Nutrire (2024) 49:55
https://doi.org/10.1186/s41110-024-00300-8

REVIEW

Inflammatory status and inflammation-enhancing factors in food insecurity

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Received: 23 June 2024 / Accepted: 14 October 2024 / Published online: 21 October 2024

Abstract

Purpose of review Inflammation plays a role in the development of diseases such as obesity, hypertension and diabetes, which are among the most common diseases worldwide. Food insecurity can alter inflammation processes by affecting people's quality of life and diet. This review aims to evaluate the relationship between food insecurity and inflammation.

Recent findings In food insecurity, the quantity and variety of food consumed may be reduced and diet quality may suffer. Thus, the intake of some vitamins, minerals and fatty acids may be insufficient. Dietary components such as omega 3, vitamin E and polyphenols, which have antioxidant effects, may be deficient. The tendency to consume salty snacks and sugary drinks may increase. The dietary inflammatory index may increase with changes in dietary intake. Dietary fiber intake may also be lower and gut health may be negatively affected. In addition, perceived stress levels may increase in food insecure individuals. Thus, oxidative stress and physiological wear and tear on the body may increase. All these factors may be influential in the inflammation process.

Conclusion In many studies, food insecurity has been associated with increased inflammatory markers. A better understanding of the relationship between food insecurity and inflammation can guide actions aimed at preventing food insecurity in order to reduce inflammation and inflammation-related diseases.

Keywords Food insecurity · Inflammation · Inflammatory markers · Food insufficiency

Introduction

Food security is defined as "all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life" [1]. Food insecurity occurs when regular access to sufficient and safe food is not available due to reasons such as food unavailability or lack of resources. Moderate food insecurity refers to uncertainty about food availability and a reduction in the quality and quantity of food consumed, while severe food insecurity involves not being able to find food for days [2]. In 2023, about 28.9% of the world's population is estimated to have experienced moderate or severe food insecurity [3]. According to the Turkey Nutrition and Health Survey 2019 report, 23.4% of individuals in Turkey reported that they were worried that they would not be able to find enough food within a year due to insufficient money and other resources [4].

Inflammation is the immune response to harmful stimuli such as pathogens, injury, and metabolic stress and plays a role in restoring homoeostasis in the damaged area [5]. The process of inflammation involves the release of various inflammatory cytokines, activation of certain signaling pathways and is terminated when the threat is removed [6]. In general, leukocytes, cytokines (such as tumor necrosis factor [TNF], interleukin-1 beta [IL-1β], interleukin 6 [IL-6]), chemokines, lipids, acute phase proteins are inflammation markers [7]. When regulatory processes are not functioning properly or when the threat persists, inflammation can become chronic and play a role in the development of metabolic diseases [6].

Food insecurity is associated with chronic non-communicable diseases such as obesity, hypertension, diabetes, heart

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disease, metabolic syndrome [8, 9] and health outcomes such as greater reduced cognitive capacity in old age, and inflammation is thought to mediate these associations [10]. Therefore, addressing inflammation in food insecurity may help understand the processes leading to such adverse health outcomes.

There are some situations that may be effective in increasing the risk of inflammation due to food insecurity. First of all, food insecurity may be associated with poor diet quality [11] or increased dietary inflammatory index [12]. In addition, perceived stress may increase in food insecure individuals [13]. It is also possible that these individuals have a diet low in antioxidant nutrients [11]. All of these situations may be effective in the formation or prolongation of inflammation. The aim of this review is to present possible evidence on inflammation in food insecurity and to evaluate factors that may increase inflammation in food insecurity. A better understanding of this relationship may shed light for identifying new routes towards achieving food security to reduce inflammation.

