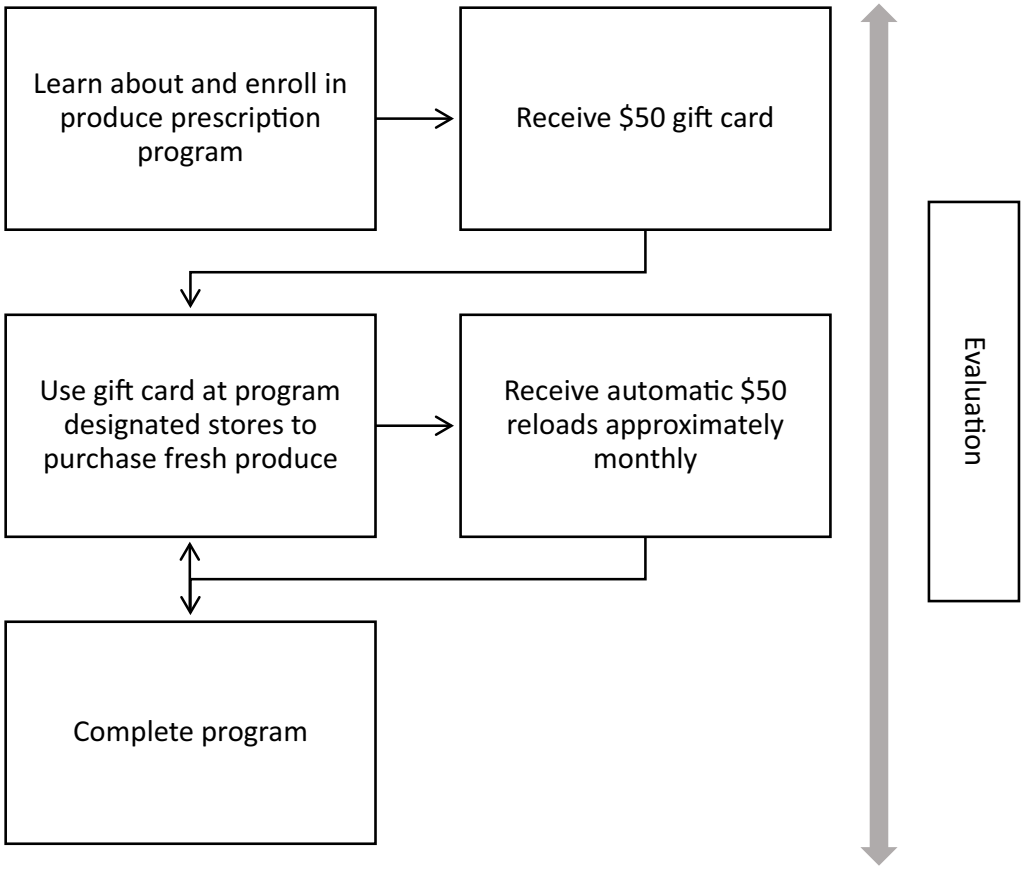

FIGURE 1
Produce prescription program components.

subjectivity based on our own life and professional experiences, including our knowledge, expectations, and views about the programs, and reflected on our potential influence on the research process before finalizing the focus group discussion (FGD) guide and reaching consensus on the organization and interpretation of the data (32).

2.2 Study design, setting, and population

Using a cross-sectional design, we conducted four FGDs with clients from produce prescription programs at two Federally Qualified Health Centers (FQHCs) in Sacramento, California (hereafter referred to as Center A and Center B). Both centers serve predominately low-income populations with a high prevalence of food insecurity. At Center A, the produce prescription program served two population groups: adult parents or guardians of children receiving pediatrics care; and adults with pre-diabetes or type 2 diabetes receiving primary care and participating in the US Diabetes Prevention Program. At Center B, the produce prescription program served adults with pre-diabetes or type 2 diabetes receiving primary care.

2.3 Produce prescription programs

In collaboration with FQHCs, Wholesome Wave designed and began operating the produce prescription programs in 2021. For clients, there were five main program components: (1) learn about and enroll in the program; (2) receive a financial incentive ($50 gift card) to purchase fresh fruits and vegetables at a designated chain of stores that offers a broad assortment of products and sells food at some but not all locations; (3) use the gift card to purchase fresh produce in person at program designated stores (not online); (4) receive automatic reloads of $50 on the gift card approximately monthly for the duration of the program; and (5) complete program evaluation (e.g., surveys, health assessments) (see Figure 1). The role of FQHC providers was to share program information and enroll individuals in the programs, as well as complete health assessments as part of the evaluation of programs. Wholesome Wave staff were responsible for sending and reloading the gift cards and administering the surveys for program evaluation. Wholesome Wave staff also offered assistance via phone and text when clients had questions about the programs or needed help with the gift cards (e.g., activating the cards). Across programs and target populations, there were variations in the level of assistance provided with the enrollment process and completion of evaluation surveys, as well as differences in how clients received the gift card (i.e., in person or via mail). The duration of the programs ranged from 6 to 8 months. We evaluated clients' experiences with all components of the programs including the evaluation, since many produce prescription programs have monitoring and evaluation systems in place.

2.4 Sampling and recruitment

We used purposive sampling to recruit participants for four FGDs and achieve diversity in our sample with regards to client characteristics (i.e., parents or guardians of pediatric patients, people with prediabetes or diabetes) and preferred language (i.e., English, Spanish). Program clients received text messages from Wholesome Wave about the study, and those who expressed interest were called and/or texted by the study team. In total, the study team contacted 57 clients, reached 25, consented 20, and 17 were available to join an FGD.

2.5 Data collection and processing

Qualitative data collection occurred from June to July 2022. Three of the FGDs were conducted with participants who had recently completed the programs, and one FGD was conducted with participants who were active program clients. FGDs were guided by a semi-structured guide, which included a free list activity in which participants were asked open-ended questions that encouraged them to share positive experiences, negative experiences, and recommendations for improving client experiences with each program component, starting with learning about and enrolling in the program and ending with the program evaluation component (Supplementary File 1). A benefit of this FGD guide structure was that the questions followed a logical order for FGD participants, as they mirrored the way in which they progressed through the programs (32). Questions also elicited information about participants' overall satisfaction and views on programs creating opportunities for feedback from clients. To refine the guide, we held several feedback sessions with the Y-G PRC Community Advisory Group to obtain input from community partners and community members. Once the guide was finalized in English, it was translated into Spanish and checked by a native Spanish speaker.

Each FGD was conducted via Zoom by one trained and experienced moderator and one notetaker, lasted approximately 75 min, and was audio-recorded. The moderator and notetaker for the Spanish FGD were both native Spanish speakers. Immediately following each FGD, the notetaker expanded the notes from the discussion and saved the lists of positive experiences, negative experiences, and recommendations generated during the free list activity. An iterative process of data collection was followed whereby the study team held a debriefing session after each FGD to identify issues in the data to explore in more depth in subsequent FGDs (32). These debriefing sessions were also used to reflect on and discuss the data as they were being collected to identify when data saturation was achieved (i.e., the point in data collection when no more new information is being identified and further data collection become redundant) and thus determine when to stop data collection (32, 33). Each audio recording was then transcribed verbatim by a professional transcription and translation service. The audio recording of the FGD conducted in Spanish was transcribed and translated into English, using a simultaneous translation and transcription approach whereby translation and transcription are conducted simultaneously leading to a single transcript in English (32). Research assistants checked each transcript by listening to the full audio recording while reviewing the transcript and made any necessary revisions to ensure accuracy. A research assistant who is a native Spanish speaker and who moderated the Spanish-language FGD checked the translation of that FGD for accuracy and appropriateness to ensure the translation conveyed the correct meaning (32). To maintain the anonymity of participants, identifying information like participant names was then removed from each transcript. FGD participants were mailed a letter and gift card to thank them for their time.

2.6 Data analysis

We used a modified framework analysis approach, which was well-suited to this project given our applied research and practice goals and team that included members with varying levels of qualitative research experience (34, 35). The analysis team included four doctoral-level researchers (ECR, KOD, RPE, JF) and one MPH-level research assistant (NO). Two analysts (ECR, NO) familiarized themselves with the data by reading all four FGD transcripts and then collaboratively and iteratively developed deductive codes from the topics of interest in the FGD guides and components of the programs with the full analysis team. Modifying the framework analysis approach, we also used inductive strategies to identify emergent codes in the data (32, 36). One analyst (NO) applied the coding framework to the FGD transcripts using MAXQDA 2022. This analyst was trained in qualitative research and had a strong understanding of the codes related to the program components as well as other codes given her role in developing the FGD guide, moderating the FGDs, reading the transcripts closely, and contributing to the development of the codebook. A second analyst (ECR) then reviewed the coded transcripts to ensure appropriate application of codes and consistency in the application of the codes across the dataset. Once the data were coded, two analysts (ECR, NO) read the coded segments closely and developed detailed narrative descriptions of the findings for each code, incorporating information from FGD notes and lists generated during the free list activities. These narrative descriptions replaced the tabular summaries of the charting procedures of framework analysis.

To share the findings with key partners, we produced a report of the preliminary findings regarding positive and negative experiences according to each of the program components (Supplementary File 2). For this paper, we conducted an in-depth analysis of participants' experiences with programs to further organize the findings into meaningful themes to support future program improvement. Members of the analysis team generated themes through a collaborative process that involved grouping data on participants' experiences with programs into categories informed by concepts from the literature on user experiences of health services, combining these categories into themes, and reaching consensus on final themes (31, 32). Throughout the analysis process, the data analysts returned to the data, re-reading the full transcripts of all four FGDs multiple times to help ensure that the findings were well grounded in the data (32).

3 Results

Table 1 presents characteristics of the individuals who participated in the FGDs. Most participants were between 18 and 64 years of age. The majority identified as women (82.4%). Participants identified as Black (29.4%), White (23.5%), Latino (29.4%), and Asian (11.8%). Education levels ranged from less than high school/GED through completion of a bachelor's degree. Most participants reported using the gift card one to two times a month.

10.3389/fpubh.2024.1295291

TABLE 1 Characteristics of all focus group discussion participants ($N = 17$).

Characteristics	*N* (%)
Age, categories in years	
18–29	4 (23.5)
30–44	5 (29.4)
45–64	7 (41.2)
65 or over	1 (5.9)
Gender	
Woman	14 (82.4)
Man	3 (17.6)
Non-binary (neither, both, or something else)	0 (0.0)
Race/ethnicity	
Black	5 (29.4)
Asian	2 (11.8)
White	4 (23.5)
Other*	5 (29.4)
Preferred not to report	1 (5.9)
Hispanic/Latino	
Yes	5 (29.4)
Education	
Less than high school/GED	2 (11.8)
High school/GED completed	3 (17.6)
Some college or associate's degree	9 (53.0)
Bachelor's completed	3 (17.6)
Coursework above a bachelor's degree	0 (0.0)
Preferred not to report	0 (0.0)
How often did they use the gift card?	
Less than once a month	1 (5.9)
Once a month	8 (47.0)
Once every two weeks	6 (35.3)
Once a week	1 (5.9)
More than once a week	1 (5.9)

*All participants who reported their race/ethnicity as "other" reported being of Hispanic/Latino origin.

First, we provide an in-depth description of participants' program experiences, organized into three themes: respectful produce prescription programming; autonomy to make food choices and select shopping locations; and program usability. We then present findings regarding participants' satisfaction with the programs, followed by their recommendations for improving client experiences with produce prescription programs.

3.1 Client experiences with produce prescription programs

3.1.1 Respectful produce prescription programming

To participants in most FGDs, respectful produce prescription programs should involve both respectful interpersonal interactions with people delivering the program and program elements that are designed to promote feelings of respect. The extent to which participants felt treated with respect and dignity during interpersonal interactions varied. When describing instances of respectful or disrespectful treatment in interpersonal interactions, participants focused on how clinic staff, program staff, and store employees did or did not practice respectful communication and support. They explained that program staff were helpful during the enrollment process, describing staff as "very sweet" in assisting them with activating their gift cards. Participants in some FGDs pointed out that when offering the program, clinic staff were "very respectful in the way they presented it." For example, clinic staff did not make them feel "ashamed" to use the program and treated them as equals, in contrast to some programs where "people talk down" to them:

> *For me, they didn't treat you like you were lower than anybody. They just had a program. They wanted you to try it. They thought it would benefit you because of whatever my conditions were like that to help us to get better. So it was for something, a positive outcome to help me to be a better person, to be healthier and to eat the right kind of things that most likely I wouldn't eat before.* (FGD 1)

During the program, participants felt that program staff practiced respectful communication and support by explaining information about the program, providing updates about reloads, responding to questions, and resolving issues participants encountered with using the cards. Similarly, participants felt respected when program staff were proactive in their communication, such as providing advance notice of delayed reloads:

> *I've been treated with respect. When I was on the program, … they was going to send the money late on the card, and they texted me ahead of time and tell me that the money was going to be a little bit late.* (FGD 4)

Participants in one FGD felt respected because they had a number to call to check their card balance or ask questions, indicating to them that they had help available if needed. On the other hand, they felt disrespected when they reached out to program staff about card issues or questions about card reloads and did not receive responses:

> *When they're taking us off the program, I think at least, they could tell us that, starting next month you won't be getting anymore refills, because I've been waiting and I text and I text and I ask and no response. So, that's what I think they fall short. They could have texted or sent us that you're going to be discontinued off the program starting next month.* (FGD 4)

Participants also shared that they felt respected when clinic staff, program staff, and store employees were patient or made a concerted effort to assist them. For example, participants reported that store employees were patient with them as they learned how to use their gift cards for the first time. They also shared stories of store employees asking other employees how to process the card when they were unsure themselves and helping to call support when the card would not work. They shared similar stories of clinic staff:

> *So, when I went in [to the clinic] and I told them about [the program], the lady in the front was just like, oh I'm not sure what program exactly that you're talking about, but let me go ahead and get you someone that could possibly know what you're talking about. So she went in the back, got me someone. And then that lady….was the one that was like, oh well I'm surprised that your provider didn't tell you about it. She apologized that the provider didn't tell me about it, so she was just like, I'm sorry that you didn't get the information, but yes, and this is the program that we're offering. And she was able to give me the steps, I got my card literally that day… So whatever the provider lacked in letting me know about it, they definitely picked it up on the reception end of it.* (FGD 2)

In contrast, participants in one FGD reported encounters with clinic staff who did not listen to their requests for a health assessment, "were not very nice" when they asked for a health assessment, or did not make an effort to complete one, despite it being a part of the program.

