

Review

Food System vs. Sustainability: An Incompatible Relationship in Mexico

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Abstract: The Mexican food system has suffered deep transformations due to multiple technological advances and political and free trade agreements, transiting from a food system for self-consumption to a system based on exports and imports that has resulted in excessive agricultural activity intensification, leading to environmental deterioration. Our species’ survival will depend on our capacity to manage systems, considering all ecosystems, especially the climate and food systems. International organizations insist that sustainable food systems could be a useful strategy to address malnutrition and hunger while respecting the environment. However, the food system in Mexico needs to be connected to the environmental, social, health, and food security dimensions. Sustainability in Mexico synthesizes the contradictions of agriculture and the Mexican diet, not only in its economic and productive dimensions but also in the social and environmental ones. Public policies in all sectors of the country must be interconnected and organized to guarantee the sustainability of a system that benefits the environment and population health while respecting the related economic and social elements. This review aims to offer a comprehensive understanding of the Mexican food system’s history and current situation and analyze proposals for its sustainability.

Keywords: food system; sustainability; Mexico; production for exportation; food security; sustainable diets; food consumption; agrifood vulnerability



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1. Introduction

Mexico is one of the world’s leading food producers, especially regarding products for export such as avocados, tomatoes, chili peppers, and berries (among others), for which Mexico provides more than 40% of the global production [1] and is the world’s 12th biggest exporter [2]. Nevertheless, more than 50% of the food consumed in the country is imported [3], especially basic food such as corn, beans, and wheat, more than 70% of which comes from imports, generating an important agri-food vulnerability and dependency [4–6].

In addition, the country is currently experiencing the worst environmental crisis ever reported [7,8], which has been repeatedly associated with the current food systems and their unsustainability [9]. Food systems comprise a comprehensive spectrum of stakeholders and their interconnected value-enhancing endeavors in producing, aggregating, processing, distributing, consuming, and disposing of food items derived from agriculture, forestry, or fisheries. Additionally, they encompass segments of the wider economic, societal, and natural landscapes within which they operate [10].

Food systems generate over a quarter of global greenhouse gas emissions (GHGE), driving over 90% of global water scarcity [9,11,12]. In addition, agriculture and livestock production have been and remain the leading causes of deforestation [9,13,14], and the country has experienced a biodiversity loss of around 30% in tropical and forest zones of

the country [15]. In addition, the lack of regulation in agrochemical use has caused severe water quality issues and further health-related problems in the population [11,16].

In addition to health problems related to unsustainable food systems, the system does not provide a healthy diet to the population [9]. Malnutrition is still prevalent and affects more than 75% of the population [17]. Meanwhile, more than 20% of the population suffers from non-communicable chronic diseases such as type 2 diabetes and coronary disease [18]. Mexico's food system faces important challenges in deciding between economic development, food security among the population, and preserving the planet [19].

Sustainability elements are on the table of the Mexican government, and indeed, Mexico has made climate and biodiversity commitments within the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Convention on Biological Diversity (CBD) [9,20]. However, intensive agriculture and forest conversion to agriculture are key drivers of the country's economic development, especially linked to highly rentable foods for export, which currently drives an essential sector of the Mexican economy [1,21–23]. Nevertheless, the increase in economics has not been equitably distributed among farmers and instead, has perpetrated low-paid jobs, with constant risk to agrochemicals, while specific sectors of the population continue to get richer. At the same time as this, natural resources are overexploited [1,21,24]. Due to the above, a sustainable food system in the country remains utopic, and, up to date, neither the societal, nor economic, nor environmental dimensions regarding Mexico's food system are sustainable.

To transform the food system into a sustainable one, it is essential to analyze its history and current situation, explore the possible solutions to the current problems, and provide adequate proposals [9]. Therefore, the key objectives of the present review include

- (1) To analyze the history and current situation of the Mexican food system and to provide an understanding of the technological changes brought by different social movements that have shaped the current system;
- (2) To explore the concept of food security and its relationship with the current food system and to understand the basic elements that must be guaranteed in the country;
- (3) To analyze the concept of sustainable food and diets as possible solutions for guaranteeing a sustainable food system;
- (4) To analyze the sustainability characteristics of available and highly consumed foods in Mexico and consider their role as a possible solution for the current environmental crisis.

In conclusion, the objective of this review was to provide a comprehensive understanding of the history and current situation of the food system in Mexico and to analyze proposals for its sustainability.

2. Literature Review: Search Methods

This review comprises seven sections. The first one (Section 3) presents a brief history of the food system worldwide and addresses its current situation. The following section (Section 3.1) discusses food consumption related to the food systems, and the next sections are dedicated to analyzing factors influencing food systems provision and threats such as the COVID-19 pandemic (Sections 3.2 and 3.3); after this, the current panorama regarding food security and the food system in Mexico is presented (Sections 4 and 4.1). Following this, the sustainability of food systems is analyzed. Then, sustainable food and diets are discussed as a solution to the presented problem, and their feasibility is analyzed in the context of Mexico (Sections 5, 5.1 and 5.2). Lastly, some proposals for change are described (Section 6), and a conclusion is given (Section 7), where the paper's major findings are summarized.