Food insecurity and inflammation

Since inflammation is thought to play a role in the association of food insecurity with adverse health outcomes, studies investigating inflammation in food insecurity (FI) have been conducted [14–16]. A cross-sectional study in the USA [14] investigated whether food insecurity was associated with nutritional levels, inflammatory response and altered immune function, using data from 12,191 participants of the National Health and Nutrition Examination Survey (NHANES) (1999–2006). In the study, in which 21.5% of the population was food insecure, food insecurity was associated with higher C-reactive protein (CRP) and white blood cell counts. According to this study the mean Odds ratio for having higher CRP was 1.21 for extremely food insecure individuals compared to those who were fully secure. In addition to this the odds of having a high white blood cell count, an indicator of infection and immune system activation, increased by about 40% in food insecure individuals. Therefore, the study determined that food insecurity is associated with increased inflammation, and the immune response also plays a mediating role. Similarly, a US study in adults over 50 years of age showed that food insecurity was associated with higher levels of inflammation and impaired immune function [15]. After adjusting for sociodemographic differences in food insecure older adults, results showed that food insecurity was associated with clinically elevated levels of inflammation and high-sensitivity C-reactive protein (hsCRP), IL6, IL-1 receptor antagonist (IL-1Ra), transforming growth factor Beta 1 (TGFß-1) and impaired immune function. In female participants living with Human Immunodeficiency Virus (HIV), food insecurity was associated with increased inflammation independent of HIV control [16]. Another study in people living with HIV found that almost half (42.7%) of 323 participants from the Miami Adult Studies HIV cohort were food insecure [17]. Although food insecurity was not associated with hsCRP, it was associated with some markers of immune dysregulation that correlated with CRP. All these results suggest that levels of inflammation and dysregulated immune responses are increased in food insecurity.

Some studies involving healthy or chronically ill adult participants have assessed food insecurity and inflammatory markers [18, 19]. According to the study, which included healthy and type 2 diabetic individuals aged 30–59, the blood glucose and inflammatory factors rate of food insecure individuals was found to be significantly higher than food secure individuals [18]. The relationship between household food insecurity and insulin resistance was examined among 121 low-income Latinos with type 2 diabetes [20]. Inflammatory markers were found to mediate this relationship. In the study, where 68% of the participants were food insecure, individuals with food insecurity had higher levels of insulin resistance, hsCRP and cortisol. Some studies investigating food insecurity and chronic disease risks have also examined markers of inflammation. In a cross-sectional study conducted on adults, food security was assessed using 10 questions and four levels of food security status were defined. These levels are as follows full food security (0 points), marginal food security (1–2 points), low food security (3–5 points), and very low food security (6–10 points). The average CRP concentration was 0.8 mg/L higher in very low food secure individuals aged 30 to 59 compared to those with full food security, and their 10-year estimated risk of cardiovascular disease was also found to be increased [21]. A cohort study followed 3024 Black adult participants without prevalent cardiovascular disease at visit 1 (2000–2004) in the Jackson Heart Study [19]. In the study, economic food insecurity was considered to be having received food stamps in the past year or feeling moderately to highly stressed about not having enough money for food. During a median follow-up of 13.8 years, 123 participants experienced a coronary heart disease event. In analyses adjusted for demographics and cardiovascular risk factors, economic food insecurity was associated with an increased risk of coronary heart disease. Furthermore, hsCRP concentrations were significantly higher in participants experiencing food insecurity compared to those not experiencing food insecurity. A cohort study of 14,394 older adults aged 50 years and older from the Health and Retirement Study investigated the relationship between food insecurity and allostatic load [22]. Allostatic load refers to the physiological wear and tear the body experiences when exposed to chronic stress, and food insecurity was associated with higher levels of allostatic load through dysregulated inflammatory and metabolic systems. These results suggest that the increased chronic disease burden and allostatic load in food insecurity are accompanied by increased inflammatory processes. Unlike these [23], a cross-sectional study was conducted with participants ($n = 124$) consisting of university students between the ages of 18–25, and markers of lipid profile and inflammatory markers in the blood were measured. However, no significant difference was found between food security and inflammatory markers, lipid profile and body composition.

Some studies on the effects of household food insecurity on children have also been found [24, 25]. A cross-sectional study of Tanzanian children aged 6–59 months used survey data for 1,387 children and elevated CRP (CRP $\geq$ 1.1 mg/L) measurements to assess inflammation [24]. Contrary to expectations, living in a food-secure household was not associated with a lower likelihood of elevated CRP. This was thought to be because the crude measure of food insecurity may be inadequate and does not distinguish households that are able to protect their children from food insecurity. Household food insecurity was assessed using "often" and "always" responses to the question "How often have you had problems meeting your household's food needs in the past year?", which may have been an inadequate measure. Among the reported limitations of the study, taking a single CRP sample from each child may have also led to inadequacy in providing information on the history of immune elevation. In another study [25] conducted in Tanzania, a sample of mother and infant dyads ($n = 88$) was investigated, considering that household conditions may affect the inflammatory response during infancy. Severe food insecurity at home was associated with higher infant CRP (OR = 2.77; SE = 1.22; $p = 0.021$). Table 1 summarizes some studies assessing the relationship between food insecurity and inflammation.