Program implementers "showing that they really cared" about participants' health and well-being was another key reason participants felt like they were treated with respect and dignity during the programs. Participants described that program staff showed genuine interest in their health and demonstrated they cared by offering the program. When program staff addressed card issues, it also indicated to participants that staff were invested in optimizing their health:

> *When I first took the card out for the first time, I couldn't activate it, and I had to spend my own money. I was a little frustrated about it at first. So, then I got a hold of the Wholesome people and they were [very passionate]. It was like, 'Oh no problem. So sorry this happened to you. This is what you do. A, B and C.' And that and stuff. He goes, 'If it doesn't work for you, please get back to me.' And that made me know that the program wasn't giving us a handout like you see in so many programs… I felt that they genuinely were trying to … help us to eat better, help us to be healthier. Their mind was in the right place.* (FGD 1)

A prominent example of a program design element that fostered a sense of respect included program provided gift cards that afforded clients privacy when purchasing produce, particularly in contrast to more conspicuous forms like EBT cards. Participants in two FGDs shared that they liked the privacy offered by the gift cards. For example, one participant commented, "When you go [to the program designated store], just use as a gift card, nobody have to know what you are buying or what you are cooking or what you do not like, it's all private." In particular, they appreciated that the card did not indicate that they had a health condition like diabetes. As one participant shared, "[The gift card] does not single you out on what you are using it for, for a medical condition or anything like that. Nobody really knows why you are using the card, what it is." Participants also explained that the gift card could not be easily identified by others in the store as cards from a food assistance program, which may make clients more willing to use the cards:

> *I think that the meaning of they making a gift card also makes it respectful because when you pay with this card, it's not like an EBT card. So, you're saying I'm using a gift card to buy these vegetables… some people might feel uncomfortable showing an EBT card at the store. But if you show this card, which is not very common, they'll be like, 'Oh, it's just another gift card. So think that make it more respectful for people to be willing to go to [the store].* (FGD 4)

For participants, another benefit of having cards that others did not know were from a food assistance program was that it prevented them from experiencing poor treatment by store employees, as they had when using benefits from other food assistance programs:

> *Sometimes even with the Food Stamp program or the EBT, sometimes cashiers would look at you and talk to you a certain way. But I didn't experience that with this program. Because I remember one time going to a store, and after I bought my groceries, I was getting ready to pay, the cashier say, "Are you going to pay with EBT?" And so, I pull out cash and it's like the expression on her face changed. But she just assumed that I'm going to pay with EBT without really asking.* (FGD 1)

However, this privacy was disrupted when participants needed to explain to store cashiers what the card was for and how to use it. To ensure maximum privacy, participants noted that they did have the option of using self-checkout for their purchases. In addition to having privacy while buying produce, participants appreciated that the programs did not monitor their food purchases, commenting "you can buy your favorite fruits and vegetables over and over and you do not get a warning, hey, you already bought these vegetables, or anything like that."

While completing program evaluation surveys, participants felt respected. For instance, they perceived baseline survey questions about their past eating habits or medical history to be non-intrusive. In the Spanish-language FGD, participants appreciated that surveys were administered in Spanish, which enabled them to fully express themselves. Additionally, in one FGD, a participant felt that program staff cared about them because survey questions went beyond participants' experiences with the program and inquired about their overall health and well-being:

> *To me, it was showing that they really cared. It was not just about the $50 card. It was about your well-being, that they really were concerned about what your mindset was, what you were going through and also your health. So, it wasn't just about one thing. It was the overall picture, the big picture.* (FGD 1)

3.1.2 Autonomy to make food choices and select shopping locations

Having control over their food choices fostered a sense of autonomy for participants. They expressed appreciation for the autonomy that came with using a gift card, in contrast to receiving a food voucher or box of food. The gift card gave them freedom to choose, unrestricted, both the desired quantity and types of fresh fruits and vegetables. Still, a few participants highlighted that they liked that the gift card could only be used for fruits and vegetables since it promoted healthy eating.

At the same time, they pointed out two elements of the current program design that limited their autonomy. First, the programs did not allow purchases of different types of fruits and vegetables, like frozen produce. Second, the card could only be used at one designated store chain. Participants strongly preferred having more options where they could purchase produce, in part because transportation to stores was a prominent barrier. The cost of gas was a concern for those with a car; for those without a car, getting to the store required finding a ride or using public transportation, which could be difficult. Additionally, since not having a car and/or farther store distance made multiple trips difficult, participants reported having to spend all the card funds in one trip, which they disliked since purchasing fresh fruits and vegetables at one time meant they had to rush to eat or freeze produce before it spoiled:

> *The only problem I have with the program is that you can only use it at [program designated store]. I have a grocery store across the street, but I can't use it across the street. I have to get a ride to [the store]. And if it was for any grocery store, then I could just go by myself and go when I want to. That way, my vegetables don't spoil by getting them all at once.* (FGD 4)

Participants also discussed that the program designated store was not their usual shopping location. In some cases, they wanted to shop at Asian or Mexican grocery stores. Others reported needing to visit multiple stores because they had to make a separate trip to buy produce at the designated store. Additionally, participants pointed out that some program designated store locations, including some closest to them, did not sell food:

> *In most of [the program designated stores], they don't have food there. So, I had to find the ones that had food, and they were pretty much out of my area. So, I'd have to have somebody take me, drive me, to go there. So, I wish it would have it at other stores…You know, stores that we actually go to.* (FGD 1)

Of the program designated stores that sold food, the selection of fresh fruits and vegetables was perceived by some participants to be "limited" and low quality, which meant participants searched for other stores or did not use the cards:

> *I wish [the gift card] wasn't just specifically at [the program designated store]. Because [the program designated store] doesn't always have the best fruit or vegetable and I just feel like, and don't get me wrong sometime I saved up my card almost a hundred dollars just because they didn't have fruits or vegetables for us or at least where it was more like good ones, like a good shipment instead of oh this is bad, just throw it out anyways and sell it.* (FGD 2)

Furthermore, there was consensus that fresh fruits and vegetables at the program designated stores were more expensive than produce at other stores. This was not preferable for participants who wanted to save money.

3.1.3 Program usability

Participants frequently discussed positive experiences with regards to the ease of use of the programs, but also pointed out usability issues that negatively affected their experiences and engagement in the programs. Many participants found the enrollment process to be quick, hassle-free, and "very straightforward." Even participants who described themselves as less tech-savvy or "computer illiterate" found the online sign-up process easy to follow. Some participants received their cards the same day or within a few days after signing up for the program, while others experienced long wait times between signing up and receiving their gift cards.

Most participants reported that activating and using the gift cards at the checkout counter or self-checkout was easy. For some participants, once they "got the hang of" using the cards, it was "very convenient," since all they had to do was swipe the card at the machine at checkout. For some participants, however, the gift cards were not as easy to use. Difficulties with using the gift cards occurred when store cashiers did not know how to process payments using the cards, and when cards would not swipe at card machines. These difficulties frustrated participants, especially when they purchased the items with money they had not budgeted for fresh produce:

> *When I first got the card, [the program designated store] wouldn't accept it at first…I said, "Well, the money's on there." And I didn't*

> *know how explain to them how to take it off. I didn't know. I think they had did it with credit, and I was trying to get them to take it off as a gift card or something…And when I got the groceries that time, I had to pay out of pocket to get it. So, I wasn't too happy about that part.* (FGD 1)

Additionally, some participants found the initial information they received about the program (e.g., instructions on how to use the card, guidelines on foods that could and could not be purchased with the card) easy to follow, while others reported that this information was unclear, leading to confusion over which foods (e.g., pre-cut vegetables, frozen vegetables) could be purchased with gift cards. They described instances when they thought produce like frozen vegetables and pre-packaged salads could be purchased with gift cards, and upon learning at checkout that they could not be, then had to use their own money to pay for these items.

Participants liked that the reloads occurred automatically and that confirmations of the reloads were sent via text message. Moreover, they liked having their cards reloaded automatically around the same time each month because it allowed them to plan their grocery trips in advance. Similarly, they appreciated receiving text messages with their remaining card balance. These aspects of the program were perceived as "convenient" and gave them one less thing to worry about. In the Spanish-language FGD, participants reported receiving text messages in English, making it difficult for them to understand information about card reloads. Participants also discussed differing experiences with regards to being notified about future reloads. Additional challenges arose when gift cards were lost or stolen requiring a replacement, cards were not automatically reloaded due to lack of use when their intention was to save funds to buy produce in bulk, or cards were not reloaded on a regular schedule making it difficult to "budget things" and plan grocery trips, especially when relying on others for transportation to the store. Lastly, some participants did not have clarity on the length of time they could participate in the program and when it would end. In one FGD, a few participants felt that the notification of their final program month came with little warning, making them feel like the program came to a sudden end. Nevertheless, others appreciated having notice that the program was ending, even if they received this notice during the last month of the program.

Regarding the program evaluation, most participants found the surveys to not take too long to complete, and those who completed health assessments liked that they could go to the health centers for the assessments at times that were convenient for them. However, some participants reported that not all clinic staff were aware that the program evaluation involved health assessments, which created confusion and negative encounters for participants during clinic visits and meant clients had to explain the health assessment to clinic staff:

> *I need to say this about the health assessment. In the email that we receive about going to get our blood drawn also says to ask a nurse to weigh the client or the patient and get their blood pressure and height. And I did this multiple times. And I don't know what was going on with [the clinic staff], but they weren't really aware of this program, or at least not everybody was aware. So, every time I went to get my blood drawn, I had to explain the whole process. It's not about my doctor asking me to get my A1C check, it's about this program, blah, blah, blah.* (FGD 4)

3.2 Satisfaction with produce prescription programs

Participants reported that they were highly satisfied with the programs. Important drivers of their satisfaction were having an extra $50 each month for purchasing fresh fruits and vegetables as well as the healthier eating and health benefits that resulted. For example, one participant who spontaneously rated the program shared:

> *I would say 9 out of 10. And I was satisfied because…I thought it was very beneficial for my kids, instead of waiting on a paycheck coming in, we have a gift card that could help you for vegetables and fruits for the time being.* (FGD 2)

Many participants appreciated having extra money dedicated to fresh fruits and vegetables, particularly during the COVID-19 pandemic and periods of inflation that led to increases in the cost of fruits and vegetables. Using the gift cards and having additional funds each month also motivated participants to eat and try healthier foods since the money could only be used to buy fresh fruits and vegetables. Not only did the gift cards allow participants to buy foods that they usually did not buy, but it also allowed them to afford more expensive produce that they usually would not purchase due to high costs. Participants with children saw improvements in their children's eating habits and felt motivated to eat healthier and try new foods. Additionally, participants viewed the extra $50 per month as money saved to pay for non-food expenses like health care costs or emergencies. However, some participants pointed out that $50 was not always enough to cover the high cost of fresh fruits and vegetables nor did it fully offset the high cost of travel associated with traveling to the store by car or public transportation. Overall, participants expressed gratitude for having the opportunity to participate in the programs and hoped that the programs would be able to reach and benefit more individuals and families in the future.

Despite having some negative experiences with the programs, such as having to travel far distances to the grocery store, not knowing what foods were covered under the programs, and having interactions with clinic staff during health assessments that felt "disrespectful," participants still described high levels of satisfaction. They explained that it is difficult to complain when the program offers free gift cards for fruits and vegetables:

> *I definitely was satisfied with the program. I think anytime you get something, I don't want to say for free, but any help that you can get, how can you complain about that? And I did notice my four year old, she's pretty picky, she definitely found more fruits and vegetables that she likes. I feel like we had more of a variety for her to try.* (FGD 2)

3.3 Recommendations for improving client experiences

Participants shared key recommendations across all themes related to client experiences (see Table 2). To make produce prescription programs more *respectful*, participants recommended that programs ensure respectful communication – for example, by

TABLE 2 Participants' recommendations for improving client experiences (n = 4 FGDs).

