

Review

Food Insecurity, Cardiometabolic Risk and Cardiovascular Disease: A Narrative Review and Call for ActionSatchit Anand Saha ¹, Katelyn Ann Williams ², George Murphy ², Sandeep Ajoy Saha ^{1, 2, *}

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doi:10.21926/obm.icm.2401006**Received:** September 24, 2023**Accepted:** January 07, 2024**Published:** January 09, 2024**Abstract**

Food insecurity and insufficient access to affordable nutrition have been associated with increased risk for the development of multiple chronic medical conditions, including cardiovascular disease. In this narrative review, we explore the association between food insecurity and the development of chronic medical conditions that confer increased cardiometabolic risk, cardiovascular disease, and mortality. We also identify the various barriers leading to food insecurity and lack of food literacy, with an emphasis on patients with high blood pressure, diabetes mellitus, stroke, congestive heart failure, and coronary heart disease. We discuss recent developments in legislation and public policies and programs designed to expand our understanding and reduce food insecurity at the local, regional, national, and international levels, and identify opportunities for future research and innovation.



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Keywords

Nutrition insecurity; social determinants; cardiometabolic risk; healthy diet; nutritional education; welfare programs

1. Introduction

Social determinants of health (SDOH) have been increasingly recognized as an important contributor to health-related morbidity and mortality. SDOH comprise the circumstances in which people are born, live, learn, work, and age. Access to healthy food for a balanced, wholesome and nutritious diet is an important SDOH which has far-reaching impact on the physical and mental well-being of communities, and is also related to other social determinants such as education, economic and employment opportunities, as well as availability of and access to government-supported and independent social welfare programs [1]. An estimated 45% of all cardiometabolic deaths can be attributed to poor dietary habits, based on an analysis using a comparative risk assessment model and data from the National Health and Nutrition Examination Survey (NHANES) and the National Center for Health Statistics [1]. Major dietary risk factors for cardiometabolic deaths include low consumption of vegetables and fruits (15%), high sodium intake (10%), low consumption of nuts/seeds (9%), high consumption of processed meats (8%), low intake of seafood omega-3 fats (8%), and high consumption of sugar-sweetened beverages (7%) [2]. Diet-related cardiometabolic diseases such as obesity, hypertension, diabetes, hyperlipidemia, and coronary heart disease (CHD) can occur as a result of inadequate consumption of healthy foods, with diabetes and heart disease being associated with an average loss of more than 10 quality-adjusted life years (QALY) in the United States [3].

In addition to inadequate access to healthy food choices, lack of healthcare literacy has also been linked to adverse cardiovascular outcomes. Individuals with low healthcare literacy can have greater difficulty accessing credible health information, and understanding the importance of preventive care, which can then impact lifestyle decisions and behaviors [4, 5]. Among patients with known CHD or congestive heart failure (CHF), low healthcare literacy is associated with higher risk of hospital readmissions and increased mortality [6, 7]. A meta-analysis of 16 observational studies of patients with known cardiovascular disease (CVD) reported that almost one-third of these patients had low healthcare literacy (32.8%), and low healthcare literacy was associated with significantly higher risk for hospital readmission (RR 1.184) and death (RR 1.621) [8].

2. Food Insecurity and Cardiovascular Disease – A Bidirectional Relationship

Food insecurity has been defined by the US Department of Agriculture (USDA) as a household-level economic and social condition of limited or uncertain access to adequate food. In 2006, the Committee on National Statistics (CNSTAT) of the National Academies convened an expert panel at the request of the USDA, and further defined ranges of severity of food insecurity as follows [9]:

- **Low food security (LFS)** (old label = Food insecurity without hunger): reports of reduced quality, variety, or desirability of diet. Little or no indication of reduced food intake.

- **Very low food security (VLFS)** (old label = Food insecurity with hunger): reports of multiple indications of disrupted eating patterns and reduced food intake.

The 2021 report of the USDA's Economic Research Service (ERS) estimates that 13.5 million US households (10.2%) were food insecure at some time during 2021, with 8.4 million households (6.4%) having LFS and 5.1 million household (3.8%) households had VLFS at some time during 2021. Almost 4.6 million US households with children <18 years (12.5%) experienced food insecurity at some time in 2021, with 3.3 million (8.9%) experiencing LFS and more than 1.3 million (3.6%) experiencing VLFS [10].

