American Heart Journal Plus: Cardiology Research and Practice 45 (2024) 100431

Contents lists available at ScienceDirect

American Heart Journal Plus: Cardiology Research and Practice

journal homepage: www.sciencedirect.com/journal/american-heart-journal-plus-cardiology-research-and-practice

Climate change versus Mediterranean diet: A hazardous struggle for the women's heart

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ARTICLE INFO

Keywords:
Climate change
Cardiovascular risk
Women
Mediterranean diet
Sustainable diet
Food quality

ABSTRACT

Climate change impacts food systems, causing nutritional deficiencies and increasing cardiovascular diseases (CVD). Regulatory frameworks like the European Farm-to-Fork Strategy aim to mitigate these effects, but current EU food safety regulations inadequately address health risks from poor diet quality and contaminants.

Climate change adversely affects food quality, such as nutrient depletion in crops due to higher CO_2 levels, leading to diets that promote chronic diseases, including CVD. Women, because of their roles in food production and their unique physiological responses to nutrients, face distinct vulnerabilities. This review explores the interplay between climate change, diet, and cardiovascular health in women. The review highlights that sustainable diets, particularly the Mediterranean diet, offer health benefits and lower environmental impacts but are threatened by climate change-induced disruptions. Women's adherence to the Mediterranean diet is linked to significant reductions in CVD risk, though sex-specific responses need further research.

Resilient agricultural practices, efficient water management, and climate-smart farming are essential to mitigate climate change's negative impacts on food security. Socio-cultural factors influencing women's dietary habits, such as traditional roles and societal pressures, further complicate the picture.

Effective interventions must be tailored to women, emphasizing education, community support, policy changes, and media campaigns promoting healthy eating. Collaborative approaches involving policymakers, health professionals, and the agricultural sector are crucial for developing solutions that protect public health and promote sustainability.

Addressing the multifaceted challenges posed by climate change to food quality and cardiovascular health in women underscores the need for integrated strategies that ensure food security, enhance diet quality, and mitigate environmental impacts.

1. Introduction

Climate change has several negative effects on food systems and, consequently, on diet, which in turn influences cardiovascular health [1]. The European Farm-to-Fork Strategy, the Zero Pollution Action Plan, the Green Deal, and the EU Chemicals Strategy for Sustainability establish the regulatory framework for promoting sustainable and healthy food production. This framework includes the impact assessment of synthetic chemical mixtures on human health and the environment [2,3].

In the EU Food Law, food safety issues are defined in terms of risk and met with stringent regulation, however, food safety assesses risk to

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https://doi.org/10.1016/j.ahjo.2024.100431
Received 31 May 2024; Received in revised form 20 July 2024; Accepted 22 July 2024
Available online 29 July 2024

biological, chemical, or physical hazards only, but without dealing with human health risk considerations [2,3]. The contribution of Diet and quality of food to the development of cardiovascular diseases occurs through various interconnected mechanisms that act throughout life, promoting atherosclerosis [4,5]. Climate change affects food by causing changes in nutritional composition that lead to nutrient depletion and an inadequate diet [2,3]. This affects the development of chronic diseases which are strongly influenced by the diet. The favorable effects of good adherence to a healthy diet are partially attenuated by the poor quality of food [6,7].

This review aims at analyzing the relationship between climate change and diet on cardiovascular health, specifically in women. There are several differences in cardiovascular disease in women compared to men and diet has a major impact on cardiovascular risk through changes in risk factors, effects on oxidative stress and endothelial dysfunction [8,9]. Furthermore, women have a different physiological response to nutrients and an even more different emotional response to the relationship with food [10]. Since it is well known that climate change affects the quality of food and that this influences the development of chronic non-communicable diseases and since women have a close relationship with food both in terms of preparation and choice of foods to offer to the family, we were interested in checking whether there are "food for thought" in the literature.

The relationship between climate and food is bidirectional: agriculture and the entire food supply chain are among the primary causes of climate change, which in turn severely impacts food systems, contributing significantly to a poor quality of food. In fact, about 30 % of global greenhouse gas emissions are caused by food systems, equivalent to the combined emissions from all cars, trucks, airplanes, and ships. Deforestation to create more agricultural land and livestock farming play substantial roles, with livestock accounting for 14.5 % of all emissions. Beef and lamb have the largest carbon footprint per gram of protein, while plant-based foods tend to have the least impact [6,11].