Theme	Recommendation	Reported examples of specific actions
Respectful produce prescription programming	Ensure respectful communication	• Ensure that program staff are responsive to clients when they ask for assistance with card issues • Ensure that messages are sent to clients in their preferred language
	Increase the accessibility of programs	• Provide an online purchase and delivery option to facilitate program participation among individuals with disabilities
	Increase the reach of programs	• Engage additional sub-populations (e.g., older adults, individuals enrolled in SNAP, individuals not enrolled in SNAP)
Autonomy to make food choices and select shopping locations	Design programs that provide clients with greater autonomy	• Expand the type of produce (e.g., frozen fruits and vegetables) that can be purchased with gift cards • Allow gift cards to be used at more stores (e.g., local ethnic grocery stores, stores closer to where clients live) • Do not restrict the timing of when funds can be used (e.g., have rollover of funds each month)
Program usability	Ensure clients understand program parameters	• Make sure all clients understand the gift card's restrictions, especially with regards to which foods can be purchased • Provide advanced notification for the last reload
	Improve communication between program and clinic staff	• Ensure all clinic staff are aware of the program and its requirements, such as health assessments
	Make programs user-friendly	• Provide training for store cashiers to increase awareness of the program and knowledge of how to use gift cards • Create an easier process for replacing gift cards • Have a phone number that clients can call to talk to program staff directly about card issues • Have reloads occur at the same time each month to help clients better plan grocery trips • Have an easier way to check the balance on gift cards • Simplify the health assessment process (e.g., by having designated days or times that assessments are completed, use pre-existing health information in the electronic health record)
	Offer more opportunities for client input	• Get feedback from participants about their experiences with gift cards, including to make sure that they did not have issues activating the cards and that they understand any restrictions (e.g., types of foods that can be purchased)

FGDs, focus group discussions; SNAP, Supplemental Nutrition Assistance Program.

ensuring that program staff are responsive to clients' requests for assistance with gift cards and that text messages are sent in clients' preferred language. Participants also suggested increasing the inclusivity of programs by increasing the accessibility and reach of programs so that more people could benefit. Participants frequently discussed their preference for greater *autonomy* within programs, including the ability to purchase additional types of produce, use gift cards at more stores, and use funds any time. Finally, participants offered numerous recommendations for improving the *usability of programs*. They desired more information about program parameters such as types of produce that can be purchased, as well as better communication between program and clinic staff. They also recommended ways to make programs more user-friendly, from providing training for cashiers to more efficient processes such as making it easier to obtain replacement gift cards and reach program staff with inquiries. Furthermore, all participants were supportive of programs creating greater opportunities for them to voice program issues and concerns and provide feedback to inform iterative program improvements. For example, one participant commented that program implementers "could improve the program by [incorporating perspectives from] the people who have experience using the program" and be "made aware of what little issues might be there and they can be ironed out," which would "make the program a lot… smoother."

4 Discussion

This qualitative study evaluated client experiences and satisfaction with produce prescription programs and identified opportunities to make these programs more person-centered and respectful moving forward. Most participants viewed respectful produce prescription programs as encompassing both respect in interpersonal interactions with individuals delivering the program (e.g., being treated well, experiencing timely communication) and program design elements (e.g., provision of gift cards that offer privacy when purchasing produce). Participants liked having the ability to choose their own fresh produce, but they preferred to not be limited to shopping only at program designated stores. Participants spoke at length about both positive and negative experiences with program usability, highlighting the many ways that ease of use of the programs strongly shaped their experiences. All participants were highly satisfied with the produce prescription programs, despite having some negative experiences. Finally, participants offered numerous recommendations for optimizing the client experience, such as increasing privacy (e.g., by educating store employees on the program so that clients do not need to explain in public what the card is for), expanding autonomy (e.g., by allowing cards to be used at more stores), and addressing issues related to program usability (e.g., creating a simpler process for replacing lost or stolen gift cards).

Many of the positive and negative program experiences as well as the recommendations for program improvement that were described by study participants are consistent with existing literature. Participants felt that people delivering the programs treated them with respect and dignity when they showed that they cared about participants' health and well-being. In a qualitative research study, Schlosser and colleagues found that participants in a produce prescription program felt cared for by providers when they took time to discuss healthy eating (24). Participants in our study also felt respected when store employees made an effort to assist them in using their gift cards during checkout. Previous qualitative studies of produce prescription programs documented that participants reported having positive interactions with farmers' market vendors when they were friendly and helped participants use their vouchers (25, 26).

Participants liked that the gift cards gave them autonomy to choose their own fresh fruits and vegetables. Similarly, Saxe-Custack and colleagues found that most caregivers participating in a pediatric produce prescription program preferred selecting their own fruits and vegetables at farmers' markets over receiving vendor-prepared produce bags (26). Notably, our study participants desired greater autonomy, particularly more options for the types of produce that could be purchased (e.g., frozen produce) and the stores where gift cards could be used. Similarly, previous studies have found that participants want incentives that can be used at multiple locations (27, 28). In our study, one primary reason participants wanted expanded options for where to purchase produce was that they faced challenges with transportation, a commonly reported barrier to redemption (23, 24, 37, 38). They also wanted to shop at Asian or Mexican grocery stores as well as stores with greater variety and higher quality produce, noting that in some cases they did not use the cards because of limited or low-quality produce. These findings are consistent with an evaluation of a produce prescription program in which participants reported that they had faced challenges with accessing high-quality fruits and vegetables before the COVID-19 pandemic and these challenges worsened during the pandemic (39). A study conducted by Lyonnais and colleagues found that participants reported that available locations where vouchers could be redeemed did not have the foods they were looking for and that this was a barrier to voucher redemption (29). Esquivel and colleagues documented similar concerns among participants in a pediatric produce prescription program (25). For instance, participants wanted to use vouchers for foods beyond fruits and vegetables (25). Their ability to select the fruits and vegetables they wanted was also diminished when using an online market due to the limited variety of produce available and the inability to personally hand pick the produce of highest quality (25, 27).

Participants in this study frequently discussed ease of use of the programs, which has been an area commonly reported upon in studies evaluating produce prescription programs. Making vouchers easy to use is a widely known facilitator to program engagement, while difficulties with voucher use such as expiration dates and vouchers that require all funds be used at one time have been documented as barriers to engagement, including use of the full voucher amount (25, 40). Moreover, previous studies found that participants want and suggest that vouchers and incentives not have an expiration date or that the expiration date be extended (27, 28). In a qualitative study on perceptions of a produce prescription program designed for Supplemental Nutrition Assistance Program (SNAP) clients, the most frequently reported reason participants did not use their incentives was difficulties with using them at checkout, which led to embarrassment and feelings of stigmatization by cashiers and other customers (28).

By exploring the experiences and perspectives of produce prescription program clients, this study expands the literature on the experiences and views of clients and adds an explicit focus on respectful programming. It also complements a small but growing body of research focused on the experiences and perspectives of health care providers implementing produce prescription programs (11, 24, 37). For example, a recent study conducted by Stotz and colleagues found that health care providers were strongly satisfied with produce prescription programs and described their positive effects on patient care (11). Similarly, we found that participants were highly satisfied with the produce prescription programs, especially given the health benefits of the programs.

Importantly, previous research has found that high satisfaction with health services is common in low-resource settings, even when services are of poor quality (31). While satisfaction is influenced by the quality of health services, it is also affected by other factors such as immediate outcomes of services, gratitude, and an individual's needs, expectations, and values (22, 31). In our study, participants indicated that their satisfaction was driven largely by their perceived benefits of the program for themselves and their families, including increased ability to purchase and consume produce and improved health. These perceived benefits have been documented in many previous qualitative and mixed methods studies evaluating clients' perspectives of produce prescription programs in a wide variety of contexts and populations. Consistent with existing literature, participants in our study also expressed strong appreciation for the programs and shared many positive experiences, including positive interactions with program staff, clinic staff, and store employees (23–26, 28, 30, 41). At the same time, they indicated that they had low expectations regarding how they were treated by cashiers. They reported previous instances of being mistreated when using EBT cards, expressed acceptance that they may experience mistreatment while using produce prescription program gift cards, and explained that they focused on the benefits of these programs rather than mistreatment by cashiers. These findings underscore that client satisfaction as a measure should be used carefully, as high satisfaction may be due, in part, to low expectations as well as other factors (22, 31). Any mistreatment violates people's fundamental right to be treated with respect and dignity (22). Evaluation of client experience can provide insights on the quality of produce prescription programs including respectful treatment, while satisfaction can shed light on the extent to which these programs are responsive to clients' expectations (22).

4.1 Strengths and limitations

This study had several strengths. By co-developing the FGD guide with a Community Advisory Group, we created questions and a free

list activity that promoted active discussion in which FGD participants probed and explained themselves to each other. This high level of interaction elicited a wide range of views on program experiences and opportunities for improvement and generated rich, nuanced data on areas with strong consensus and differing views among participants. Conducting this research through an equitable partnership enhanced our ability to produce results of high relevance and utility for healthcare systems and organizations implementing produce prescription programs.

This study also had limitations. First, three FGDs had fewer than the target number of six to eight participants due to challenges with scheduling at times that work for most but not all interested clients and clients agreeing to participate but then being unable to attend the FGDs. Despite the small size of these FGDs, there was still active group interaction wherein participants built on each other's comments and debated and justified issues. As such, the FGDs still brought out valuable insights and a variety of perspectives. Second, we conducted one FGD with Spanish speakers. It is possible that new issues would have been identified if we had conducted additional FGDs with Spanish speakers. However, it is important to point out that we did not identify major differences in views and experiences between English-speaking and Spanish-speaking participants. Third, as explained in the methods section, the FGDs were conducted via Zoom, which may have made it more challenging to build rapport compared with in-person FGDs. The detailed information and stories that participants shared, including both positive and negative experiences, indicated that participants felt comfortable to share openly and honestly. Fourth, the data were coded by one analyst and inter-coder reliability was therefore not assessed. Recognizing the importance of ensuring the analyst who coded the data applied the codes appropriately and consistently across the four transcripts, another analyst checked segments of the coded transcripts. Notably, no issues with the application of codes were identified.

Finally, there are a variety of ways to design produce prescription programs. For example, the two programs evaluated in this study offered $50 gift cards to purchase fresh produce in person at designated stores, while some programs offer vouchers or debit cards of varying amounts that can be used to purchase both fresh and frozen produce in stores or online. As such, findings regarding clients' experiences and satisfaction with various aspects of the programs evaluated in this study may not be directly transferable to all produce prescription programs in the US or other countries, but the methods used to elicit them are applicable as they were based on pragmatic and rigorous approaches to collecting and analyzing qualitative data. Process and impact evaluations of clients' experiences and satisfaction with programs that are designed differently are warranted.

4.2 Lessons and opportunities for research and practice

In 2022, the Biden-Harris Administration National Strategy on Hunger, Nutrition, and Health highlighted policy and practice activities for expanding and increasing utilization of produce prescriptions in various types of government-sponsored healthcare programs (42). National agencies like the Indian Health Service, Veterans Health Administration, Centers for Medicare and Medicaid Services, US Department of Agriculture (USDA), and CDC, as well as state and local level government agencies, community-based organizations, and health systems are pushing this agenda forward in states across the country. As pointed out by Downer and colleagues, there is a need for greater investment in studies in the US using rigorous study designs that can produce high-quality evidence on the effects of produce prescription programs on food security, diet quality, and cardiometabolic health outcomes (4). As research on produce prescription programs expands, it will be important to include a focus on client experiences with programs, including the extent to which they feel treated with respect and dignity (1). Qualitative research is well suited to exploring client experiences with programs and understanding how, why, and in what context produce prescription programs promote positive experiences, including respectful treatment (1). A validated measure to quantitatively assess client experiences and respectful treatment is also sorely needed.

Optimizing person-centered and respectful program delivery requires tailoring, which our study indicates could be achieved through co-design, an approach wherein members of the community and community partners actively collaborate to develop social innovations (43). A major advantage of this approach is that it centers the voices and perspectives of community members and community partners (43). Program and research-funding agencies like USDA, donors, and others could encourage and offer funds for co-design of produce prescription programs.

5 Conclusion

This study sheds light on clients' experiences and satisfaction with produce prescription programs in California and identifies their specific recommendations for making programs more person-centered – insights that can inform programming among similar populations in the US. This focus will be vital to upholding people's fundamental right to be treated with respect and for facilitating optimal use of produce prescription vouchers or debit cards, and thereby improving the effectiveness of programs.

Data availability statement

The datasets presented in this article are not readily available because they include focus group discussion transcripts. Requests to access the datasets should be directed to ER, elizabeth.rhodes@emory.edu.

Ethics statement

All the methods were carried out in accordance with the relevant guidelines and regulations. The project was reviewed and deemed exempt from further review by the Yale University Institutional Review Board. We chose to obtain verbal informed consent to participate in an audio-recorded focus group discussion from all study participants.

Author contributions

ER: Writing – original draft, Writing – review & editing, Conceptualization, Investigation, Formal analysis. RP-E: Writing – review & editing, Conceptualization, Investigation, Formal analysis. NO: Writing – original draft, Writing – review & editing, Investigation, Formal analysis. AH-F: Writing – review & editing. JF: Formal analysis, Writing – review & editing. JM: Writing – review & editing. BD-B: Writing – review & editing, Investigation. KD: Writing – review & editing, Conceptualization, Investigation, Formal analysis.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was made possible through the support of the Yale Griffin Prevention Research Center Cooperative Agreement Number 5 U48DP006380-02-00 funded by the US Centers for Disease Control and Prevention, Prevention Research Center Program (PI: RP-E). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the US Centers for Disease Control and Prevention or the US Department of Health and Human Services. This research was made possible by the Walmart Foundation. The research was conducted by the authors alone and do not necessarily reflect the opinions of the Walmart Foundation.