Food insecurity does not carry the same definition as hunger, which is experienced at an individual level and is a physical condition characterized by physical discomfort, illness, weakness, or pain caused by prolonged, involuntary lack of food. Food insecurity does not necessarily cause hunger, but can have long-term negative consequences due to consumption of unhealthy, unsanitary, and unwholesome foods which can lead to chronic diseases such as hypertension, obesity, diabetes mellitus, hyperlipidemia, certain types of cancers, and micronutrient deficiencies.

Several studies have shown that food insecurity is associated with increased cardiometabolic risk, cardiovascular disease, and unhealthy lifestyle choices. A cross-sectional study of 10,455 US adults ≥ 20 years of age from the NHANES database (2003-2008) showed increased predicted 10-year CVD risk $>20\%$ among VLFS participants aged 30-59 years compared with food-secure participants (adjusted prevalence ratio = 2.38, 95% CI 1.31-4.31, $p = 0.03$). In this study, food security status was also significantly associated with hypertension (defined as systolic blood pressure ≥ 140 mm Hg or diastolic blood pressure ≥ 90 mm Hg or the self-reported current use of antihypertensive medications) ($p = 0.004$), hemoglobin A1c $\geq 6.5\%$ ($p = 0.01$), high-density lipoprotein cholesterol (HDL) <40 mg/dl in men or <50 mg/dl in women ($p = 0.002$), body mass index (BMI) ≥ 30 kg/m² ($p = 0.03$), C-reactive protein >3 mg/l ($p = 0.002$), and urinary albumin-creatinine ratio ≥ 30 mg/g ($p = 0.01$) [11]. Another cross-sectional study of 41,854 US adults 19-64 years living $\leq 200\%$ federal poverty level (FPL) from the National Health Interview Survey (2011-2015) showed that as food insecurity worsens, the likelihood of having hypertension (LFS, $\beta = 0.35$, $p < 0.01$; VLFS, $\beta = 0.64$, $p < 0.01$), coronary heart disease (LFS, $\beta = 0.43$, $p < 0.01$; VLFS, $\beta = 0.76$, $p < 0.01$), stroke (LFS, $\beta = 0.52$, $p < 0.01$; VLFS, $\beta = 0.78$, $p < 0.01$), and diabetes mellitus (LFS, $\beta = 0.36$, $p < 0.01$; VLFS, $\beta = 0.58$, $p < 0.01$) increased relative to those in food-secure households [12]. Another cross-sectional study of 30,010 US adults ≥ 18 years from the 2011 National Health Interview Survey showed that LFS adults had higher odds for hypertension (OR = 1.18, 95% CI 1.04-1.35) and diabetes (OR = 1.26, 95% CI 1.06-1.51) when compared with FS adults, and VLFS adults had higher odds for coronary heart disease (OR = 1.75, 95% CI 1.37-2.24), heart attack (OR = 1.40, 95% CI 1.08-1.81), hypertension (OR = 1.42, 95% CI 1.22-1.65) and diabetes (OR = 1.23, 95% CI 1.02-1.48) compared with food-secure adults [13]. Additional studies have shown that food insecurity may be associated with obesity [14, 15], diabetes mellitus [16, 17], and hypertension [18]. Collectively, these studies indicate that food insecurity can increase the odds of developing medical conditions that can confer higher cardiometabolic risk, and is also associated with higher odds of developing CHD and stroke.

Multi-morbidity is characterized by the coexistence of two or more chronic medical conditions in the same individual. The prevalence of multi-morbidity has been increasing worldwide over the past 20 years (overall prevalence 37.2%), affecting 43.1% of the population in North America and even more in some countries such as Ireland (73.3%) [19]. Although multiple socio-economic factors may impact the development of multi-morbidity, food insecurity is thought to be an important