Pathways in the relationship between food insecurity and inflammation

Food insecure individuals experience varying degrees of lack of access to adequate and nutritious food [2]. Therefore, it is possible that a balanced diet cannot be achieved and diet quality is reduced [26]. A healthy, high-quality dietary pattern rich in foods such as fruits, vegetables, whole grains and fish and low in foods such as processed meats and sugary drinks, which are inversely associated with plasma CRP levels, can be difficult to achieve [27]. Food insecure individuals may tend to consume lower amounts of fruits and vegetables and higher amounts of processed meat, sugary drinks, and salty snacks [26]. In addition, a low-quality diet may be deficient in health-protective and anti-inflammatory nutrients, and the dietary inflammatory index, which reflects the role of diet on inflammation, may increase [28]. Food insecurity and dietary inflammatory index have been previously associated [29, 30]. In addition, failure to consume healthy dietary patterns may negatively affect the microbiota, increasing systemic endoctoxemia and contributing to increased inflammation [31].

Perceived stress may increase with food insecurity [13]. In addition, failure to consume a balanced diet can lead to unhealthy dietary patterns that are deficient in antioxidant nutrients such as omega 3 fatty acids, vitamin A, vitamin E and polyphenols [6]. Increased stress [32] and unhealthy dietary patterns [33] can increase oxidative stress. Oxidative stress is effective in the development of inflammation [34]. Additionally, persistent stress may play a role in inflammation by increasing allostatic load [35].

Some of the more prominent causes of the relationship between food insecurity and inflammation are summarized in Fig. 1.

Dietary inflammatory index

The Dietary Inflammatory Index is a tool developed to assess the role of diet on inflammation. With this tool, the effects of nutrients on inflammatory markers are taken into account and the inflammatory potential of the diet is determined [36]. Since the intake of proinflammatory nutrients may increase and the intake of anti-inflammatory nutrients may decrease in food insecure individuals, increased dietary inflammatory index may be effective in the relationship of food insecurity with inflammation [12, 29]. In a study conducted with female high school students in Iran, the prevalence of food insecurity was found to be 40.8% and dietary inflammatory index was higher in the food insecure group [12]. In the study where cross-sectional data were taken from NHANES 2007–2014 ($n = 10{,}630$), the dietary inflammatory index score increased at higher levels of food insecurity [29]. This study found that people with very low food security had a 0.31 (95% CI = 0.12 to 0.49) higher dietary inflammatory index score compared to those with high food security. Another study examined cross-sectional data of 8624 adults aged 20 years and above from the Korean National Health and Nutrition Examination Survey 2014–2015 [30]. In the study, household food security status was assessed using an 18-item food security survey module, and greater food insecurity was significantly associated with higher dietary inflammation index score. According to the study, the mean difference in dietary inflammatory index between the "moderate-severe" food insecurity group and the "food secure" group was 0.43 (95% CI, 0.06–0.80). In a cohort study of 409 residents of low-income urban neighborhoods in the United States, Supplemental Nutrition Assistance Program recipients were found to have high Dietary Inflammatory Index scores, which may be due to inadequate intake of anti-inflammatory nutrients in this

Table 1 Studies evaluating the relationship between food insecurity and inflammation