Acknowledgments

We acknowledge and thank Wholesome Wave for their partnership in this project, especially Natalia Kedves Feinstein, Brent Ling, and Katina B. Gionteris. We would also like to thank Benjamin D Perkins from Upstream Impact Solutions Consulting and Daniel C Ross from DAISA Enterprises for providing input on the conceptualization of the study. We are grateful for Leslie Brown, a community research fellow at Yale-Griffin CDC Prevention Research Center, who conducted the Spanish-language focus group discussion. We would also like to thank One Community Health for their partnership in this project, especially Andrew Luckett, Family Medicine Physician. We are also grateful to the produce prescription program clients who participated in the focus group discussions for this study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1295291/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 26 June 2024
DOI 10.3389/fpubh.2024.1374815

OPEN ACCESS

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RECEIVED 22 January 2024
ACCEPTED 12 June 2024
PUBLISHED 26 June 2024

CITATION
Gaitán-Rossi P, Hernández-Solano A, López-Caballero V, Zurita-Corro R, García-Ruiz X, Pérez-Hernández V and Vilar-Compte M (2024) Predictors of persistent moderate and severe food insecurity in a longitudinal survey in Mexico during the COVID-19 pandemic. *Front. Public Health* 12:1374815. doi: 10.3389/fpubh.2024.1374815

Predictors of persistent moderate and severe food insecurity in a longitudinal survey in Mexico during the COVID-19 pandemic

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Background: Household food insecurity (HFI) increased in Latin America by 9% between 2019 and 2020. Scant evidence shows who was unable to recover from the COVID-19 pandemic. Our aim was to use a Machine Learning (ML) approach to identify consistent and influential predictors of persistent moderate or severe HFI over 2 years.

Methods: We use a three-wave longitudinal telephone survey with a probabilistic sample representative of the Mexican population. With a response rate of 51.3 and 60.8% for the second and third waves, the final sample size consisted of 1,074 individuals. The primary outcome was persistent HFI, i.e., respondents who reported moderate or severe HFI in 2021 and 2022. Twelve income-related predictors were measured in 2020, including baseline HFI. We employed 6 supervised ML algorithms to cross-validate findings in models, examined its precision with 4 standard performance indicators to assess precision, and used SHAP values (Shapley Additive exPlanations) to identify influential predictors in each model.

Results: Prevalence of persistent moderate/severe HFI in 2021 and 2022 was 8.8%. Models with only a HFI 2020 baseline measure were used as a reference for comparisons; they had an *accuracy* of 0.79, a *Cohen's Kappa* of 0.57, a *sensitivity* of 0.68, and a *specificity* of 0.88. When HFI was substituted by the suite of socioeconomic indicators, *accuracy* ranged from 0.70 to 0.84, *Cohen's Kappa* from 0.40 to 0.67, *sensitivity* from 0.86 to 0.90, and *specificity* from 0.75 to 0.82. The best performing models included baseline HFI and socioeconomic indicators; they had an *accuracy* between 0.81 and 0.92, a *Cohen's Kappa* between 0.61 and 0.85, a *sensitivity* from 0.74 to 0.95, and a *specificity* from 0.85 to 0.92. Influential and consistent predictors across the algorithms were baseline HFI, socioeconomic status (SES), adoption of financial coping strategies, and receiving government support.

Discussion: Persistent HFI can be a relevant indicator to identify households that are less responsive to food security policies. These households should be prioritized for innovative government support and monitored to assess changes. Forecasting systems of HFI can be improved with longitudinal designs including baseline measures of HFI and socioeconomic predictors.

10.3389/fpubh.2024.1374815

KEYWORDS

persistent household food insecurity, machine learning, COVID-19 pandemic, Mexico, longitudinal survey

1 Introduction

Household food insecurity (HFI) is defined as the "limited or uncertain availability of nutritionally adequate and safe foods or the limited or uncertain ability to acquire acceptable foods in socially acceptable ways" (1). Copious evidence has shown HFI is associated with worse physical health [i.e., non-communicable diseases as diabetes (2) and hypertension (1)], nutrition outcomes [i.e., obesity, anemia (3), and stunting (4)], higher levels of stress and mental health conditions, such as depression (5), and lower early childhood development outcomes (6). Physical and mental health consequences have even been identified throughout the spectrum of HFI, from mild to severe (7). Moderate or severe food insecurity in the year 2020 affected 30.4% of the world population, but it spiked to 40.9% in Latin America and the Caribbean (8). Population surveys conducted in Latin America between 2019 and 2020 estimated that moderate and severe HFI increased by 9% (8). In Mexico, using monthly telephone surveys, HFI increased by up to 15 percentage points during the early months of the pandemic, rising from 60% in April to 75% in August 2020 (9). The most common factors globally by which the COVID-19 pandemic increased HFI was by declines in income that jeopardized access to food (10)—on average, 36% of the population stopped working during the initial lockdowns, 65% of households reported a decrease in income, and cash transfers were recommended as a key strategy to mitigate HFI (11, 12). Despite the concern and aid toward HFI, most studies were unable to estimate pre-post pandemic persistence in the same households after the pandemic began (13).

Persistent food insecurity is defined as the consistent reporting of HFI in at least two waves of a longitudinal survey (14). Persistent HFI is associated with lower cognitive assessments and a diminished health status (14). Factors exacerbating persistent HFI include being female, being married, and reporting only a "fair" self-assessed health status (15). Persistency of HFI over time can be a relevant indicator to identify those facing conditions that systematically restrain them to be food secure and are likely resistant to common interventions. However, this indicator is rarely monitored or considered when designing and implementing programs to address HFI. The scarcity of longitudinal studies to assess HFI is a key difficulty in estimating the persistence across time in the same households (16, 17). Consequently, more evidence is needed to assess if the predictors of persistent HFI are similar to those of HFI, as regularly measured in cross-sectional surveys.

Machine Learning (ML) techniques have the potential to predict more precise estimates of HFI (18) by enabling the effective modeling of complex relationships (13). These methods have demonstrated superior performance in predicting indicators, such as poverty, compared to traditional models, like linear regressions (19, 20). There is an increasing interest in the food security literature to use ML techniques when high predictive precision is desirable (21, 22). Models combining primary and secondary data suggest that longitudinal data is advisable because previous prevalence of HFI yields a higher explanatory power and lower errors compared with models using only secondary data—up to a 73% accuracy (23). ML models with panel data from Nigeria exemplify the accuracy of these techniques, as it led to a 78–90% accuracy in reporting HFI (24). These new approaches to HFI have some limitations. Data-driven ML techniques tend to have low explanatory power because of the difficulties to identify the importance of single-variables, which hampers its policy value (23). Nevertheless, technical improvements are tackling these shortcomings (25) and longitudinal designs are becoming more common (18), suggesting this is a promising approach to improve the accuracy and usefulness of ML models, while adding to our understanding of HFI.

The aim of the study was to use Machine Learning algorithms to identify constant and influential socioeconomic predictors of persistent moderate or severe HFI in Mexico in 2021 and 2022. It pursued two interrelated objectives: (1) to compare the predictive performance of multiple ML algorithms when a baseline measure of HFI is combined with socioeconomic predictors; and (2) to identify the consistently important variables in predicting persistent HFI in 2021 and 2022.

2 Materials and methods

2.1 Sample

We used data from the ENCOVID-19 project, whose main objective was to monitor well-being indicators during the COVID-19 pandemic (26). The longitudinal component of the ENCOVID-19 project collected data of the same individuals in the years 2020, 2021, and 2022 through a telephone survey representative of the Mexican population 18 years and older who had a mobile phone—as was a regular research practice during pandemic lockdowns (10). Baseline data was collected between April and August 2020 ($N = 4,480$) during the first lockdown. Follow-up was conducted between July and August 2021 ($N = 2,300$), when the Delta variant was dominant, and the last contact occurred in March 2022 ($N = 1,400$), during the last phase of the Omicron-1 variant. During these two waves no lockdown was enforced (27). Surveys were collected using a one-stage and probabilistic sample, stratified for each state of the country ($n = 32$). Mobile numbers were randomly selected from the most recent version of the National Dialing Plan at the time (28) and data collection was implemented with a Random Digit Dailing technique (29). By 2019, the share of households with access to mobile phones in Mexico was 89%, with high coverage even in rural areas (72.5%) and in households in the lowest income decile (64%) (30). Response rates in the second and third waves of the longitudinal ENCOVID-19 were 51 and 61%, which is standard in these types of designs (31). Due to missing values, the final sample size was 1,074 respondents. An attrition analysis, in Supplementary Table 1, shows there are significant differences between respondents who dropped out the study or had missing

values, and those who answered until the third wave and comprise the analytic sample. The group lost in follow-up were younger (3 years), mostly women (+4%), with lower education from the head of household, a lower household's socioeconomic status, and had higher moderate and severe HFI (+7%).

2.2 Variables

HFI was measured using the 8-item adult version of the ELCSA scale (32). It asks if, in the last 3 months, due to a lack of money or other resources, the respondent or any other adult in the household (i) worried to run out of food, (ii) were unable to eat healthy, balanced and nutritious food, (iii) ate only a few kinds of foods, (iv) skipped breakfast, lunch or dinner, (v) ate less than s/he thought should have, (vi) ran out of food, (vii) were hungry but did not eat, and (viii) went without eating for a whole day. Responses to all items are dichotomous (i.e., Yes/No). After computing the total summative score for the eight items, HFI was categorized into two levels: food secure/mild insecurity (total score = 0 to 3), and moderate/severe food insecurity (total score = 4 to 8). We grouped moderate/severe HFI to align our results to Mexico's multidimensional poverty measure (33). *Persistent* HFI was used as a dependent variable in all models. It is a dummy variable scored as 1 when a respondent reported moderate or severe food insecurity in the 2021 and 2022 waves of the survey. The 2020 variable was used exclusively as a baseline predictor because it has been the most relevant predictor in previous studies (23) and is thus used as a starting point for model comparison. Since mild levels of food insecurity can have a detrimental impact in people's well-being, as sensitivity analyses in Supplementary Table 2, we repeated our models by categorizing *Persistent* HFI as mild/moderate/severe HFI (total score = 1–8), while food security was scored with a 0 (total score = 0).

Given the sum of evidence showing that declines in income were the main drivers of the increase of HFI during the COVID-19 pandemic (10), the ML approach used 12 socioeconomic variables as predictors (Table 1), all from the 2020 baseline survey using the analytic sample. We dichotomized all variables –except the AMAI index and baseline HFI. Available demographic predictors included age of the head of household (dummy variable—scored as 1 when above the mean of 52 years old) and self-reported sex of the head of household, household size (dummy variable—scored as 1 when above 4 members), indigenous language, or disabilities by any household member, and living in a rural locality. Socioeconomic predictors were the AMAI assets-based socioeconomic status index, where A/B is the highest and E is the lowest (34), and a variable indicating whether the household received government aid. We also included variables related to economic shocks including if the household experienced an income reduction after the COVID-19 quarantine; if someone in the household lost his/her job; and a dummy variable showing if, due to lack of money or resources, the household used coping strategies like evading paying debts, credit cards, or basic household services, borrowing money from family, friends, banks or lenders, pawning objects, or doing some extra activity to get money. The coping strategies variable is not commonly included in population surveys in Mexico, but debt has been found to be a relevant variable during crises (31). Finally, we included the 2020 ELCSA scale in the first round of models categorized into 4 levels (food-secure households, and mild, moderate, and severe HFI).

2.3 Analysis

To estimate and predict persistent moderate/severe HFI in 2021 and 2022 we ran three sets of models with a different combination of predictors: first, only with 2020 baseline HFI; second, we removed HFI and added all the 2020 socioeconomic predictors; and, finally, we used the 2020 baseline HFI and the 2020 socioeconomic predictors together. We start by including baseline HFI because it is the strongest predictor in the literature, so it sets a reference point to compare the added predictive value of the socioeconomic predictors. In the second set of models, we remove baseline HFI to assess a scenario where the only predictors are socioeconomic variables. Finally, the third set reflects a best-case scenario, with all the variables, where we predict persistent HFI with a baseline prevalence and socioeconomic predictors. The hypothesis is that the third set of models yields the highest performance. After describing the percentages of the 2020 predictors in the analytic sample, the analytic strategy followed a series of steps:

1. As is customary in a ML modeling approach, we randomly split the dataset into a training (60%), validation (20%), and testing subsets (20%). The training dataset was used to specify the model parameters, the validation dataset to fine-tune them, and then the testing dataset verified the model performance with new, unseen data (35). An important challenge for the ML approach was the small sample size, specifically the low number of respondents reporting persistent moderate/severe HFI. To address this shortcoming, we used a Synthetic Minority Over-Sampling Technique (SMOTE) where we over sampled the minority class of interest (i.e., the dependent variable) and introduced synthetic examples based on randomly chosen nearest neighbors (36). The inclusion of synthetic cases prompts the ML algorithm to generate larger and less specific decision regions. Consequently, this aids the algorithm in concentrating on information from the minority class, leading to more generalizable results (33).
2. For the estimation we ran 6 supervised models for each of the three sets. Each model used a different ML algorithm tailored to predict binary responses: Logistic Regression (LR), Random Forest (RF), Extreme Gradient Boosting (XGBoost), Support Vector Classifier with a Gaussian kernel function (SVCG), Neural Networks (NN), and Multi-layer perceptron (MLP). We chose these models because they have shown to have high predictive power for dichotomous responses. Moreover, these algorithms are able to handle correlations among variables (23).