determinant leading to multi-morbidity. Food insecurity may lead to multi-morbidity due to individuals consuming inadequate food (caloric deprivation) or consuming calorie-dense foods that do not provide balanced nutrition (nutrient deprivation). Food insecurity is also often associated with other adverse social determinants such as low income, lower educational level, residence in nutritionally disadvantaged communities (“food deserts”) with inadequate access to healthy nutritious foods, mobility limitations, and transportation barriers. Individuals with food insecurity may also have other unhealthy habits such as lack of physical activity [20], high-risk health behaviors and substance abuse [21]. A study of 9,203 obese adults ≥ 20 years old from NHANES (2007-2014) found that food insecurity was associated with increased odds of CHD (OR 1.5, 95% CI 1.1-2.0, $p < 0.05$), and VLFS was associated with higher odds of CHD (OR 2.0, 95% CI 1.3-3.0, $p < 0.01$), diabetes mellitus (OR 1.3, 95% CI 1.0-1.7, $p < 0.05$), and dyslipidemia (OR 1.3, 95% CI 1.0-1.6, $p = \text{NS}$). Using propensity-score weighted models, food insecure adults had significantly more obesity-related comorbidities than food-secure adults ($\beta = 0.09$, 95% CI 0.02-0.15, $p = 0.01$), and this effect was more pronounced in participants with very low food security ($\beta = 0.17$, 95% CI 0.07-0.28, $p = 0.003$) [22].

A recent systematic review and meta-analysis investigated the impact of food insecurity on the risk of developing multi-morbidity in adults ≥ 18 years of age and vice-versa. A total of 7 cross-sectional population-based studies published between 2013 and 2022 were selected. Using data from 4 studies that included 45,404 individuals, they found that food insecurity was significantly associated with the presence of multi-morbidity (odds ratio 1.55, 95% CI 1.31-1.79, $p < 0.001$) compared to those without food insecurity. These authors also studied the phenomenon of reverse causation to determine whether the presence of multimorbidity (≥ 2 comorbid conditions) could lead to food insecurity. Using data from 4 studies that included a total of $>83,000$ adults, they found that individuals with multi-morbidity had more than 2.5 times higher odds of having food insecurity (odds ratio 2.58, 95% CI 1.66-3.49, $p < 0.001$) when compared to those without multi-morbidity (presence of 0-1 comorbid conditions), although the heterogeneity of the included studies was high ($I^2 = 89.7\%$, $p < 0.001$) [23]. An analysis of 57,517 adult NHANES participants between 1999-2018 with either known cardiovascular disease (CHD, stroke, CHF) or diseases that confer cardiometabolic risk (hypertension, diabetes, hyperlipidemia, obesity) found that the overall prevalence of food insecurity in this population was 11.8%, but increased over time from 8.2-10.2% in 1999-2006 to 18.2-18.5% in 2015-2018. Among patients with individual cardiometabolic risk factors such as hypertension, diabetes, dyslipidemia and obesity, the prevalence of food insecurity was as high as $\sim 20\%$ in 2017-2018. During the same period, the prevalence of food insecurity was even higher in patients with known CHD (41.3%), stroke (43.7%), and CHF (45.3%). They reported that among participants with cardiovascular disease, food insecurity was almost 2 times as common compared to those without (38.1% versus 17.2% in 2017-2018, $p = 0.051$ for interaction). This effect was most pronounced among patients with CHF (45.3% versus 17.9% in 2017-2018, $p = 0.003$ for interaction) [24]. Food insecurity has also been shown to increase the risk of death. A longitudinal study followed 9,245 US adults aged ≥ 20 years living $<130\%$ FPL and reported that food insecurity was associated with 28% higher mortality rate than food secure individuals [25]. A county-level longitudinal analysis using data for US adults aged 20-64 years from 3142 counties across 50 states and Washington D.C. (2011-2017) reported that an estimated 1% point increase in food insecurity was associated with a 0.83% (95% CI 0.43-1.25%, $p < 0.001$) increase in age-adjusted cardiovascular mortality [26].