Poor quality of food can exacerbate the effects of risk factors for CVD on chronic inflammation and oxidative status [5,6].

Climate change can lead to lower nutrient densities in crops. Higher atmospheric CO_2 levels reduce the concentrations of essential nutrients like zinc, iron, and protein in staple crops.

These climate-induced crop failures and extreme weather events can lead to food shortages and price spikes. Furthermore, water scarcity affects the availability of fresh fruits and vegetables, essential for a heart-healthy diet [12]. These factors limit access to healthy foods, leading people to consume cheaper, calorie-dense but nutrient-poor foods, which contribute to obesity and metabolic syndrome, key risk factors for CVD [13,14].

Reduced nutrient density in crops due to climate change, driven by elevated CO_2 levels, leads to deficiencies in essential nutrients such as zinc, iron, and protein. These deficiencies contribute to increased oxidative stress, impaired immune function, and chronic inflammation, which are critical factors in the development of cardiovascular diseases [15].

Together with the poor quality of food which reduces the effectiveness of a healthy diet, pollution leads to an accumulation of toxic substances such as heavy metals. Contaminants like lead, cadmium (Cd), and mercury (Hg) can accumulate in crops and enter the human body through consumption. These heavy metals are known to be associated to hypertension, atherosclerosis, and other cardiovascular conditions [16]. Exposure to heavy metals such as Hg and Cd may have a high risk of triggering endothelial dysfunction and, by penetrating the placental barrier, may increase the risk of preeclampsia. Several immunological biomarkers such as certain cytokines associated with Hg and Cd exposure are also involved in the pathophysiology of preeclampsia in pregnant women [17,18].

Furthermore, pollutants that settle on crops and are ingested can also add to this oxidative stress. Oxidative stress may serve as a common mechanism linking food contamination to CVDs, as evidenced by studies showing impaired oxidative stress biomarkers following exposure to food contaminants [19,20].

Persistent organic pollutants accumulate in the food chain, particularly in fatty tissues of animals, and are linked to endocrine disruption and cardiovascular toxicity [21].

Both pollution and poor diet due to climate impacts increase oxidative stress and inflammation, major factors in the development of atherosclerosis [17,19].

Climate change poses significant challenges to food security, with unique and profound impacts on women. Women face unique challenges and vulnerabilities due to their roles in food production, preparation, and household nutrition.

Moreover, women play a pivotal role in food systems, especially in developing countries where constitute a significant portion of the agricultural workforce, often engaging in subsistence farming to feed their families. According to FAO, women produce between 60 and 80 % of the food in most developing countries and are responsible for half of the world's food production, yet their role as food producers and providers [19,22]. Furthermore, women are primarily responsible for food preparation and nutrition within households, influencing dietary habits and health outcomes.

Addressing these challenges requires a gender-sensitive approach that recognizes and supports the critical role of women in food systems.

2. Climate change, agriculture and effects on food

Recent studies on climate change and food have highlighted various aspects of how global warming impacts agricultural production and food security. Pequeno and coworkers explores how climate change exacerbates the risk of wheat blast disease, which significantly threatens wheat production worldwide. Authors underline how a more humid and warmer climate in the future (Representative Concentration Pathway 8.5) is likely to increase the area suitable for wheat blast infection, particularly in the Southern Hemisphere, and reduce global wheat production by 69 million tons/year (13 % decrease) by mid-century. The study emphasizes the need for climate-resilient crop varieties and better disease management strategies [23].

A recent review from Brunet and coworkers, discusses how climate change impacts pollinators, such as bees and butterflies, which are crucial for crop yields and biodiversity. The study points out that changing weather patterns and increased temperatures are disrupting pollinator populations, thereby threatening food production [24].

Godde and coworkers review the risk of climate-related impacts along the land-based livestock food supply chain. They point out that although a quantification of the net impacts of climate change on the livestock sector is beyond our current knowledge, there is clear evidence that there will be impacts throughout the supply chain, from agricultural production to processing, storage and transport operations, up to retail and human consumption [25].