Author, year	Study design	Population	Impact measure	Outcome measures	Main findings
Gowda et al., 2012	Cross-sectional	1999–2006 NHANES data ($n=12191$)	US Department of Agriculture's food security scale module	White blood cell count, C-reactive protein	21.5% of the study population is food insecure. Food insecurity is associated with higher CRP (adjusted odds ratio [AOR] = 1.21; 95% CI = 1.04, 1.40) and white cell count (AOR = 1.36; 95% CI = 1.11, 1.67).
Aljahdali et al., 2024	Cross-sectional	US adults over age 50 from the Health and Retirement Study ($n=3924$)	Six-item Short Form Food Safety Survey Module	Markers of inflammation (neutrophil-to-lymphocyte ratio, albumin, hsCRP, IL6, IL10, IL-1Ra, TGFβ-1) and immune functioning	The weighted prevalence of FI is 18.8%. Multivariable-adjusted regression modeling showed that food insecurity was associated with high risk categories for hsCRP (OR 1.34, 95% CI 1.06, 1.68), IL-6 (OR 1.66, 95% CI 1.28, 2.14), IL-1Ra (OR 0.67, 95% CI 0.48, 0.93), TGFß-1 (OR 1.87, 95% CI 1.45, 2.42). FI has been associated with systemic inflammation in older adults.
Leddy et al., 2019	Cross-sectional	Female participants living with HIV from the Women's Interagency HIV Study ($n=421$)	Household food insecurity in the last 6 months with the validated 18-item United States Department of Agriculture Household Food Security Survey Module	IL-6 and tumor necrosis factor receptor 1 (TNFR1) levels	31% of participants were food insecure. In adjusted analyses, food insecurity was associated with 1.23 times the IL-6 level (95% CI, 1.06–1.44) and 1.13 times the TNFR1 level (95% CI, 1.05–1.21).
Janzadeh et al., 2020	Case control	200 people with Type 2 diabetes and 200 healthy individuals between the ages of 30–59	18-item Household Food Security survey	Blood glucose, CRP and some socioeconomic factors	The prevalence of food insecurity was 24.9% and 71% in the control and intervention groups, respectively. The rate of inflammatory factors in food insecure individuals was found to be significantly higher than in food secure individuals ($P<0.001$).
Nur Atiqah et al., 2015	Cross-sectional	Participants aged 18 to 25 ($n=124$)	Adult Food Safety Survey Module	Lipid profile (total cholesterol, triglyceride, LDL, HDL) and inflammatory marker (hsCRP)	No significant relationship was found between FI and inflammatory markers.

Table 1 (continued)

Author, year	Study design	Population	Impact measure	Outcome measures	Main findings
Hadley and Decaro, 2014	Cross-sectional	Children aged 6–59 months ($n = 1387$)	How often the household had trouble meeting its food needs in the past year (answers often and always were considered food insecurity)	CRP measurements	Living in a food secure household was not associated with a lower likelihood of CRP elevation.
Decaro et al., 2016	Cross-sectional	Babies under 12 months ($n = 88$)	Household Food Insecurity Access Scale	hsCRP measurements	An association was found between severe food insecurity at home and elevated infant CRP (OR = 2.77; SE = 1.22; $P = 0.021$).
Ford, 2013	Cross-sectional	Individuals over 20 years of age from the National Health and Nutrition Examination Survey 2003–2008 ($n = 10455$)	10-question food security survey; full food security (0 points), marginal food security (1–2 points), low food security (3–5 points) and very low food security (6–10 points)	10-year cardiovascular disease risk, CRP	The mean CRP concentration was 0.8 mg/L higher among participants with very low food security compared to those with full food security.
Zierath et al., 2023	Cohort	3024 black adults free of heart failure and coronary heart disease at baseline	Participants who received food stamps in the past year and participants who felt stressed regarding the statement “not enough money for basic needs such as food” were considered economically food insecure.	Risk of cardiovascular events, hsCRP	Economic food insecurity has been associated with increased risk of coronary heart disease and higher hsCRP level.

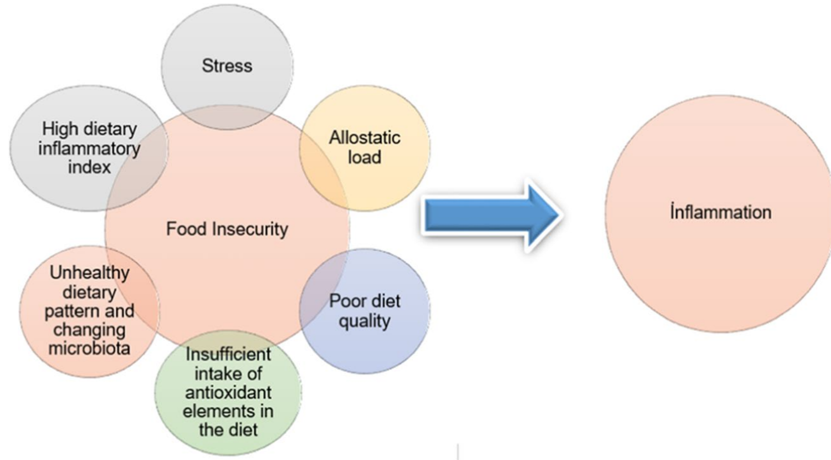

Fig. 1 Factors influencing the relationship between food insecurity and inflammation

population despite assistance [37]. These results indicate that the inflammatory potential of the diet increases with low income status and food insecurity.