2.1 Ethnic Minorities

Prior studies have shown that food insecurity impacts ethnic and racial minorities to a larger extent when compared to Caucasian households. Food insecurity trends among non-Hispanic Black and Hispanic households is more than twice that of non-Hispanic White households [10]. In the study by Brandt et al, Black (18.2%) and Hispanic (24.0%) adults with known CVD were disproportionately more impacted by food insecurity compared to Asian (8.0%) and White (8.5%) adults. The prevalence of food insecurity for Black adults with cardiovascular disease was as high as 37.3% in 2013-2014, and the prevalence of food insecurity among Hispanic adults with cardiovascular disease was as high as 42.2% in 2017-2018 [24]. A prospective study showed that economic food insecurity was associated with significantly higher risk of coronary heart disease and systolic heart failure among 3,084 Black participants in the Jackson Heart Study, even after adjustment for baseline cardiovascular risk and socio-economic factors [27]. Hispanic/Latino adolescents are a particularly vulnerable group and have the highest prevalence of adolescent obesity in the United States [28]. A cross-sectional study of 1325 Hispanic/Latino youth (8-16 years of age) showed that LFS/VLFS at the household and individual levels were associated with adverse cardiometabolic risk factor levels such as low HDL levels and high plasma glucose and triglyceride levels, even after adjustment for clinical and socio-economic factors [29]. In a study of 9,907 respondents from the 2009 and 2012 Behavioral Risk Factor Surveillance System in Hawai'i, food insecurity was associated with higher odds of having diabetes and cardiovascular disease among Native Hawaiian or other Pacific Islander (NHOPI) participants, and the magnitude of the risk was higher in NHOPI participants compared to food-insecure White participants [30]. In addition, strategies employed by parents to cope with food insecurity have been found to vary by race/ethnicity. A 2018 systematic review revealed subtle differences in the coping strategies used by African-Americans, Native American, Hispanic, and Caucasian parents and households experiencing food insecurity. Social stigma was identified as a major barrier to the use of public assistance programs among African-American parents, while immigration status was identified as a barrier amongst Hispanic parents [31].

3. Legislation and Policies to Reduce Food Insecurity

In October 2021, the 117th US Congress approved Bill S.3064, which authorized a White House Conference on Food, Nutrition, Hunger, and Health - the first such conference in more than 50 years. This Bill acknowledged that access to healthy food and good nutrition should be a fundamental priority for every US resident, and in the aftermath of the COVID-19 pandemic, more than 42 million individuals (13 million children) are projected to experience food insecurity. The Bill also highlighted the fact that diet-related diseases led to worse clinical outcomes from COVID-19 infection and were responsible for nearly two-thirds of all COVID-19 related hospitalizations in the US. The Bill also acknowledged that disruption of food supply chains at the global, national, regional, and local levels related to the COVID-19 pandemic demonstrated the fragility and shortcomings of the food production and distribution system and constituted a national security issue. The true cost of hunger and illnesses related to food and nutrition insecurity is conservatively estimated at about US \$160 billion per year in direct medical costs, most of which is paid by CMS (Medicare and Medicaid). The economic burden related to food insecurity, related to lower productivity, higher healthcare costs,

higher public education costs, and emergency food distributions is estimated at a staggering \$178.9 billion per year [32].

The White House Conference [33] identified 5 pillars to define the scope and identify action steps to be taken as a result of the conference proceedings:

1. **Improve food access and affordability:** The overarching goal is to end hunger by making it easier for everyone (urban, suburban, rural, and Tribal communities) to access and afford food. This pillar emphasizes expanding eligibility for and increasing participation in food assistance programs and improving transportation to places where food is available.
2. **Integrate nutrition and health:** This pillar emphasizes the role of nutrition and food security in overall health including disease prevention and management, and ensures that our health care system addresses the nutrition needs of all people.
3. **Empower all consumers to make and have access to healthy choices:** This pillar encourages environments that enable all people to easily make informed healthy choices, increases access to healthy food, supports healthy workplace and school policies, and invests in public messaging and education campaigns that are culturally appropriate.
4. **Support physical activity for all:** This pillar enables people to be more physically active by ensuring that everyone has access to safe places to be active, increasing awareness of the benefits of physical activity, and encouraging research on the benefits of physical activity.
5. **Enhance nutrition and food security research:** This pillar focuses to improve nutrition metrics, data collection, and research to inform nutrition and food security policy, particularly on issues of equity, access, and disparities.

There is now growing consensus that food programs and policies in the US need to transition away from the narrow definitions of "food security" and instead use a broader term "nutrition security" – which includes having stable and equitable availability of nutritious food, ensure adequate access, improve affordability of nutritious foods, and stable utilization of nutritious foods over time. Towards this end, the United Nations Committee on Food Security also identified 4 pillars of nutrition and food security: availability, access, utilization, and stability [34].