3. Mediterranean diet and climate change: connections and implications

The Mediterranean diet (MedD), renowned for its health benefits, particularly in reducing CVD, consists of high consumption of fruits, vegetables, legumes, nuts, whole grains, fish, and olive oil, with moderate wine consumption and low intake of red meat and dairy [11,26].

Álvarez-Álvarez L et al. found that higher adherence to the MedD is associated with lower environmental impact, particularly in terms of acidification, eutrophication, and land use. Reducing meat consumption can contribute to greater environmental sustainability [27].

Climate change, however, poses significant challenges to the sustainability and availability of the food integral to this diet [11,28].

Climate Change impact on the MedD at different levels. The first level is agricultural production and crop yields. Rising temperatures can affect crop yields. Heat stress can reduce the productivity of key crops

such as olives, grapes, and various vegetables.

Furthermore, the Mediterranean region is particularly vulnerable to water scarcity. Droughts can severely impact the cultivation of water-intensive crops like fruits, vegetables, and legumes. Climate change can lead to soil degradation through erosion, desertification, and loss of soil fertility, affecting the growth of crops essential to the Mediterranean diet [29]. The Mediterranean diet is also influenced by marine changes; rising sea levels and ocean temperatures can disrupt marine ecosystems, affecting fish populations. Key species like sardines, anchovies, and other oily fish, which are staples of the Mediterranean diet, may become less available.

Extreme weather events, such as storms and floods, can damage crops and infrastructure, leading to food shortages and increased prices. These events can disrupt supply chains, making it difficult to transport food from farms to markets [30].

The Mediterranean diet's emphasis on plant-based foods generally has a lower carbon footprint compared to diets high in animal products. Legumes, grains, fruits, and vegetables require less energy and water to produce. Traditional Mediterranean farming practices, such as crop rotation and polyculture, enhance soil health and reduce the need for chemical fertilizers and pesticides, thereby lowering greenhouse gas emissions.

The diet includes moderate consumption of meat, primarily poultry and fish, and limited red meat. Reduced meat consumption leads to lower methane emissions from livestock, a significant contributor to climate change.

Emphasis on sustainable fishing practices helps preserve marine biodiversity and maintain fish populations, reducing the environmental impact of overfishing.

The Mediterranean diet is not only beneficial for health but also has the potential to mitigate climate change impacts due to its focus on plant-based foods and sustainable practices. However, climate change poses significant threats to the availability and sustainability of the food integral to this diet. By adopting resilient agricultural practices, efficient water management, and sustainable fishing, and through supportive policies and community actions, it is possible to adapt the Mediterranean diet to changing environmental conditions and continue reaping its health benefits while contributing to climate change mitigation.

MedD has been classified accordingly by FAO and Biodiversity International as Sustainable Diet [31]. The definition of sustainable diet is a "dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable" [32].

In 2012 Lairon developed a 6-factor model to further delineate the key components of a sustainable diet: 1. Food security and accessibility; 2. Healthy food; 3. Respect for environment and biodiversity; 4. Fair trade; 5. Locality/Seasonality; and 6. Protection of culture, heritage, and skills [33]. However, the omission of socioeconomic and cultural factors, particularly affordability, in the analysis of sustainable diets represents a significant shortcoming and an important research gap [34–36].

Recent studies highlight the significant health benefits of the Mediterranean diet for women, particularly in reducing the risk of cardiovascular disease and mortality. Sex-specific interactions with diet may be influenced by differences in pathophysiology, hormones, and nutrient metabolism. Di Renzo and coworkers assessed the effects of MedD treatment in healthy human volunteers on the expression of ten genes related to oxidative stress and inflammation in women and men [37]. The study showed significant differences between females and males in body composition and biochemical parameters before and after MedD treatment. Moreover, a significant upregulation of Apolipoprotein E and Angiotensin I-Converting Enzyme in females was reported. Sex differences impact MedD treatment response, and influence the genetic expression of genes related to oxidative stress. Authors concluded that their findings may help to personalize diet therapy and contribute to overall health and well-being. The Nurse's Health Study (NHS) included over 74,000 women (aged 30 to 55 years) followed for 20 years. They found that higher adherence to the MedD was associated with a 29 % lower risk of coronary heart disease [38]. Cohort studies have shown a similar efficacy of the MedD in reducing the risk of cardiovascular disease (CVD) in both women and men [39–41]. There are also findings suggesting that the MedD has a more pronounced effect on CVD risk reduction in men than in women, while a few studies have reported significant effects on CVD risk exclusively in women, not men [42,43].