   The LR models are the common analytic approach but estimated within the ML framework (i.e., evaluated in the testing dataset). RF and XGBoost are ensemble tree-based models (i.e., supervised, non-parametric classification models), where the algorithms select a predictor, a cut-off point, and then estimates a hierarchy of subsequent predictors that increase the likelihood of identifying the dependent variable (37, 38). The algorithms repeat this process with subsampling and randomly chosen predictors until it can average predictions from all trees. Ensemble tree-based based models have the advantage over other ML algorithms of producing readily interpretable output. Particularly, these models excel when the associations between predictors and the dependent variable is

TABLE 1 Description of predictors from the 2020 baseline survey.

Predictor	Survey question or description	Values	Prevalence (%)
Age	Age of the head of household above the average of 52 years	1 = yes 0 = no	1 = 51.95 0 = 48.04
Sex	Sex of the head of household	1 = woman 0 = man	1 = 31.37 0 = 68.62
Size	Number of household members is above the national average, 4 members	1 = yes 0 = no	1 = 61.26 0 = 38.73
Indigenous	Do you or someone in your household speaks an indigenous language?	1 = yes 0 = no	1 = 12.56 0 = 87.43
Disabilities	Do you or someone in your household have one or more permanent disabilities?	1 = yes 0 = no	1 = 11.82 0 = 88.17
Rural	Do you consider that the location where you currently live is rural or urban?	1 = rural 0 = urban	1 = 28.39 0 = 71.60
Aid	Household receives any type of government aid.	1 = yes 0 = no	1 = 26.81 0 = 73.18
SES	AMAI Household socioeconomic level, where A/B is the highest and E is the lowest.	1 = E 2 = D 3 = D+ 4 = C- 5 = C 6 = C+ 7 = A/B	1 = 2.88 2 = 19.45 3 = 14.24 4 = 12.56 5 = 14.24 6 = 18.71 7 = 17.87
Reduction	Considering the household income from last month, was this income less than it was before the quarantine (February 2020)?	1 = yes 0 = no	1 = 63.22 0 = 36.77
Unemployment	At least one household member lost his/her job in the last month	1 = yes 0 = no	1 = 13.96 0 = 86.03
Coping	Describes whether during the last month due to lack of money or resources, the household took coping strategies such as: stopping paying debts, credit cards, or basic household services, borrowing money from family, friends, banks or lenders, pawning objects or doing some extra activity to get money.	1 = yes 0 = no	1 = 53.53 0 = 46.46
Baseline HFI	Describes the household's previous food insecurity level	0 = secure 1 = mild 2 = moderate 3 = severe	0 = 36.68 1 = 41.71 2 = 13.96 3 = 7.63

The cutoff point for dichotomizing 'Size' was determined using the respective national median of the number of household members, as reported in the 2020 Population and Housing Census conducted by the National Institute of Statistics and Geography (INEGI). The AMAI index is estimated using 5 indicators: (1) education level of head of household; (2) Number of rooms in household; (3) Number of complete bathrooms; (4) Number of employed members aged 14 or over; (5) Ownership of a car or van; (6) Internet connection in household.

not linear and complex interactions are in play (39). The way these trees manage interactions is by tracing multiple pathways with varied combinations. The XGBoost algorithm uses the errors from previous trees to adjust weights and avoid overfitting.

The Support Vector algorithms are supervised parametric classification models using deep learning principles (38). Based on input variables, these algorithms create different layers or patterns of variables to predict the dependent variable. Different algorithms used different distributional assumptions (i.e., Gaussian kernel function). Lastly, the NN and MLP algorithms imitate the behavior of interconnected neurons that learn from each other. The algorithms start with a random solution and iterate by optimizing variable weights until the predictions are improved (38). Each network algorithm uses different learning assumptions.

3. We used four post-estimation performance metrics to assess the models: (i) *accuracy,* which is the ratio of the number of correct predictions over total predictions, (ii) *Cohen's kappa* to reduce the probability of having correct predictions by chance—and is thus preferred over *accuracy* (iii) *sensitivity,* that is a key metric for policy because it shows the probability of identifying a food-insecure household when the household is indeed insecure (the true positive rate), and (iv) *specificity,* which is the probability of detecting a food-secure household when the household is secure (the true negative rate). We compare the metrics between the models first against random estimation (i.e., above 0.5) and then estimating percent change using the first set of models as reference.
4. Finally, we used SHAP values—SHapley Additive exPlanations—to rank the relative contribution of each variable to compare between algorithms. SHAP values are calculated

with the weighted sum of the prediction gaps with and without predictors and the weight is estimated by ranking all combinations of predictors (39). To determine the global ranking of the predictors´ importance, we calculate the average of the absolute SHAP values for each variable across all observations in the test dataset, and then we sort them based on their magnitude (23). This approach should be interpreted with caution because these algorithms operate under different assumptions and processes and are therefore not strictly comparable among them. Nonetheless, they illustrate which variables may be consistently relevant across different estimation techniques. The hypothesis is that baseline 2020 HFI will be the most influential predictor of persistent HFI, followed by the index of socioeconomic status, because these variables have been consistently salient in the literature using cross-sectional studies (2, 13, 33).

We used the Python programming language for data preparation and model execution. The models were estimated through the implementation of various Machine Learning frameworks, including TensorFlow, Scikit-learn, and XGBoost. The SHAP values were computed with the SHAP (SHapley Additive exPlanations) library (40).

3 Results

In the analytic sample, with responses in the dependent variable from the three waves of the survey ($N = 1,074$), head of households were mostly males (68.6%), with a mean age of 52 years old, and the majority of participants (61.26%) lived in a household with 4 or more residents (Table 1). Indigenous language was spoken by 13 and 12% reported a disability. The sample included respondents from all socioeconomic levels, and 27% reported receiving some type of governmental support. During the first months of the pandemic, in 2020, 63% recognized an income reduction, 14% unemployment in a household member, and 53% of respondents engaged in some financial coping strategy. In 2020, 37% were food-secure households, while 41% reported mild HFI, 14% moderate HFI, and 8% severe HFI. Moderate and severe HFI was 21% in 2021 and 16% in 2022. The prevalence of persistent moderate/severe HFI insecure in 2021 and 2022 was 8.8% ($n = 96$ respondents; 1,315 with the SMOTE synthetic cases).

In Table 2, the first set of models—only with baseline HFI—were slightly better than predicting persistent HFI randomly (i.e., *Cohen's Kappa* was 0.57). The first set of models were able to correctly identify households with persistent HFI with a *sensitivity* of 0.68 and to correctly identify non-persistent households with a *specificity* of 0.88. The second set of models —only with socioeconomic predictors and without HFI—had a higher precision (i.e., *Cohen's Kappa* was between 0.40 and 0.67) than the first set of models with a 12 to 17% improvement. Similarly, the *sensitivity* increased to 0.86 and 0.90—an improvement between 26 and 32%—except for Logistic Regression, that decreased to 0.65. The *specificity* decreased in all the models in the second set to 0.75 and 0.82—a reduction in *specificity* between 7 and 14%, when compared with the first set of models. The third set of models—including both, baseline HFI and socioeconomic predictors—were the most precise models for predicting persistent HFI (i.e., *Cohen's Kappa* was between 0.61 and 0.85), an improvement between 7 and 49% when compared with having HFI-only in the first set of models. The third set of models were also better in *sensitivity*, reaching values from 0.74 to 0.95, an improvement between 8 and 40%. The third set of models marginally improved in *specificity* when compared to the first set of models, with values ranging between 0.85 and 0.92, an increase between 3 and 6%. To sum up, as hypothesized, performance metrics indicate the third set of models, with all variables, are the best performing combination based on *Cohen's Kappa, sensitivity*, and *specificity*. Moreover, the second set, with socioeconomic predictors only, was strongest in *sensitivity*, while the first set, with baseline HFI only, was strongest in *specificity*.

While all ML algorithms showed similar results in the performance metrics, the ones with the highest *Cohen's Kappa* and *sensitivity* were the Random Forest and the Support Vector Classifier with a Gaussian kernel function (SVCG). As an example, Figure 1 shows the tree that maximizes the sensitivity metric in the test subset among the trees generated by the Random Forest algorithm, which were estimated from the second set of models, without baseline HFI. Nodes in gray indicate where the sample has a higher percentage of households with persistent HFI. Each node includes a condition that splits the sample and maximizes the prediction. Pathways are interpreted top-down, where upper nodes are more relevant in predicting the outcome. The pathway goes to the left when the condition is *true* and to the right when the condition is *false*. For example, following the gray pathway, a household engaging in coping strategies, that is not receiving government aid, with an indigenous background, and a male respondent, is at a higher risk of experiencing persistent HFI. Similarly, the tree that maximizes the sensitivity metric in the third set of models shows that a household engaging in coping strategies, not receiving government aid, and reporting moderate/severe HFI in 2020 is at a higher risk of experiencing persistent HFI in 2021 and 2022 (Figure 2).

A strategy to make "black box" algorithms more interpretable is the use of SHAP values, a statistic that shows the relative contribution of each predictor across multiple ML algorithms. In the second set of models, without baseline HFI, the most important predictor in every algorithm is socioeconomic status, a structural variable that is likely invariant since the beginning of the pandemic (Figure 3). The second most consistent predictor is engaging in coping strategies resulting from financial risk and unemployment of a household member during the first month of the pandemic. The rest of the variables shift in importance and consistency across the algorithms. As expected, the most predictive variable in all algorithms in the third set of models was baseline HFI (Figure 4). As with the previous finding, the second most important variable was socioeconomic status. Engaging in coping strategies, as well as receiving aid from the government, were common in most algorithms, but its relevance did not follow a specific pattern.

Analyses with a different specification of the dependent variable—including mild food insecurity–yield different results in the performance metrics (Supplementary Table 2). The prevalence of persistent mild/moderate/severe HFI in 2021 and 2022 is 32.7% – nearly four times than the one without the mild level. The sets of models follow a similar gradient as in the main results, where the lowest performance is observed in the first set of models (*Cohen's Kappa* is 0.33), the second set slightly improves (*Cohen's Kappa* is 0.40 on average), and the third model increases in performance (*Cohen's Kappa* is 0.51 on average). While *sensitivity* and *specificity* are higher than *Cohen's Kappa,* the

TABLE 2 Performance metrics for three sets of models using 2020 data to predict persistent household food insecurity in 2021 and 2022.

	Logistic regression	Random forest	XGBoost	SVCG	Neural networks	MLP
Accuracy						
1. HFI	0.79	0.79	0.79	0.79	0.79	0.79
2. SES Predictors	0.70	0.83	0.84	0.84	0.82	0.83
3. SES Predictors and HFI	0.81	0.92	0.90	0.92	0.90	0.90
Cohen's Kappa						
1. HFI	0.57	0.57	0.57	0.57	0.57	0.57
2. SES Predictors	0.40	0.67	0.67	0.67	0.64	0.66
3. SES Predictors and HFI	0.61	0.85	0.80	0.84	0.80	0.80
Sensitivity						
1. HFI	0.68	0.68	0.68	0.68	0.68	0.68
2. SES Predictors	0.65	0.88	0.86	0.90	0.87	0.90
3. SES Predictors and HFI	0.74	0.93	0.93	0.95	0.91	0.95
Specificity						
1. HFI	0.88	0.88	0.88	0.88	0.88	0.88
2. SES Predictors	0.75	0.80	0.82	0.78	0.77	0.77
3. SES Predictors and HFI	0.86	0.92	0.87	0.90	0.89	0.85

HFI, Household Food Insecurity measured with the adult-version of the ELCSA scale; SES, socioeconomic status measured with the assets-based AMAI index; XGBoost, Extreme Gradient Boosting; SVCG, Support Vector Classifier with a Gaussian kernel function; MLP, Multi-layer perceptron.