In a recently published public policy statement [35], the American Heart Association (AHA) espoused the same foundational pillars of food and nutrition security identified by the United Nations. According to the AHA policy statement, the components of nutrition security include:

1. **Availability, accessibility, affordability:** Nutritious foods should be available in every community in both sufficient quantity (calories) and sufficient quality (nutrients). Individuals in the community, regardless of physical and/or mental disability/impairment or location of residence, should be able to access nutritious foods that align with their social, cultural, and dietary preferences. All individuals within the community should be able to afford nutritious foods.
2. **Utilization:** The term "utilization" includes all the steps between the time of access to nutritious food to the time when the nutrients are available and used by the body. Physiological utilization of nutrients requires proper food storage, food preparation, and equitable distribution within the various members of the household. Each of these steps have specific requirements and increasing the emphasis on home-cooked healthy meals that are aligned with the household's cultural and dietary preferences requires all the above conditions to be met. A breakdown in one of more of these steps may have an adverse impact

on a household's ability to consume more homemade nutritious meals and increase reliance of pre-prepared, over-processed, and nutrient-poor alternatives.

3. **Stability:** This refers to ensuring that nutritious foods of sufficient quantity and quality are available year-round, and that the sources of nutritious foods are consistently available to all the individuals within the community.

4. Practical Strategies to Counteract the Impact of Food Insecurity

4.1 Enhancements to Existing Federal, State, and Local Nutrition Assistance Programs

Although the US has considerable food resources, extending food resources to LFS and VLFS groups remains a long-standing problem. Federal nutrition assistance programs such as the Supplemental Nutrition Assistance Program (SNAP) have varying access by month or season, and have eligibility limitations that can change regionally or locally [36]. Disbursement of benefits as a lump sum at the start of the month can lead to inadequate resources to acquire nutritious foods towards the end of the month. Up to 25.8% and 21.7% of households below 130% of the poverty line who use SNAP benefits remain low and very low food secure, respectively [37]. An analysis of adult NHANES participants (1999-2018) with either known cardiovascular disease or diseases that confer high cardiometabolic risk who also had food insecurity, more than 4 in 10 individuals were not participating in the federal SNAP program [24]. Households at $\leq 185\%$ of the FPL are also supported with free and reduced-price meals for children through the National School Breakfast [38] and National School Lunch Programs [39], while the Special Supplemental Program for Women, Infants, and Children (WIC) provides supplemental foods containing key nutrients for younger children and pregnant women [40]. However, cessation of the school breakfast and lunch programs over the summer can threaten nutrition stability for school-aged children, and although the Summer Food Service Program [41] and the Seamless Summer Option [42] are designed to close this gap, practical issues such as complex eligibility criteria and inadequate transportation to food distribution centers can hinder access to these programs for the most vulnerable members of the community. Immigrant families face additional problems as they are often ineligible for SNAP, and families with children who are no longer eligible for WIC benefits and who are in the pre-kindergarten age group may not have access to the school breakfast and lunch programs. These and other reasons explain why despite the presence of these federal programs, food insecurity with accompanying poor dietary quality, inadequate nutrient intake and health disparities are more prevalent among households with children, pregnant women, and low-income households compared with all households [37].

Increasing funding for federal nutrition assistance programs such as SNAP, WIC, as well as other programs such as The Emergency Food Assistance Program (TEFAP) [43], the Head Start program [44], and the school-based National Smart Breakfast [38] and School Lunch [39] programs can ensure that all eligible individuals and families have access to these important public welfare programs. In addition, forging collaborations between federal nutrition assistance programs and local, nonprofit organizations and programs to provide additional incentives to individuals for nutritious food purchases such as fresh fruits and vegetables, incentives to electronic benefits transfer (EBT) retailers to stock and market healthy foods, and increase the awareness and education about the nutritional value of the foods being purchased, can help to increase access, educate, and inculcate healthy food choices.

Federal, state, and/or local funding are also available for other nonprofit organizations that provide crucial resources and support to reduce food insecurity within the communities. Food banks, food pantries, and prepared meal delivery programs provide an important service to reduce the impact of inadequate access and/or affordability on food security within communities. The Meals on Wheels program provides home delivery of daily nutritious meals to enrolled adults ≥ 60 years of age, their spouses and caregivers, as well as adults < 60 years of age who are homebound [44]. Individual states have also used Medicaid funding for programs to reduce food insecurity within Medicaid participants, although these programs vary by state and region. The CSFP (Commodity Supplemental Food Program) provides a monthly box of commodity foods that can be picked up at a local food bank or food bank distribution site, and can also provide home delivery in some areas [45].