In mixed-sex cohorts, the proportions of women and men were mostly balanced, with few having a higher proportion of females [44].

The great majority of randomized controlled trials on the MedD and CVD have often failed to report sex-disaggregated results and tended to recruit a lower proportion of female participants [45].

Recently, Pant and coworkers performed a metanalysis on sixteen prospective cohort studies including n = 7 22,495 female participants [46]. In women, higher adherence to a Mediterranean diet was associated with a lower CVD incidence (HR 0.76, 95 % CI 0.72 to 0.81; I2 = 39 %, *p* test for heterogeneity = 0.07), total mortality (HR 0.77, 95 % CI 0.74 to 0.80; I2 = 21 %, p test for heterogeneity = 0.28), and coronary heart disease (HR 0.75, 95 % CI 0.65 to 0.87; I2 = 21 %, *p* test for heterogeneity = 0.28). Stroke incidence was lower in women with higher Mediterranean diet adherence (HR 0.87, 95 % CI 0.76 to 1.01; I2 = 0 %, p test for heterogeneity = 0.89), but this result was not statistically significant. This study supports a beneficial effect of the Mediterranean diet on primary prevention of CVD and death in women, and is an important step in enabling sex specific guidelines [46].

The Women's Health Study, a cohort study, that included 25,315 initially healthy women explored the relationship between MedD adherence and all-cause mortality over an average follow-up of 24.7 years [47]. The study found a 23 % lower risk of all-cause mortality in women with higher adherence to the MedD with multiple cardiometabolic factors partially explaining this associations. The objective of the study included the analysis of several metabolic biomarkers related to inflammation, lipids and lipoprotein, glucose metabolism and insulin resistance. Of the biomarkers examined, small molecule metabolites and inflammatory biomarkers contributed most to the lower mortality risk (explaining 14.8 % and 13.0 %, respectively, of the association), followed by triglyceride-rich lipoproteins (10.2 %), body mass index (10.2 %), and insulin resistance (7.4 %). Other pathways, including branched-chain aminoacids, high-density lipoproteins, low-density lipoproteins, glycemic measures, and hypertension, had smaller contributions (<3 %). The findings support the adoption of the Mediterranean diet as a preventive measure for improving women's long-term health outcomes [47].

Resilient agricultural practices play a crucial role in mitigating the impacts of climate change by improving the sustainability and adaptability of agricultural systems [48]. Several agricultural practices can be beneficial: improving soil health, carbon sequestration, and diversifying crops and livestock [48]. Planting cover crops helps maintain soil structure, reduce erosion and increase organic matter, improving the soil's ability to retain moisture and sequester carbon. Reducing or eliminating tillage helps maintain soil integrity and increase soil carbon storage, reducing greenhouse gas emissions from soil disturbance [48]. Diversifying crops through rotation can break the cycle of pests and diseases, improve soil fertility and reduce dependence on chemical inputs [49]. Integrating trees with crops and livestock systems offers multiple benefits, including shade for livestock, greater biodiversity and greater carbon sequestration.

Water management through efficient irrigation systems can also act favorably. The implementation of drip or sprinkler irrigation systems reduces water waste and ensures that crops receive an optimal water supply, which is crucial in drought [50].

Collecting and storing rainwater for agricultural use helps farmers cope with erratic rainfall patterns.

The introduction of climate-smart farming also fits in this direction.

Developing and planting crop varieties that are more tolerant to drought and heat stress can support agricultural productivity under changing climate conditions [51].

Similarly, selecting and breeding livestock that are more resistant to heat and disease ensures continued productivity of the livestock.