The effects of the inflammatory potential of diet on markers of inflammation have been investigated. In a study of an Italian population aged 35 years and older ($n = 20823$), higher dietary inflammatory index scores were associated with increased low-grade inflammation ($\beta = 0.131$; 95% CI, 0.089–0.174 for the highest and lowest quintiles of the dietary inflammatory index) [38]. A study conducted in women aged 56–74 in a Scandinavian population examined the relationship of the Dietary Anti-Inflammatory Index (AIDI) with chronic inflammation [39]. Women in the highest quintile of AIDI were found to have 26% lower hsCRP concentrations than those in the lowest. Each 1-point increase in AIDI was associated with 0.06 mg/L lower hsCRP. Unlike these [40], when the inflammatory potential of the diet of South Africans and its relationship with inflammatory markers were investigated using the energy-adjusted dietary inflammatory index, diet was not found to be associated with the measured inflammatory markers. However, the authors of the study reported that this may be due to the limited diversity and monotonous diet of the participants. The lack of clarity about whether the participants' diet was pro-inflammatory or anti-inflammatory may have caused its low effect on inflammatory markers. Therefore, in general, dietary inflammatory index and thus inflammation can be expected to increase in food insecure individuals.

Diet quality

Nutrient elements or groups play a role in the development and prevention of diseases [41]. However, since various foods are consumed together in the diet, it may be misleading to evaluate the effect of the consumption level of a single nutrient on a particular health outcome in the relationship between diet and health. For this reason, it has been found useful to determine diet quality by examining nutritional intake indices, which express many aspects of the diet [42]. Diet quality is measured by how closely dietary patterns match national dietary guidelines. Although diet quality can be defined in different ways, most diet quality indices are based on food groups, nutrients and food diversity. Components of the indexes generally include items such as vegetables, fruits, grains, meat and dairy products, fish, olive oil, sodium and dietary fiber [43].

Measuring diet quality allows for the examination of associations between food and health status. Different indices can be used to assess diet quality, such as the Healthy Eating Index, the Diet Quality Index or the Mediterranean Diet Score [43]. As intake of essential nutrients and dietary diversity may be reduced in food insecure groups, diet quality may be reduced. In a study of children [44], diet quality was assessed using the Health Eating Index-2015 (HEI-2015) and food insecurity was associated with lower HEI-2015 total scores (β=-3.17; 95% CI=-5.28,-1.06; $p = 0.003$). In the study compared to food secure children, food insecure children had lower scores for greens and beans, seafood and vegetable protein components. In adults, using 1999–2008 NHANES data, differences in dietary intake and diet quality according to household food security were investigated in 8,129 people [26]. Although no differences were observed in terms of total energy and macronutrient intake, food insecurity was significantly associated with lower Healthy Eating Index-2005 and Alternative Healthy Eating Index-2010 scores. Adults experiencing food insecurity have been found to consume more palatable foods, such as high-fat dairy products and salty snacks, and sugar-sweetened beverages. Consumption of more red/processed meat, nuts, seeds and legumes, and less consumption of vegetables and flour desserts has been associated with food insecurity. Among women ages 36 to 43, food insecurity was also associated with greater consumption of high-fat and high-sugar (overly palatable) foods [13]. Lower diet quality in food insecure groups may be due to lack of access to healthy and adequate food, or a preference for tasty foods to cope with stress.

Food insecurity is associated with lower consumption of vegetables, fruit and dairy products in adults and lower fruit consumption in children [11]. Whereas a healthy dietary pattern rich in fruits and vegetables, legumes, poultry, fish and whole grains is inversely associated with plasma CRP concentrations, a Western dietary pattern rich in highly refined grains, red meat, butter, processed meat, high-fat dairy products, sweets, fast food, hydrogenated oils and soft drinks is positively associated with CRP [27, 45].