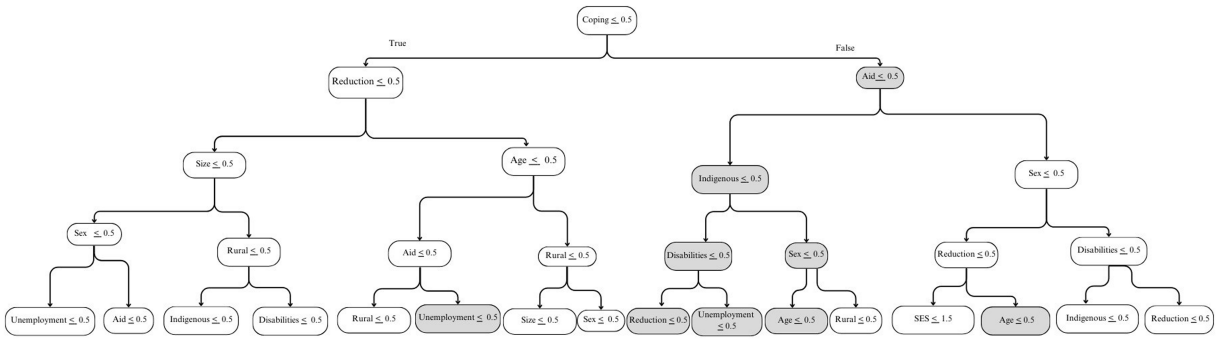

FIGURE 1
Five-node diagram of the tree with the highest sensitivity value using a Random Forest algorithm in a model without baseline household food insecurity. Nodes in gray indicate concentrations of the sample with higher percentages of persistent HFI. Pathways start with the first node, coping strategies, and show the threshold. When the condition in the threshold is true, the pathway goes to the left; it goes right if the condition is not met.

relevant conclusion is that—beyond guessing at random (*Cohen's Kappa* > 0.50)—our independent variables are not suitable to predict a measure of persistent HFI that includes mild food insecurity.

4 Discussion

A three-year panel survey allowed us to estimate persistent HFI and to test the predictive power of socioeconomic variables. Our study shows that 8.8% of Mexican households reported having persistent moderate/severe food insecurity in 2021 and 2022. Persistent HFI can be a relevant policy indicator because it identifies households that may be resistant to regular interventions intending to reduce food insecurity. Unfortunately, this is a rarely used indicator that depends on having at least two points in time of longitudinal data (14). The effectiveness of food insecurity interventions needs to be closely monitored because these households might be compounding several deleterious effects related to poverty in a syndemic dynamic that may reduce its impact (41). One example of how to increase these supports is the temporary Child Tax Credit, implemented in the United States of America during the pandemic to help households with minors, and contributed to a reduction by 50% in child poverty (42). Research on persistent HFI—especially during periods without large crises, as the COVID-19 pandemic—would illuminate the design and implementation of adequate interventions targeted at supporting these uniquely challenged households.

The first objective of the study was to compare the predictive performance of multiple ML algorithms. In line with previous research (24), our results show that these algorithms have on average adequate predictive power on persistent moderate/severe HFI, reinforcing the relevance of the ML approach. Random Forest and the Support Vector

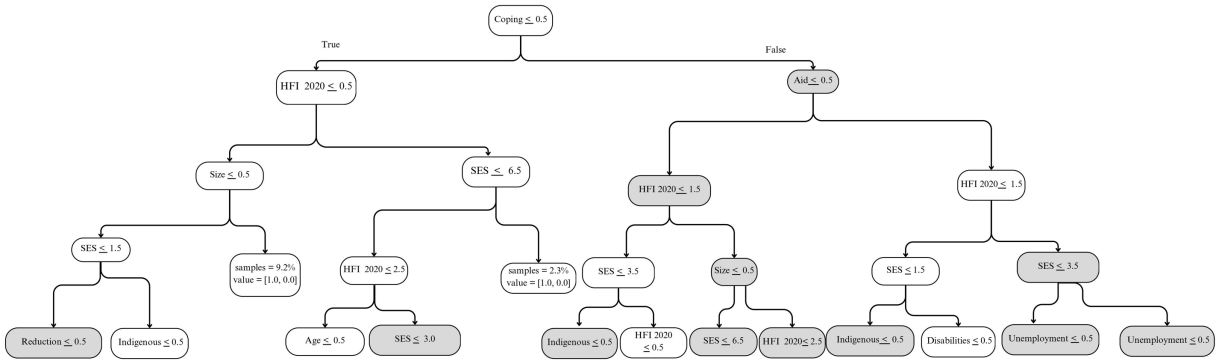

FIGURE 2
Five-node diagram of the tree with the highest sensitivity value using a Random Forest algorithm in a model with baseline household food insecurity.

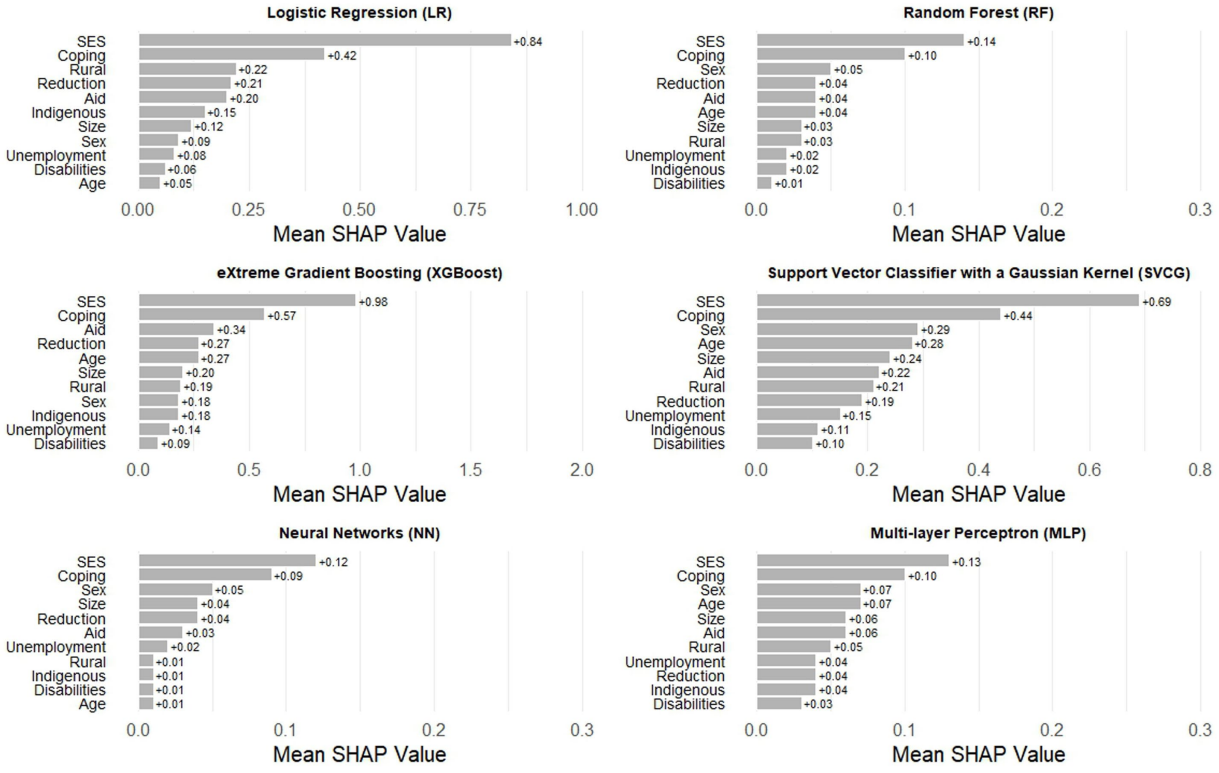

FIGURE 3
Ranking of SHAP values for the six Machine Learning algorithms in the set of models without baseline household food insecurity.

Classifier with a Gaussian kernel function (SVCG) were the best performing algorithms. Research on HFI could benefit on adopting ML best practices such as partitioning datasets to assess accuracy. Likewise, timely data collection and with sufficient sample size is paramount for the usefulness of these predictions.

A key finding is the role of baseline HFI in the models—which has been identified as the most predictive variable for HFI (21, 28). Focusing on *Cohen's Kappa,* when baseline HFI is the only predictor, the precision of the algorithms is 0.57. When baseline HFI is absent, the suite of socioeconomic indicators increased precision, on average, up to 0.65. Importantly, the combination of baseline HFI *and* socioeconomic indicators increases the precision to an average of 0.82 (except for Logistic Regression). With both types of variables, these models were able to accurately identify 8 out 10 households reporting persistent HFI. Our model specification confirms baseline HFI is a very relevant predictor and should be collected when possible. In addition, our results show that socioeconomic indicators offer important information beyond baseline estimates of HFI. Predictive models of persistent HFI should aim to have a combination of both types of variables to achieve greater precision. At the same time, our sensitivity analyses show this suite of indicators is not adequate to predict a measure of persistent HFI that includes mild food insecurity. It has been shown that mild food insecurity affected a larger share of the population and during the first months of the pandemic increased

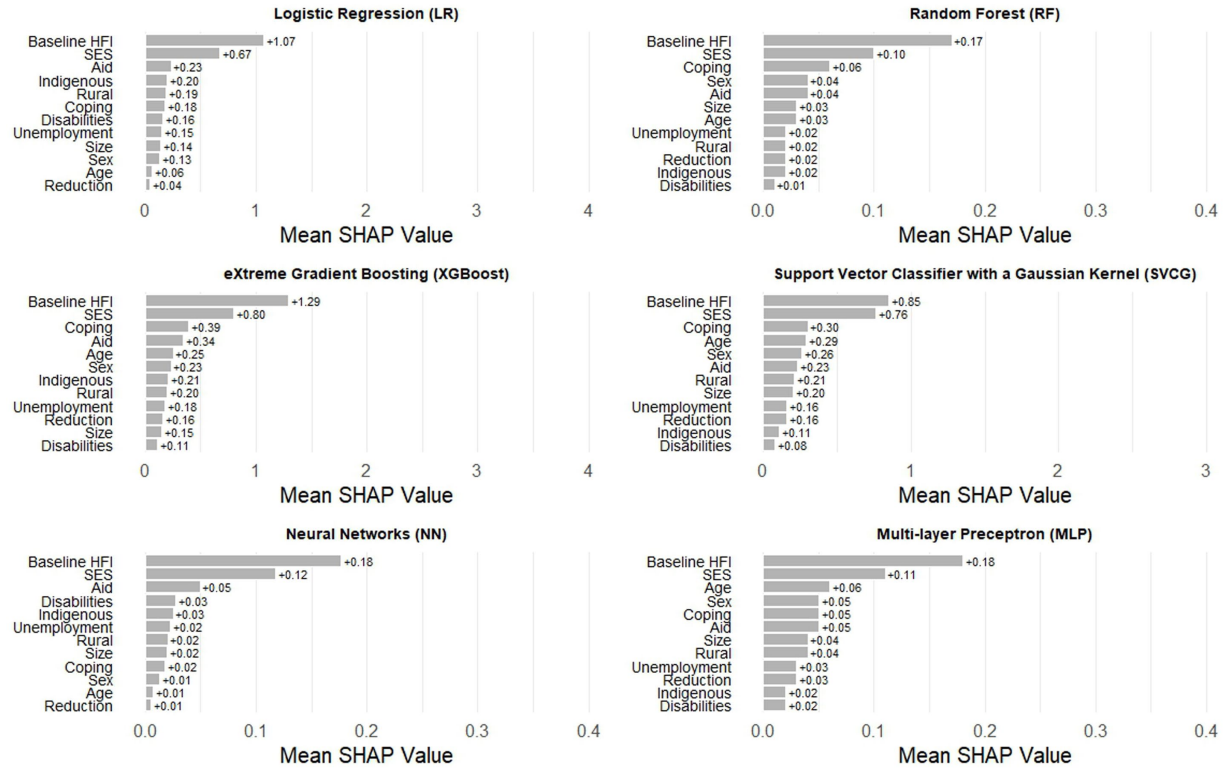

FIGURE 4
Ranking of SHAP values for the six Machine Learning algorithms in the set of models including baseline household food insecurity.

at a higher rate than moderate and severe food insecurity, so additional predictors need to reflect a different dynamic (32).

The second objective of the study was to identify the consistently important variables in predicting persistent moderate/severe HFI. There is some consensus over the fact that HFI increased during the COVID-19 pandemic due to a reduction of income that hampered access to food (10). The study assessed income-related predictors to better understand which were more important to identify persistent HFI in a disaster context. The use of six algorithms helped cross-validate the findings and highlight the most prominent predictors, regardless of the analytic assumptions behind single statistical techniques. Besides baseline HFI, two predictors stand out. Socioeconomic status, measured with an assets-based index, was the most consistent predictor, as has been reported in several other studies (13, 18). This is a structural and pre-existent variable that is available in most population surveys and should be included in prediction models. The prominent role of SES reflects that structural poverty is a fundamental determinant of persistent moderate and severe HFI and, if this is a chronic condition, it requires decisive policies to support these households. The second consistent predictor was engaging in coping mechanisms, such as eschewing payments, selling assets, or gaining debt. This indicator is not frequently collected but was important to consider because it relates with the immediate effects of the pandemic on income. Indicators associated with debt should be considered in population surveys as they provide more nuance to the financial situation and the stress in households with HFI. Moreover, these results suggest that short-term financial instruments—like small loans or postponing debt—can be pertinent disaster relief options for future crises. Receiving government aid was a variable that featured in several models, especially when baseline HFI was included, but it was not as consistent as the other two predictors. Contrary to previous research (9), other features of the household were less important for persistent HFI, like the head of household being female or with a disability, age, and household size. Unexpectedly, reductions in income and unemployment were not consistently relevant to predict persistent HFI.

This list of predictors provides important information for future emergency preparedness and response programs, including the relevance of monitoring such variables. In the specific Mexican pandemic context, these findings suggest that government relief actions were insufficient. Mexico's social policy is mostly based on cash transfers, and, during the pandemic, additional alleviation strategies were nearly inexistent (43). More detailed research could help disentangle the effects of each government program on HFI. Nonetheless, these findings can orient targeting strategies of policy programs aiming to increase food security.