An additional benefit is gained from integrated pest management [52]. Using natural predators and organic practices to control pests reduces reliance on chemical pesticides, which can be harmful to the environment and human health [52]. Using techniques such as crop rotation, intercropping and selecting pest-resistant crop varieties help manage pest populations sustainably. The use of technology identifies precision agriculture [53]. Using GPS, drones and other technologies to monitor crop health and optimize inputs can increase efficiency and reduce environmental impact. Similarly, using weather forecasting tools has the benefit of providing farmers with accurate forecasts and climate information helps them make informed decisions about planting and harvesting [53].

By implementing these resilient agricultural practices, farmers can not only mitigate the adverse effects of climate change but also enhance their productivity and sustainability, ensuring food security for future generations.

4. Sex and gender differences in adherence to diet

The known differences between gender and eating habits are influenced by a complex interaction of intrapersonal factors (e.g. biological, psychological) and interpersonal factors (e.g. sociocultural, socioeconomic, cultural) [54,55].

Eating behavior is influenced by several factors that go beyond basic metabolic needs. These include food type preferences, sociocultural and religious influences; attitudes and beliefs regarding different foods [8,56–59]. For women in particular, there is a notable relationship between quality of life and body satisfaction, and the influence exerted by social media with a greater propensity to disordered eating [57].

There are also biological differences and, furthermore, energy homeostasis can be disrupted by physiological anomalies that influence appetite and calorie needs, such as changes in the hormonal cycle in a woman's life [58]. Women's hormonal fluctuations, particularly during menstruation, pregnancy, and menopause, can significantly influence their response to stress. For instance, changes in estrogen and progesterone levels can impact mood and sensitivity to stress [35,59]. During the woman's hormonal life, pregnancy is a condition that could be characterized by psychological fragility and profoundly influences eating behavior [60,61].

Several studies analyzing the impact of stress during pregnancy suggest that nurses play a fundamental role in caring for expectant mothers. They recommend that nurses provide guidance on adequate nutrition and methods to reduce anxiety and stress [62,63]. Jackson H and colleagues assessed pregnant women's recall of the nutritional advice given by their healthcare providers during pregnancy [64]. They discovered that about half of the women surveyed remembered receiving nutritional counseling. Among those who received such counseling, 73 % reported altering their behavior based on the recommendations they received [64].

Furthermore, the intake of any contaminants in food can cause side effects in both the mother and the fetus. Recent studies highlight the significant impact of climate change on pregnant women, emphasizing the heightened risks and vulnerabilities they face. In a recent review published on "Journal of Global Health", Conway F and coworkers describe the current landscape of available epidemiological evidence on key climate risks on maternal and newborn health [65]. Extreme heat has been linked to an increase in preterm births, stillbirths, hypertension, and gestational diabetes during pregnancy. Authors concluded that, despite the lack of comprehensive evidence for some climate hazards and for many maternal, perinatal, and newborn outcomes, they observed repeated findings of the impact of heat and air pollutants on birth outcomes, particularly preterm birth. This review underscore that the health risks associated with climate change have been critically underestimated for pregnant women, necessitating urgent action to protect this vulnerable population.

The impact of climate change affects the health of pregnant women and the fetus through both extreme weather events and extreme temperature variations.

Events such as floods, hurricanes and heat waves can directly harm pregnant women and children, and these disasters can cause displacement, leading to food insecurity and malnutrition and exposure to infectious diseases. In the Mediterranean regions such events are extremely rare, while exposure to temperature variations is more frequent. It is well known that pregnant women and young children are particularly vulnerable to heat stress which can lead to complications such as preterm birth and stillbirth [66,67].

Climate change modified the quality of food leading to unhealthy diet. Poor nutrition is a major contributor to hypertension, dyslipidemia, and obesity through various mechanisms, including excessive sodium and calorie intake, low consumption of potassium and fiber, and unhealthy fat intake. These conditions are interrelated and collectively increase the risk of cardiovascular diseases. Improving nutrition through balanced diets rich in fruits, vegetables, whole grains, lean proteins, and healthy fats is essential for mitigating these risk factors and promoting overall cardiovascular health.