High diet quality is associated with low systemic inflammation [46]. Improved diet quality and increased inclusion of healthy dietary components play a role in reducing inflammatory effects. For example, healthy eating patterns such as the Mediterranean diet have been associated with anti-inflammatory effects. Previously, the Mediterranean diet supplemented with extra virgin olive oil or nuts showed an anti-inflammatory effect, reducing serum CRP, IL-6, and endothelial and monocytic adhesion molecules and chemokines [47]. Low adherence to the Mediterranean diet was directly associated with a worse profile of plasmatic inflammation markers and greater adherence to the Mediterranean diet was associated with lower plasma leptin, TNF-α, PAI-1 and hs-CRP levels in adult men and lower plasma hs-CRP levels in women [48]. Adherence to Healthy, Mediterranean and Anti-inflammatory diet scores is associated with lower inflammatory status [49].

One of the important pathways in the influence of diet on inflammatory processes is the alteration of the microbiota [50]. Intestinal permeability to bacterial lipopolysaccharides (LPS), a potent inflammatory stimulus, appears to be an important trigger for low-grade systemic inflammation [51]. LPS, which is found in the outer membrane of Gram-negative bacteria and acts as an endotoxin, may be an important factor in the development of inflammation [52]. Ensuring high diet quality plays a role in reducing this endotoxin. This is because healthy dietary patterns predict lower LPS activity, and healthy dietary choices such as consumption of fish, fresh vegetables, fruits and nuts have previously been reported to reduce systemic endotoxemia [31]. In a study of 643 participants, 22.8% of whom were food insecure, dietary scores were associated with changes in the adult gut microbiome among food secure and food insecure individuals. More bacterial species were found to be important in relation to higher dietary scores in people reporting food insecurity, suggesting that nutrition is more important in shaping the gut microbiome for food insecure individuals [53]. Therefore, food insecure individuals may be more susceptible to more frequent consumption of food groups that may increase inflammation, less intake of food groups rich in anti-inflammatory nutrients such as vegetables and fruits, tendency to unhealthy dietary patterns, decreases in diet quality and changes in gut microbiota. It is conceivable that this situation may increase systemic inflammation.

When evaluated in terms of nutritional elements, a decrease in diet quality may lead to increases in the intake of inflammatory nutrients or deficiencies in the intake of anti-inflammatory nutritional components. In this context, one of the studies evaluating nutrients in food insecurity and different dietary inflammatory potentials was conducted in Iran. In this study ıt was determined that protein, vitamin D and vitamin B_{12} intake was lower in the food insecure group of high school female students. The study found higher intakes of energy, total fat and saturated fatty acids and lower intakes of carbohydrate, protein, fiber, magnesium, zinc, folate, selenium, vitamin A, B_6 and C, thiamine, riboflavin, niacin and tea in the highest tertile compared to the lowest tertile of the dietary inflammatory index [12]. In a cohort study in the United States, low-income Supplemental Nutrition Assistance Program recipients were found to have lower intakes of dietary fiber, β-carotene, magnesium and vitamin E [37]. Inadequate intakes of vitamin A, folate, iron and magnesium were also found to be common among food insecure women in Canada [54]. In adults, food insecurity has been associated with lower intakes of vitamins A and B_6, calcium, magnesium and zinc [11]. Although studies have generally focused on adults, a previous study in Bangladesh with 18-month-old children observed that children whose iron and vitamin A status was improved by supplementing with complementary foods for one year were less prone to inflammation [55]. Another study investigating nutrient intake in food insecurity focused on older adults [56]. Food insecure older adults were found to have lower intakes of energy, protein, carbohydrates, saturated fat, niacin, riboflavin, vitamins B6 and B12, magnesium, iron, and zinc. Although the studies looked at different age groups, based on these results it appears that groups experiencing food insecurity may have lower intakes of some nutrients such as folate, magnesium, vitamin A, vitamin E and dietary fiber.