4.1 Limitations of the study

The study has some limitations. The definition of "persistent" HFI was limited by ELCSA's three-month recall period, whereas other measures use a 12-month period, which classify persistence as "often" or "almost every month" (44). This limitation means we are unable to capture fluctuations in HFI status between the two measurement periods. For example, Nord (45) found that, throughout a year, 55% of households experienced one or a few episodes of HFI (some of them lasting several months), 23%

experienced low levels of HFI throughout the year with one severe episode, and 22% were persistently food insecure. Likewise, data collected during a 5-year period found that 51% reported HFI once a year, 21% in 2 years, and 14% in 3 years (46). Our scale with a three-month period, measured once a year, is unable to capture this detailed dynamic, which may be relevant in the context of the pandemic, where fluctuations in unemployment and income were common (18). Therefore, we need more research to ensure these patterns hold throughout a year and in the absence of a pandemic.

A larger sample would provide more details on the characteristics of households experiencing persistent HFI. This was partially mitigated using a SMOTE technique, which helps focus the objectives of the algorithms and by adding synthetic cases might artificially increase the accuracy of the algorithms, but unfortunately is unable to provide the needed granularity. Prevalence estimates of persistent HFI might be limited by the normal attrition of panel studies. In this case, the response rate was 51.3 and 60.8%, which is reasonable (31), but may bias prevalence estimates of subsequent survey rounds. Attrition was not random and those who dropped out had a higher moderate/severe HFI (+7%), suggesting our results may be underestimated. These ML algorithms could be even more powerful if secondary data is combined with primary data (24), such as poverty rates, COVID-19 mortality rates, or even food prices (22). However, the present study focused on survey data because there are several high-quality forecasting models available and less longitudinal surveys that may guide variable selection (21). Results would have been stronger if pre-pandemic measurements were collected, if added survey frequency could reflect seasonality, and more variables were considered in the survey, especially for children (47), but the ENCOVID-19 survey began a few weeks after the pandemic started and telephone modality limits survey length. It is desirable to have ongoing panel monitoring systems to have a better understanding of the multiple effects of emergencies and disasters, as well as to inform ongoing policymaking.

5 Conclusion

The COVID-19 pandemic had an important impact on household food insecurity (HFI), mostly because income reductions decreased access to food. Throughout the pandemic many households were able to recover, however, the study shows that 8% reported persistent moderate/severe HFI across 2 years. These households are generally characterized by having low socioeconomic status, engaging in coping mechanisms, and receiving government aid. Longitudinal models and powerful predictive algorithms—as the ones in a ML approach—can help improve the identification and monitoring of at-risk households of HFI. Persistent moderate/severe HFI is a relevant indicator that shows the most challenging households for food policy interventions. If we want to reduce the global incidence of HFI we need to account for those who are consistently left behind.

Data availability statement

The datasets presented in this article are not readily available because the ENCOVID-19 datasets are under a one-year embargo and will be available at ZENODO repository. The datasets analyzed for this study are available upon reasonable request. Requests to access the datasets should be directed to victor.hernandez@ibero.mx.

Ethics statement

The studies involving humans were approved by Comité de Ética en Investigación de la Universidad Iberoamericana. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because the survey was conducted by telephone.

Author contributions

PG-R: Writing – original draft, Supervision, Project administration, Methodology, Conceptualization. AH-S: Writing – review & editing, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. VL-C: Writing – review & editing, Methodology, Formal analysis. RZ-C: Writing – review & editing, Formal analysis. XG-R: Writing – review & editing, Methodology, Formal analysis. VP-H: Writing – review & editing, Data curation, Conceptualization. MV-C: Writing – review & editing, Conceptualization.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The ENCOVID-19 project was funded by UNICEF Mexico.

Acknowledgments

We appreciate the work of Graciela Teruel Belismelis from EQUIDE for conceptualizing and funding acquisition for the ENCOVID project. Likewise, we acknowledge Brenda Tapia Hernández for her help conducting part of the literature review.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1374815/full#supplementary-material

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 17 July 2024
DOI 10.3389/fpubh.2024.1387638

OPEN ACCESS

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RECEIVED 18 February 2024
ACCEPTED 01 July 2024
PUBLISHED 17 July 2024

CITATION
Mokari-Yamchi A, Faghfouri AH, Gholami S, Nattagh-Eshtivani E and Gheibi S (2024) Association of household food insecurity with sociodemographic factors and obesity in US youth: findings from the National Health and Nutrition Examination Survey 2017–2018. *Front. Public Health* 12:1387638. doi: 10.3389/fpubh.2024.1387638

Association of household food insecurity with sociodemographic factors and obesity in US youth: findings from the National Health and Nutrition Examination Survey 2017–2018

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Background: The objective is to determine the prevalence of household food insecurity (HFI) based on sociodemographic factors and their relationship to obesity in youth.

Methods: The study included a sample of 1,962 youth (aged 6–18) from the National Health and Nutrition Examination Survey (NHANES). The US Household Food Security Survey Module is used to measure food security over the past 12 months. Logistic regression models were used to estimate adjusted odds ratios (ORs) while controlling for covariates.

Results: In total, 27.4% of the individuals surveyed experienced HFI. Youth from food insecure households were more likely to be obese (adjusted odds ratio [aOR]: 1.59 [95% confidence interval: 1.19–2.13]) and also having abdominal obesity (aOR: 1.56 [95% CI: 1.19–2.03]). however, factors such as non-Hispanic ethnicity, having a Head of household with a college degree, and households with an income exceeding 350% of the poverty line were associated with a reduced risk of facing HFI.

Conclusion: Hispanic individuals, households with lower parental education levels, and lower family incomes, are disproportionately affected by food insecurity. Furthermore, HFI has been associated with an increased risk of overweight and abdominal obesity among youth. Addressing FI requires targeted policies and interventions that prioritize vulnerable groups.

KEYWORDS

food insecurity, obesity, youth, NHANES, sociodemograhic factors

Introduction

Household Food insecurity (HFI) is defined as the inconsistent economic and physical access to obtain enough safe and nutritious food to lead an active and healthy lifestyle (1). It encompasses a broad spectrum, ranging from concerns about an inadequate food supply to more sever levels of hunger (2). According to a recent report by the Food and Agriculture Organization (FAO), approximately 735 million people worldwide are still struggling with hunger on a daily basis, indicating the widespread and persistent nature of the issue (1). Additionally, the 2022 report from the US Department of Agriculture (USDA) estimates that roughly 17 million household in the US are affected by food insecurity (3).

Numerous studies have demonstrated the potential consequences of HFI, particularly on children and adolescents, which may include inadequate nutrient intake and various physical and mental health issues, including anemia, asthma, cognitive impairments, as well as behavioral concerns such as aggression and anxiety (4–6). HFI is a strong predictor of childhood malnutrition due to its close connection with the accessibility and quality of food in a household. Various studies have also found that food insecurity can contribute to both underweight and overweight among young people, making it a potential barrier to preventing and treating obesity (7–9).

Recent findings from National Health and Nutrition Examination Survey (NHANES) reveal a concerning trend of increasing obesity rates among youth from 1999 to 2000 to 2015–2016. Conducting research to identify risk factors contributing to adolescent obesity is essential for identifying potential areas of intervention, such as lifestyle modifications and socioeconomic interventions. Recent studies, like the one conducted by Jun et al. (10), have found an correlation between food insecurity and older age, as well as lower household income and educational background.

However, there is conflicting evidence on the relationship between food insecurity and markers of metabolic syndrome. For example, Holben and Taylor analyzed NHANES data and found that youth from food secure families had higher high-density lipoprotein (HDL) values (11). In contrast, Fulay et al. conducted a study among youth aged 12–17 and did not find any significant associations between HFI and Body Mass Index (BMI) for age Z-score, total cholesterol, HDL-C, fasting triglycerides, LDL-C, or fasting plasma glucose (12).

Also an earlier study conducted by Fleming et al. showed no significant associations between food insecurity and obesity among US youth. Nevertheless, it is important to note that the study used a BMI threshold of ≥95th percentile to define obesity, and a BMI percentile range of >5th percentile to <95th percentile for the non-obese group (13). Despite previous research, there is still conflicting evidence regarding the connections between food insecurity and obesity among youths. Thus, our aim in this study, using NHANES data, is to examine the association between food security status, obesity, metabolic syndrome biomarkers, and sociodemographic factors among youths.

Materials and methods

We conducted our study using data from the 2017–2018 NHANES, a robust cross-sectional survey conducted by Centers for Disease Control and Prevention (CDC). NHANES employs a meticulous multistage probability sampling method to select participants, ensuring that the non-institutionalized U.S. civilian population is adequately represented. The survey results are carefully weighted to provide an accurate reflection of population demographics. More details on the sampling method can be found on the NHANES website.[1] In this study, all youth who were 6–18 years of age were eligible for inclusion. The total sample size we analyzed consisted of 1,962 participants.

Sociodemographic variables

In our analysis, we considered various demographic characteristics, including age, gender, ethnicity, and three indicators of socioeconomic status: family income to poverty guidelines ratio (FIPR), highest level of education received by the head of the family, and marital status. FIPR was divided into three categories: low income (0–1.3), middle income (1.3–3.5), and high income (>3.5–5). To determine obesity status, we utilized age- and sex-specific BMI percentiles calculated as weight in kilograms divided by height in meters squared, based on the 2000 CDC growth charts. A BMI ≥85th and <95th percentile was considered overweight, while a BMI ≥95th percentile was classified as obese. Additionally, we assessed abdominal obesity by using a waist-to-height ratio (WHtR) threshold of ≥0.5.

Food security measurement

The assessment of HFS in the NHANES study involved the use of a validated 18-item questionnaire developed by the USDA (14). This questionnaire evaluates the food security status of the household over the course of the past 12 months. Based on the responses from the Household Food Security Scale (HFSS), households were categorized into two groups: (1) food secure (fully and marginal food secure) and (2) food insecure (low and very low food secure).

Laboratory tests

Laboratory tests were performed directly in CDC laboratories in accordance with established protocols using blood samples collected by trained phlebotomists at the Mobile Examination Center (MEC). Enzymatic methods were used to measure serum total cholesterol, LDL-C, and HDL-C levels. Fasting glucose levels were assessed through hexokinase enzymatic and immunoenzymatic assay methods. More details on the measurement of laboratory tests can be found on the NHANES website (see text footnote 1).

Statistical analysis

The statistical analysis was conducted using SPSS software (V 22; SPSS Inc., Chicago, IL), and $p < 0.05$ were considered

1 https://www.cdc.gov/nchs/nhanes/index.htm

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statistically significant. An independent sample t-test was performed to determine the statistical differences in serum health variables, between youth from food secure and food insecure households. Logistic regression analysis was employed to examine the relationship between sociodemographic factors, obesity status, and HFI and odds ratio (OR) with 95% confidence intervals (CIs) were reported. Adjustment for potential confounding variables, such as age, sex, race, household income, and the education and marital status of the head-of-household, was performed during the analysis.

Results

The study included 1,962 participants between the ages of 6 and 18. 27.4% of participants were HFIs. The sample was ethnically diverse; 32.9% were Hispanic, 37.9% were non-Hispanic white individuals, and 29.2% were non-Hispanic black individuals. Additionally, 50.2% of the participants were male (Table 1).

Table 2 displays the findings from logistic regression analyses investigating the relationship between variables related to HFI. Non-Hispanic Black and White households were significantly less likely to be food insecure than Hispanic households (aOR: 0.5 [95% confidence interval (CI): 0.36–0.69], and 0.62 [95% CI: 0.45–0.86], respectively). The likelihood of food insecurity was higher among youth who lived with a single parent (aOR, 1.44 [95% CI, 1.06–1.95]). Additionally, having a head of household with a college degree compared to less than a high school education was associated with a lower odds ratio of HFI (aOR, 0.34 [95% CI, 0.2–0.6]). In addition, there was a decrease in the likelihood of food insecurity among youth living in households that had an income equal to or greater than 350% of the poverty line (aOR: 0.25 [95% CI: 0.14–0.47]). Additionally, the probability of food insecurity decreased for youth in households with an income at or above 350% of the poverty line (aOR: 0.25 [95% CI: 0.14–0.47]), while those below 130% of the poverty line had a higher risk of food insecurity (aOR: 2.43 [95% CI: 1.8–3.2]).

As shown in Table 3, there were no significant differences in average levels of total cholesterol, blood glucose, and LDL cholesterol between youth from food secure and food insecure households. However, participants from food secure households had higher average levels of HDL cholesterol and lower levels of hsCRP compared to those from food insecure households ($p < 0.01$).

Figure 1 displays the association between HFI and the risk of overweight and obesity in youth, both in crude and adjusted models. The logistic regression analysis, after accounting for confounding variables, indicated that youth from food insecure households had 1.59 and 1.76 times greater odds of being overweight and obese, respectively.

Furthermore, Figure 2 showed that food insecurity was linked to higher odds of abdominal obesity in the unadjusted model (OR: 1.72 [95% CI: 1.41–2.12]), a relationship that persisted even after adjusting for various factors (aOR: 1.56 [95% CI: 1.19–2.03]). However, when BMI was included in the adjusted model alongside other confounders, the association was no longer statistically significant (aOR: 1.22 [95% CI: 0.75–1.98]).