Food pantries are community-supported sources of food assistance that offer food directly to households at no cost, and may be completely private, supported by community or faith-based groups, or they may be public-private partnerships. Feeding America [46] is the largest U.S. hunger-relief organization and is comprised of a network of more than 200 U.S. food banks and 60,000 community partners, where foods are offered with limited identity or income requirements, enhancing food access to those who may have difficulty accessing federal food assistance or who are fearful to disclose personal information to governmental agencies. The food offered at food pantries may contribute up to 25% of the dietary intake of households using them and may reduce the health impact of food insecurity [47, 48].

Providing food choices that are both healthy and culturally appropriate in neighborhoods with a large proportion of ethnically diverse or immigrant families is also crucial for more widespread acceptance and participation in nutritional assistance programs. Partnerships between food sources (food banks, food pantries, food growers, food distribution organizations, retailers) and cultural organizations (e.g. places of worship, community-specific social organizations) are crucial to increase awareness and access to racial/ethnic minority populations who may have specific barriers to entry and inclusion in publicly funded and private nutrition assistance programs. Strategies to reduce the social stigma and simplifying the application process and eligibility criteria for nutritional assistance programs are also important to increase utilization of these resources by those who need it the most. Other initiatives such as expanding and increasing access to specific federal income support benefits such as the earned income tax credit (EITC), increasing opportunities for gainful employment and ability to earn a living wage, and training of healthcare providers to screen for food insecurity and provide appropriate referrals to federally-funded and charity-based nutritional assistance programs in a culturally sensitive and appropriate fashion, can pave the way to reduce the racial/ethnic disparities in food and nutrition security.

4.2 Increasing Awareness of Existing Programs to Support Healthy Food Choices in Patients with Chronic Diseases

The majority of federally-funded nutritional assistance programs are based on household income, but few programs focus on individuals with chronic medical illnesses who may not necessarily experience food insecurity in the form of inadequate calories, but may have limited resources to tailor their dietary intake based on the healthcare provider's recommendations. For individuals with chronic medical conditions such as obesity and type 2 diabetes mellitus, programs in the form of

medically-tailored meals and grocery lists, and "produce prescriptions" can help encourage better food choices and enable these individuals to be more proactive in better managing their medical conditions.

- i. **SNAP-Ed** is a federally funded program that offers SNAP participants support and resources on shopping and cooking healthy food on a budget. The program also provides nutritional knowledge and skills that contribute to increased use of healthy foods [49].
- ii. The **EFNEP (Expanded Food and Nutrition Education Program)** provides nutrition education to adults through a series of lessons, and children as part of after school or community-based educational programs [50].
- iii. The **GusNIP (Gus Schumacher Nutritional Incentive Program)** provides competitive grants for programs that incentivize purchase of fruits and vegetables at the point of purchase. Previously called the Food Insecurity Nutrition Incentive (FINI), GusNIP funds projects that provide nutritional incentives and "produce prescriptions" to SNAP-eligible enrolled participants [51].
- iv. The **FFVP (Fresh Fruit and Vegetable Program)** is an application based federally funded program aimed at elementary school-age children and provides enrolled children with access to free fresh fruits and vegetables outside of regular meals [52].
- v. The **WIC Farmers Market Nutrition Program (WIC FMNP)** provides coupons to participants of the WIC program to purchase fresh, locally grown fruits and vegetables at farmers markets or similar settings [53].
- vi. The **SFMNP (Senior Farmers' Market Nutrition Program)** is a federally funded program aimed at older adults ≥ 60 years of age with household income $\leq 185\%$ of the federal poverty level and provides monthly coupons that can be exchanged for eligible foods at farmers markets, roadside stands, and other community supported agriculture programs [54].

In a recent narrative review of U.S. food pantry users with incomes less than 185% of the poverty-income-ratio in the US, food insecurity ranged from 48% to 89%, with 27% to 44% meeting criteria for LFS and 14% to 52% meeting criteria for VLFS. The prevalence of obesity, diabetes mellitus, hypertension, hyperlipidemia, coronary heart disease, stroke, and depression in these food pantry users was significantly higher than the age-adjusted prevalence in the general US population [55]. Longitudinal cohort studies of food pantry clients show that food pantry utilization for short periods (6 weeks to 6 months) can reduce food insecurity by 10-15% [56, 57]. Using a randomized, controlled study design, Seligman et al showed an ~9% improvement in food security among food pantry clients with diabetes after a 6-month intervention that included about 20-25% of household food, diabetes education, health care referral and glucose monitoring. They also showed an improvement in hemoglobin A1c (an indicator of glycemic control) by offering diabetic-appropriate foods lasting 1-2 weeks with recipes for healthy meals, blood sugar monitoring, and referrals [58]. Such studies suggest that important health outcomes (e.g. body weight, glycemic control) can be improved through food pantry-based interventions that provide disease-specific foods and recipes, nutrition education, referrals, clinical monitoring, and tailored outreach to vulnerable populations that utilize food pantries.