Some nutrients that are inadequately or insufficiently consumed in situations of food insecurity have anti-inflammatory roles. For example folate, which can have low serum levels in food insecure people, is involved in the activation of the immune system [14]. Magnesium deficiency is thought to be an important contributor to chronic low-grade inflammation. Magnesium deficiency may lead to leukocyte and macrophage activation, release of inflammatory cytokines and acute phase proteins, and excessive free radical production [57]. On the other hand, ω-3 fatty acids, vitamin E and plant flavonoids, which are abundantly available through healthy dietary patterns, reduce inflammatory mediator production through effects on cell signaling and gene expression, and antioxidant vitamins neutralize harmful oxidants. Prebiotics such as dietary fiber also promote intestinal barrier function and anti-inflammatory responses [6]. Polyphenols, abundant in fruits and vegetables, show anti-inflammatory effects by activating the gene transcription factor PPAR-γ, which inhibits the activation of Nuclear factor kappaB (NF-κB), which stimulates the synthesis of inflammatory products. In addition, resolvins derived from omega 3 fatty acids are effective in ending the inflammatory response. Consequently, an anti-inflammatory diet should be rich in omega-3 fatty acids and colorful, non-starchy vegetables [58]. Thus, food security seems to be essential for adequate intake of healthy food groups and nutrients with anti-inflammatory effects.

Stress

Stress may play a role in the relationship between food insecurity and inflammation. Because food insecurity is associated with increases in perceived stress levels [13, 59]. Just as various dietary components can modulate pathways to inflammation, such as oxidative stress, NF-κB activation and proinflammatory cytokine production, stressful events can influence inflammation through the same processes, and stress can increase circulating inflammatory markers [32, 60]. Higher perceived stress is associated with higher oxidative and inflammatory stress and impairment of the immune system [61]. Oxidative stress activates NF-κB and plays an important role in the development and maintenance of inflammation [34]. In addition, stress may increase dietary inflammatory potential by increasing the preference for more unhealthy foods. Previously, perceived stress has been associated with more frequent consumption of sweets, fast food and less fruit and vegetable consumption [62].

Another condition that increases stress is increased allostatic load [35]. Allostatic load is the wear and tear on the body and brain resulting from chronic overactivity or inactivity of physiological systems normally involved in adapting to environmental challenges [63]. Markers of allostatic load represent cardiovascular, metabolic, inflammatory and neuroendocrine systems [64]. Previously, associations between household food insecurity and cumulative biological risk, a measure of the body's physiological response to chronic stress, have been examined [65]. Using data from 5005 adults in the 2007–2010 NHANES study, cumulative biological risk scores were calculated based on biomarkers from the cardiovascular, metabolic and immune systems. Thus, a score for cumulative biological risk was created within the allostatic load framework. According to the study, in which 26.2% of participants were food insecure, marginally food secure and food insecure adults were more likely to have higher mean CRP levels ($p = 0.005$) compared with food secure adults. Among women, food insecurity was associated with a higher cumulative biological risk score of 0.30 units (95% CI 0.14–0.45, p-trend = 0.0004). These findings support the hypothesis that food insecurity may be associated with chronic stress and chronic health outcomes in women. Using data from the longitudinal Boston Puerto Rico Health Survey among 733 adults aged 45 to 75 years, FI was assessed at 5-year follow-up [66]. For allostatic load components, FI was significantly associated with higher 5-year cortisol and waist circumference and lower 5-year systolic and diastolic pressure, but FI was not significantly associated with having a high total allostatic load. This may have been due to an older adult population with existing chronic disease at baseline or a short follow-up period.

Conclusion

Food insecurity has been associated with higher inflammatory markers in many studies. People experiencing food insecurity may be more likely to experience more stress, consume more low-quality Western-style diets high in high-sugar and fat foods that are considered palatable, or have diets deficient in nutrients that play a role in anti-inflammatory processes. Among people experiencing food insecurity, ensuring regular access to a diet that includes fruits and vegetables rich in anti-inflammatory elements, fish and seafood, and healthy oils, and working to reduce perceived stress may play a role in reducing inflammation. Future comprehensive and epidemiologic studies may be more effective in elucidating the factors linking food insecurity and inflammation. The impact on inflammatory processes can be observed through intervention studies aimed at reducing food insecurity. A better understanding of this relationship will contribute to taking steps and planning actions that can reduce inflammation and the accompanying negative health outcomes in individuals experiencing food insecurity.

Author contributions HPB contributed to the writing and editing of the article and created figures and tables. HY contributed to writing the manuscript, reviewed and edited the manuscript. All authors approved the published version of the article.

Funding No funding.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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