TABLE 1 Sociodemographic characteristics of the youth by food security status, 2017–2018 NHANES.

Variable	Sample size	Food secure	Food insecure
Overall	1,962	1,424 (72.6)	538 (27.4)
Gender			
Male	984	725 (50.9)	259 (48.1)
Female	978	699 (49.1)	279 (51.9)
Age group, y			
6–9	654	449 (31.5)	205 (38.1)
10–13	622	467 (32.8)	155 (28.8)
14–18	686	508 (35.7)	178 (33.1)
Race/ethnicity			
Hispanic	511	312 (21.9)	199 (43.3)
Non- Hispanic white	589	469 (32.9)	120 (26.1)
Non- Hispanic Black	453	312 (21.9)	141 (30.7)
Obesity status			
Normal	1,126	873 (61.3)	263 (47)
Over weight	335	228 (16)	107 (19.9)
Obese	501	323 (22.7)	178 (33.1)
Abdominal obesity status			
WHtR <0.5	1,180	903 (66.1)	277 (53)
WHtR ≥0.5	710	464 (33.9)	246 (47)
Head-of-household gender			
Male	871	674 (47.3)	197 (36.6)
Female	1,091	750 (52.7)	341 (63.4)
Head-of-household education level			
< high school	376	220 (16.2)	156 (29.5)
High school	1,083	747 (54.8)	336 (63.6)
College graduate ≤	431	395 (29)	36 (6.8)
Head-of-household marital status			
Married	1,336	1,028 (74.2)	308 (58.8)
Single	573	357 (25.8)	216 (41.2)
Income (%FIPR)			
<130%	695	387 (29.7)	308 (61.7)
130–349%	714	546 (41.8)	168 (33.7)
≥350%	395	372 (28.5)	23 (4.6)

Values are frequency (%). FIPR, family income to poverty level ratio; NHANES, National Health and Nutrition Examination Survey; WHtR, waist-to-height ratio,

Discussion

This study investigated the relationship between HFI and anthropometric measurements, metabolic syndrome indicators, and sociodemographic factors among youth in the United States. The data revealed that HFI was associated with an increased risk of overweight, obesity, and central obesity in youth. Consistent with these findings, previous studies have also shown a clear connection between HFI and obesity (13, 15). For example, Ortiz-Marrón et al. found that children experiencing HFI had nearly double the prevalence of childhood overweight and obesity compared to those with access to HFS (16), However, some other studies have not found such a connection (12, 17). The coexistence of obesity and FI has raised concerns among

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TABLE 2 Logistic regression of household food insecurity depending on sociodemographic factors, 2017–2018 NHANES.

	Food insecure	
Variable	Unadjusted[1]	Adjusted[2]
Gender		
Female	1	1
Male	0.89 (0.73–1.09)	0.88 (0.68–1.13)
Age group, y		
6–9	1	1
10–13	0.72 (0.57–0.93)	0.78 (0.58–1.07)
14–17	0.76 (0.6–0.97)	0.78 (0.57–1.06)
Race/ethnicity		
Hispanic	1	1
Non-Hispanic white	0.4 (0.3–0.52)	0.5 (0.36–0.69)
Non-Hispanic Black	0.71 (0.54–0.92)	0.62 (0.45–0.86)
Head-of-household gender		
Male	1	1
Female	1.55 (1.27–1.9)	0.84 (0.62–1.12)
Head-of-household education level		
<High school	1	1
High school	0.63 (0.49–0.8)	0.9 (0.66–1.23)
College graduate ≤	0.13 (0.08–0.19)	0.34 (0.2–0.6)
Head-of-household marital status		
Married	1	1
Single	2 (1.63–2.49)	1.44 (1.06–1.95)
Income (%FIPR)		
130–349%	1	1
<130%	2.58 (2.05–3.25)	2.43 (1.8–3.2)
≥350%	0.2 (0.12–0.31)	0.25 (0.14–0.47)

FIPR, family income to poverty level ratio; NHANES, National Health and Nutrition Examination Survey. Model[1]: crude mode. Model[2]: adjusted for all variables shown in the table. Different from the food insecure category.

TABLE 3 The health measures of the youth by household food security status, NHANES 2017–2018.

Variable	Food secure	Food insecure	*P*-value
Total cholesterol, mg/dL	157.36 (28.26)	155.96 (26.98)	0.35
HDL cholesterol, mg/dL	54.43 (11.8)	52.62 (11.32)	0.005
LDL cholesterol, mg/dL	88.36 (24.47)	87.95 (25)	0.89
Fasting glucose, mg/dL	97.69 (7.83)	99.75 (13.75)	0.24
HS-CRP (mg/L)	1.59 (3.85)	2.11 (5.26)	0.032
Systolic blood pressure (mmHg)	105.39 (10.11)	105.43 (9.96)	0.94
Diastolic blood pressure (mmHg)	55.6 (18.55)	54.66 (18.83)	0.38

Values are Mean (SD). HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; HS-CRP, high-sensitivity C-reactive protein; NHANES, National Health and Nutrition Examination Survey.

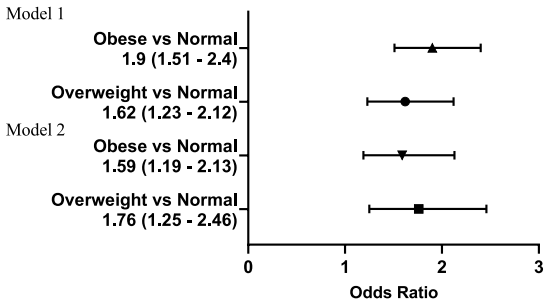

FIGURE 1
Association of household food insecurity with risk of overweight and obesity in youth 6 to 18 y; OR with 95% CI. Model 1 = Unadjusted Model; Model 2 = adjusted for age, sex, race, household income and Head-of-household marital and education status.

researchers due to the apparent contradiction that individuals with limited access to food can still become obese. There are several potential factors that may contribute to the association between food insecurity and youth obesity. These factors include the consumption of energy-dense foods in excess (18), overeating during periods of food abundance (19), and reduced family support and attention toward making healthy nutritional choices (20, 21).

Youth from food secure households had significantly higher levels of serum HDL-C compared to those from food insecure households. However, there were no significant differences in other metabolic syndrome indicators like blood pressure, total and LDL-C, and fasting glucose levels between the two groups. These findings align with Holben et al.'s study, which showed that adolescents facing marginal food security or food insecurity were more likely to have increased central adiposity, be overweight or obese, and have lower HDL-C levels compared to those with full food security (11). The higher levels of HDL-C observed in youth from food secure households may be attributed to various factors, including greater engagement in physical activity, fewer limitations in resources, or residing in neighborhoods that offer better infrastructures for physical activity (22).

Youth who come from food insecure households have been found to have significantly higher levels of hs-CRP in their serum. This trend has also been observed in previous studies with food insecure adults (23). Elevated hs-CRP levels during childhood and adolescence can predict future cardiovascular disease risk (24). Food insecurity may lead to increased inflammation through various mechanisms, including poor diet quality due to inadequate access to nutritious foods and the stress of food scarcity or uncertainty about meal availability (23, 25).

The correlations identified between HFI and sociodemographic factors are consistent with the findings reported in previous studies (13, 26–28). Households with parents who have lower education levels, lower family incomes, and single parental status showed a higher prevalence of food insecurity. An increase in parents' education level can lead to more job opportunities and higher income which provides the power to buy food (26). Additionally, higher parental education levels have been linked to improved awareness, attitudes, and actions regarding family nutrition (29, 30).

Our findings also indicated that non-Hispanic youth are less likely to be food insecure compared to Hispanic youth. This supports the

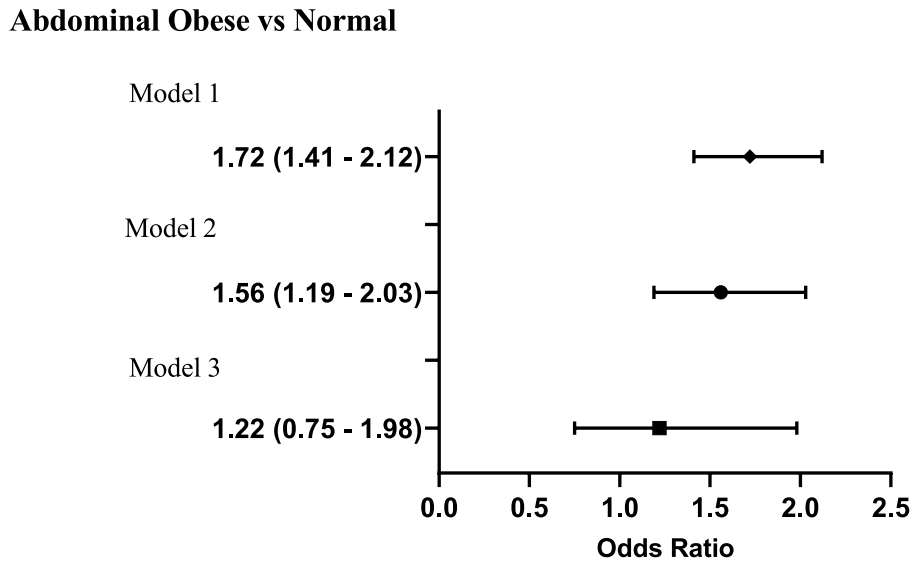

FIGURE 2
Association of household food insecurity with risk of abdominal obesity (WHtR≥0.5) in youth aged 6 to 18 y; OR with 95% CI. Model 1 = Unadjusted Model; Model 2 = adjusted for age, sex, race, household income and Head-of-household marital and education status; Model 3= adjusted for age, sex, race, household income and Head-of-household marital and education status and BMI.

findings of Fleming et al., who reported a high prevalence of food insecurity among Hispanic youth (13). Hispanic youth face various challenges related to acculturation, including adapting to new norms and family dynamics, as well as economic factors such as low-income status and neighborhood isolation. These factors collectively contribute to their increased risk of food insecurity. Additionally, immigration status and associated difficulties may further exacerbate food insecurity among Hispanic youth and their families. Concerns about deportation can act as barriers to accessing government assistance programs, making them more susceptible to food insecurity (31–33).

Implementation of targeted, specific policies like the Supplemental Nutrition Assistance Program (SNAP) in the US, which offers food assistance to low-income individuals and families, as well as initiatives like the National School Lunch Program and the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), which provide nutritious meals and support to children and pregnant or postpartum women from low-income households, can play a crucial role in addressing these disparities. By focusing on improving access to healthy and nutritious foods for youth from food-insecure households, targeted nutrition programs can help reduce the heightened risk of overweight, obesity, and central obesity associated with HFI.

The main limitation of the current study is its cross-sectional design, which does not provide conclusive evidence of causality. To enhance our comprehension of the connection between sociodemographic factors, food security and health related problems in youth, it is imperative to conduct longitudinal studies.

Conclusion

Food insecurity disproportionately affects specific population groups, including Hispanic individuals, households with lower parental education levels, lower family incomes, and single parental status. Furthermore, youth living in households with food insecurity have a higher likelihood of being overweight and having abdominal obesity. It is crucial to address food insecurity by implementing policies and interventions that focus on improving economic stability, parental education, and household income. The study highlights the importance of targeted policies and programs, in addressing food insecurity and its associated health risks among vulnerable youth populations. These measures have the potential to alleviate the negative health consequences associated with food insecurity, particularly among vulnerable populations.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The NHANES protocol has been reviewed and approved by the National Center for Health Statistics research ethics review board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

AM-Y: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. AF: Data curation, Methodology,

Writing – original draft. SaG: Writing – original draft. EN-E: Writing – review & editing. ShG: Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

Authors would like to thank, Urmia University of Medical Sciences for providing financial support.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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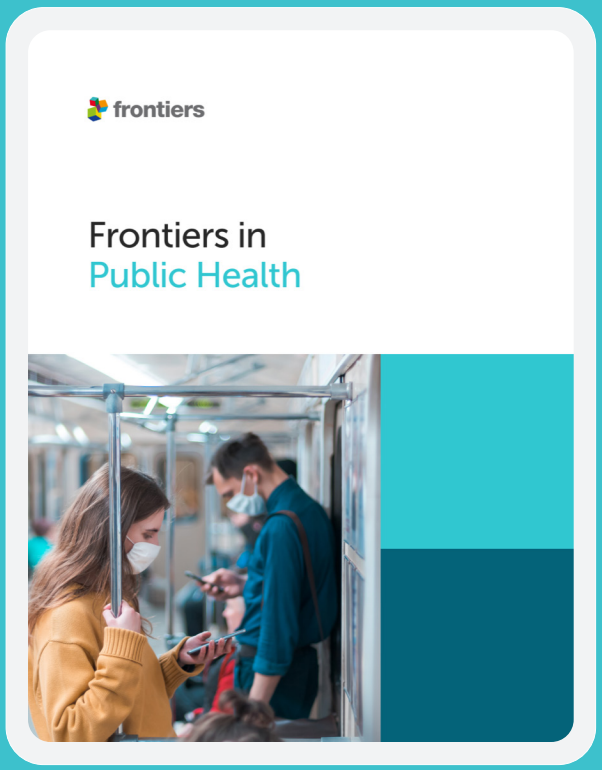

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