4.3 Nutritional Programs to Improve Overall Health-A Focus on Fresh Fruits and Vegetables

Fruits and vegetables contain a wide variety of nutrients and phyto-chemicals, and are particularly good sources of vitamin C, keratinocytes, antioxidants, potassium, flavonoids, and fiber. In addition to the nutritional value of fresh fruits and vegetables, these foods also reduce chronic disease risk indirectly by displacing other unhealthy foods that are high in saturated fat, glycemic load, sodium, and preservatives. In a meta-analysis of 95 studies, the consumption of fruit and vegetables was associated with significantly reduced risk of cardiovascular disease, cancer, and all-cause mortality. For every 200 g/day of combined fruits and vegetable consumption, the investigators observed a mean risk reduction of 8% in coronary heart disease, 8% in cardiovascular disease, 16% in stroke, and 10% in all-cause mortality. Interestingly, these reductions in risk were observed up to 800 g/day of combined fruit and vegetable consumption, with up to a 24% relative risk reduction in coronary heart disease, 28% relative risk reduction in cardiovascular disease, 33% relative risk reduction in stroke, and a 31% risk in all-cause mortality [59]. In contrast, intake of *tinned* fruits was associated with increased risk of cardiovascular disease and all-cause mortality, validating the emphasis on fresh fruit and vegetable intake to reduce the risk of chronic disease. The US IMPACT Food Policy Model projects that a 30% fruit and vegetable subsidy for low-income SNAP participants, along with a 10% price reduction in fruits and vegetables, could prevent approximately 230,000 cardiovascular disease-related deaths by 2030 [60]. A cost-effectiveness analysis of an expanded fruit/vegetable SNAP subsidy found that such a financial incentive would also save costs through long-term reductions in diabetes and cardiovascular disease [61].

There are several programs that are designed to incentivize the purchase and consumption of nutritious, wholesome foods such as fresh fruits and vegetables. In addition to the FFVP, the GusNIP, and the FMNP programs described above, several initiatives have been launched at the state, regional, and local level. The Double Up Food Bucks (DUFEB) program aims to increase healthy food access among low-income families who qualify for SNAP benefits, and incentivizes the purchase of fruits and vegetables by doubling the value of SNAP benefits spent on fruits and vegetables at participating farmers markets and grocery stores. A study of the DUFEB program in Michigan over 3 consecutive years (2016-2018) showed that participation in the DUFEB program led to a 20% increase in more frequent fruit and vegetable purchase (≥ 4 -5 times per month), and those who participated in DUFEB for 7 months or longer reported significantly higher fruit and vegetable intake, and tended to have less food insecurity than those with shorter durations of DUFEB participation [62]. In 2005, the New York City Department of Health and Mental Hygiene introduced a coupon-based nutritional incentive program called "Health Bucks" for low-income New Yorkers to shop at farmers' markets in the city's most poverty-stricken neighborhoods. The incentive was initially offered in the form of \$2 coupons to be used at participating farmers' markets, and in 2006 the program was expanded to provide a \$2 coupon for every \$5 of EBT credits spent to encourage SNAP participants to use their EBT cards and food stamps to purchase fruits and vegetables. A preliminary economic analysis suggested that nutritional incentive programs such as Health Bucks can encourage low-income shoppers to preferentially purchase healthy foods from participating farmers markets instead of conventional retail stores, and the subsequent increases in financial support for the EBT incentive by the New York City human resources administration in 2008 made it one of the largest farmers market financial programs in the United States at the time [63]. A systematic review of 29 published studies looking at healthy food pricing incentive programs from 2000-2019 showed that nutritional

incentives were an effective approach to significantly increase healthy food consumption, especially the consumption of fresh fruits and vegetables, and a decrease in healthy food prices encouraged increased consumption [64]. Encouraged by these results, grass-root nonprofit organizations such as Homemade Nourish [65] have been developed to provide nutritional incentives and other discounts to individuals with known chronic medical conditions in conjunction with their healthcare providers, to encourage the adoption of healthy food choices and provide nutritional education and support. Other nonprofit organizations such as Healthy Food America [66] also support advocacy efforts to impact public policy, raise awareness, and evaluate ongoing research.