This literature review included original and review articles, published until March 2023, in English and Spanish, in Google Scholar, Science Direct, Scopus, Scielo, Dialnet, and Web of Science. Some articles' reference lists were considered for identifying papers of interest. In addition, some official web pages were directly consulted. According to each section, specific terms were used. For the third section regarding Food System's History

and Current Situation, the following terms were used: food systems OR food system history OR Neolithic Revolution OR British Agricultural Revolution OR Green Revolution. In the case of Section 3.1, Food Consumption and Food Systems, the following terms were used: food consumption OR food intake OR Nutrition Transition OR diet change OR Dietary Transition OR Nutrition Transition AND economic growth OR Nutrition Transition AND population growth OR Nutrition Transition AND Mexico. For Section 3.2, Factors Influencing Food System Provision, the following terms were searched: food production OR food production AND environment OR food production AND natural resources OR food production AND water OR food production AND climate change OR food production AND Mexico OR food production AND Mexico AND water OR food production AND Mexico AND climate change. In the case of Section 3.3, Threats to the Food System: The COVID-19 Pandemic, the following terms were used: COVID-19 AND food system OR COVID-19 AND food production.

Regarding Section 4, Food Systems towards Food Security, Healthy Nutrition, and Food Safety, the terms used were food security OR healthy nutrition OR food safety OR food security AND healthy nutrition AND food safety. For Section 4.1, Current Food Security Related to Food Systems, the terms used were food security OR food system OR food security AND food system OR food security AND Mexico OR food insecurity AND Mexico OR food insecurity AND Mexico. For Section 5, Sustainability of Food Systems, the terms used were food system AND sustainability OR Sustainable Development Goals OR sustainable food system OR sustainable economic competitiveness. For Section 5.1, Sustainable Food as a Solution, the search terms used were sustainable consumption OR sustainable agriculture OR dietary patterns AND Mexico. In the case of Section 5.2, Food Sustainability in Mexico, the terms used included food system AND Mexico OR agri-food system AND Mexico OR avocado production AND Mexico OR food production AND Mexico OR sustainable food production AND Mexico OR production for export AND Mexico. For Section 5.3, Adopting a Sustainable Diet in Mexico, the terms used were sustainable diet OR Mexican Traditional diet OR sustainable Mexican diet OR milpa diet OR adherence AND sustainable diet. Finally, Section 6, Proposals for Change, and Section 7, Conclusions, were developed based on the analysis of the whole review.

3. Food System History and Current Situation

In previous decades, the main objective of agriculture was to satisfy the nutritional needs of the human population while respecting the natural food systems and the environment. However, through history, several movements have deeply transformed food systems [25,26]. With the Neolithic Revolution 10,000 and 5000 years ago, humanity moved from hunting and gathering to agriculture and the domestication of animals. Permanent agricultural communities were established, changing the relationship between people and the land [27,28]. Following, other movements, such as the British Agricultural Revolution in the 18th century, marked the beginning of agricultural modernization in Western Europe. With this revolution, productivity increased significantly by introducing several improvements in agricultural techniques, such as crop rotation, seed selection, and the implementation of agricultural machinery [29,30].

More recently, in the 1940s decade, the Green Revolution ended to transform the agricultural system into how it is known today. This movement was driven by advances in agricultural science and technology and started in Mexico based on technologies from the United States [31,32]. The Green Revolution was an effort to increase global food production, and it did. According to Sonnenfeld [32], crops such as corn, beans, wheat, and sorghum increased exponentially from 1940 to the 1980s. Corn production went from 1.6 to 14.1 million tons in that period. Meanwhile, bean production went from 97,000 tons to 1.5 million, and wheat production increased from 464,000 tons to more than 5.2 million tons in the same period. Sorghum production increased by over 2 million tons, going from 200,000 tons to 2.7 million. Through most of the 1970's, Mexico produced sufficient food for its own people, even while exporting agricultural products. Those increases

were attributed to machinery introduced to agriculture, especially chemical fertilizers and pesticides. Although this led to a significant increase in food production, it also raised environmental and social concerns [33].

Among the environmental implications of the green revolution is the loss of diversity, attributed to the introduction of monocultures of high-yield crops and to the reliance on a few crop varieties, which leads to reduced genetic variety, making crops more susceptible to diseases and pests [34]. Soil and water pollution are also severe consequences of this food system transformation; the extensive use of chemical fertilizers and pesticides has contributed to soil and water pollution. These chemicals can infiltrate groundwater and surface water bodies, affecting water quality and damaging aquatic ecosystems [35].