5. Socio-cultural factors impacting food choices in women

Socio-cultural factors have a different effect on women and men. Cultural traditions and norms greatly influence women's food choices. In many cultures, women are responsible for meal preparation, which shapes their food preferences and nutritional habits [8,9]. Traditional foods and cooking methods are often passed down through generations. Furthermore, in some cultures, women may prioritize feeding their families over themselves, leading to nutritional deficiencies [68,69]. Additionally, certain cultural practices might restrict women's access to diverse and nutritious foods.

In recent times women have faced a change in their social role with an increase in women carrying out jobs outside the home and with great responsibility. Women's multiple roles as caregivers, professionals, and homemakers often limit their time to prepare healthy meals, leading to reliance on convenient, processed foods [8,9]. Women in low-income households may face financial constraints, making it challenging to afford healthy food options [70]. We must also pointed out that social pressure is changed over the year. Societal pressures to maintain a certain body image can influence women's eating behaviors, leading to unhealthy dieting practices or disordered eating. Media portrayal of ideal body types can affect women's food choices and their relationship with food, often promoting restrictive diets that lack nutritional balance. Artificial intelligence (AI) has a significant impact on image manipulation which significantly affects body image and self-esteem, particularly among women. AI enables the creation of hyper-realistic fake videos and images through deepfake technology. This can lead to dissemination of misleading content. Women may experience increased body dissatisfaction as they compare themselves to these edited images.

6. Interventions tailored to women

Specific interventions should include educational programs that provide women with knowledge about balanced diets, portion sizes and healthy cooking methods. These programs must guide them to make better food choices. To be effective, these interventions must respect cultural sensitivity. Tailoring educational materials to respect cultural food practices and preferences can improve acceptance and effectiveness.

Community support initiatives are also helpful: creating support groups where women can share experiences and strategies for healthy

eating can foster a supportive environment. Similarly offering cooking classes that teach healthy, time-efficient recipes can help women incorporate nutritious foods into their busy schedules.

Policy and environmental changes focused on food accessibility are helpful. Policies that increase access to healthy, affordable foods in low-income communities can help women make healthier choices. Similarly, providing healthy food options and nutritional information in the workplace can support women's health and well-being.

Important help must come from healthcare workers through personalized nutritional consultancy services that consider individual health needs, lifestyle and cultural background [63].

It is also important to carry out regular screening for nutritional deficiencies and eating disorders that identify problems early and provide targeted interventions [63].

Nowadays it is important to set up media campaigns aimed at conveying a positive body image. Campaigns that promote diverse and healthy body images can reduce social pressure and encourage healthier eating behaviors. Using the media to highlight the benefits of a balanced diet and practical advice for healthy eating can reach a large audience of women and have a significant social impact.

Developing regulations around the ethical use of AI in image manipulation and promoting transparency in digital content can mitigate some of the negative impacts. Encouraging responsible AI use by platforms can also help address these issues.

7. Conclusions

Climate change-induced alterations in food production and quality have far-reaching clinical implications, ranging from nutritional deficiencies and exacerbation of chronic diseases to increased prevalence of foodborne illnesses. In conclusion, combating the threat of climate change on cardiovascular health in women requires integrated public health strategies that act on interdisciplinary approaches. By involving policymakers, health professionals and the agricultural sector, we can develop and implement effective solutions that protect public health and promote sustainability. Integrating efforts across sectors is vital to a comprehensive approach to addressing the health impacts of climate change. Collaboration can take the form of: 1. Multisectoral task forces bringing together experts from the health, environmental, agricultural and political sectors; 2. Joint research initiatives to better understand the links between environmental factors and cardiovascular health; and 3. Public awareness campaigns that educate communities and women about the benefits of sustainable practices and healthy living. This comprehensive approach not only addresses immediate health problems, but also promotes a healthier environment for future generations.

Funding

None.

CRediT authorship contribution statement

Valentina Bucciarelli: Writing – original draft, Methodology, Data curation. **Federica Moscucci:** Writing – original draft, Data curation. **Camilla Cocchi:** Writing – original draft, Data curation. **Savina Nodari:** Validation, Methodology. **Susanna Sciomer:** Validation, Methodology, Conceptualization. **Sabina Gallina:** Writing – original draft, Validation, Supervision, Conceptualization. **Anna Vittoria Mattioli:** Writing – original draft, Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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