5. Areas for Further Study and Innovation

5.1 Improvement in Research Tools to Measure Food Security/Nutrition Security

The majority of population-based studies in the United States use the USDA Food Security Survey Modules as a research tool to measure food security. These modules consist of a 6-item to 18-item questionnaire to determine a household's ability to afford and access sufficient calories [67], but unfortunately do not completely assess a household's ability to consume sufficient nutritious food consistent with the US dietary guidelines for Americans [68]. In addition, these research tools do not adequately capture the number of Americans who have limited resources and are nutrition insecure or at risk for nutrition related chronic diseases. Further enhancement of these tools to incorporate a more comprehensive assessment of nutrition security, stability of food sources, and nutrient utilization are needed. Additional tools to assess the impact of ethno-socio-economic diversity and dietary preferences also need to be developed in incorporated in future studies.

5.2 Development of Evaluation Tools to Measure the Public Health Impact of Nutritional Programs

Projects and initiatives designed to counteract the impact of food insecurity are diverse with regards to their scope, funding sources, target population, levels of participation, and public health impact. These differences, coupled with the complexities associated with developing, implementing, and ensuring ongoing funding for these programs, make it challenging to develop and assess the actual impact of these community-based interventions on nutritional behavior and overall chronic disease burden. Since the inauguration of the GusNIP program in 2018, a variety of nutritional incentive and produce prescription projects have been funded to increase fruit and vegetable purchase and intake in various communities nationwide. However, significant heterogeneity in the project type, size, type of incentive program, and outcome measures have led to uncertainty about the public health impact and cost-effectiveness of the various projects. The National Training, Technical Assistance, Evaluation, And Information Center (NTAE) within the GusNIP program has identified a "shared measures" approach to standardize the evaluation and assessment of the various projects [69], which requires identification of outcome parameters at the individual, household, and organizational level. Such evaluation tools need to be available freely and be amenable to implementation with minimum impact on existing resources, and also need to be applicable across different study and project types. Such evaluation tools are essential to gain insights from the real-world implementation of different approaches to improve the nutritional status of our communities, and also to guide decisions for future funding of existing programs and development of new programs developed from real-world evidence.

5.3 Anticipating and Meeting the Increasing Food and Nutritional Needs of Growing Populations

The human population worldwide is growing, and there are large demographic shifts between rural and urban populations, increasing the strain on an already fragile food production and delivery system. Policy makers and legislators will need to identify and predict these changing demographic trends and implement policies to ensure adequate allocation of agricultural land and resources, incentives for farmers and food growers engaging in the cultivation of nutritious crops, increasing awareness and supporting climate-resilient agricultural practices, and investment in a durable and equitable food distribution system that can adapt to the socio-economic, cultural, and dietary pattern disparities among different communities and neighborhoods.

6. Closing Remarks

Food insecurity is an important social determinant of health, and a large body of research shows that food insecurity is associated with cardiometabolic risk as well as cardiovascular disease and mortality, and emerging evidence shows that the presence of multiple medical co-morbidities can also increase the risk of food insecurity (reverse causation). The public health impact of food insecurity is enormous, and strategies to reduce food insecurity require action at multiple levels to improve access and availability of nutritious foods at affordable prices, ensure year-round stability of food sources, increase awareness about healthy nutrition and encourage/incentivize healthy food choices, and public education about the various government-funded and other nutrition assistance programs in the community, especially for its most vulnerable members (women, children, racial and ethnic minorities). Future studies need to incorporate freely accessible, evidence-based evaluation tools to study the specific barriers to food security and the impact of nutritional interventions within their communities, with an emphasis on cost-efficiency, social and cultural inclusion, and equity.

Author Contributions

Satchit A. Saha contributed to the conception, planning, literature review, prepared the initial draft, and edited the manuscript. Katelyn A. Williams and George Murphy contributed to the drafting, critical review, and editing of the manuscript. Sandeep A. Saha contributed to the conception, planning, literature review, editing, and provided overall supervision for this project.

Competing Interests

The authors have declared that no competing interests exist.

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