On the other hand, the depletion of water resources is one of the main concerns nowadays since the intensification of agriculture with the Green Revolution has led to greater water consumption for irrigation. In many areas, this has led to the depletion of local water resources, posing significant challenges, especially in drought-prone regions [36]. Soil erosion is also common when employing intensive agricultural practices, such as excessive tillage and lack of soil conservation techniques, which contribute to soil erosion. The loss of fertile surface layers can affect long-term productivity and contribute to sedimentation problems in nearby water bodies [37]. The intense agro-production brought by the green revolution also had an impact on natural ecosystems since the expansion of cropland has often resulted in the transition of natural ecosystems, such as forests and wetlands, to agricultural land, which can lead to the irreversible loss of natural habitats and negatively affect native fauna and flora [31,37].

Currently, we find our global food system disrupted by a set of factors revolving around economic interests, focusing on increasing productivity to the detriment of the natural environment [38]. This set of changes in the evolution of food systems has brought a global food crisis, where one in ten people is malnourished, and almost half the world's population cannot afford a healthy diet [39]. Producing food for economic purposes without respecting planetary boundaries has importantly contributed to heat waves, floods, droughts, and wars, disrupting food supplies. Around 30% of the world's greenhouse gases are emitted by the food sector. The expansion of cropland, pasture, and tree plantations generates 5.5 million hectares of forest loss per year, mainly in the tropics [40]. Inadequate agricultural practices degrade soils, contaminate and diminish water supplies, and reduce biodiversity. As these interrelationships become clearer, approaches to food are shifting away from production, consumption, and value chains towards security, networks, and complexity [41,42].

Besides all the environmental implications brought by the evolution of food systems, human health has also been affected [37]. The indiscriminate use of pesticides and chemical fertilizers in the Green Revolution has raised concerns about human health. Exposure to these chemicals can negatively affect the health of farmers and communities near growing areas. In addition to the climate crisis we are facing right now and the health problems related to new food systems, biological disasters such as the COVID-19 pandemic have worsened the global situation. In just one year (2019 to 2020), the number of hungry people increased by 13%. Armed conflicts have also contributed to these figures [43–45].

Considering this perspective, international organizations have structured possible solutions to the actual situation, and therefore, the “food system” as a concept is in divergence. In 2021, the first United Nations Food Systems Summit (UNFSS) was organized to increase the understanding of food and agriculture's critical role in the anthropogenic climate change [44]. The first Food Systems Pavilion at the Conference of the Parties (COP27) of the United Nations Framework Convention on Climate Change (UNFCCC) was released in November 2022, a paper that analyzes how influential actors harness the system concept as a product of fieldwork, with organizations trying to transform the food system's future [46]. However, although the food system can be seen as a limiting object for all people, society, and government that unites them, the interpretative flexibility of the

concept hides the fact that people can have very different frameworks that are profoundly incompatible [47].

The global food system requires comprehensive renovation across policies and institutions, alongside advancements in social, business, and technological domains [48]. Food intersects numerous disciplines, such as agriculture, health, climate science, food insecurity, digital science, political science, and economics, among others. Considering the indirect impacts of policies on climate change, biodiversity loss, and health outcomes, it is crucial to determine true food costs. By doing so, we can triple the global value assigned to food markets and facilitate the expedited transition of food systems toward enhanced health, sustainability, equity, and resilience [45].

3.1. Food Consumption and Food Systems

The population's diets have suffered from deep transformations that have been explained by demographic and epidemiological transitions, causing a nutrition transition [49,50]. Those transitions have explained why the global population has left behind their traditional diets and has adopted dense-caloric Western diets, rich in meats and ultra-processed products [51]. This transition has been experienced by a range of countries worldwide, from the United States and Canada to Asian countries like China, African like Morocco, Egypt, and Kuwait, and Latin-American countries such as Ecuador and Brazil [50–52]. Mexico is also a clear example of a nutrition transition since we have transitioned from suffering from under-nutrition-related diseases to having an overweight and obesity prevalence of 75% [18,53]. In addition, 50% of the population's diet is composed of ultra-processed products, and animal source food intake (beef, pork, poultry, eggs, and milk) increased by 73% between 1961 and 2013, from 104.8 to 181.4 kg year^{−1} [6], with Mexico becoming the sixth largest meat consumer globally [54]. Although maize consumption increased by 400% between 1961 and 2013 (from 5.4 to 27 million tons), a decrease has been observed since 2010. In addition, the principal increases regarding maize have been related to the consumption of maize for animal feed (mainly yellow maize or corn), which rose by 1700% from 1961 to 2013. However, it is essential to mention that since the 1980s, such consumption has been met through imports that in the late 2000s constituted 70% of importation [6].

Although the nutrition transition has been influenced by several factors, economic growth has played a crucial role in modifying the population's diets. Economic growth has been significant in recent decades. Global gross domestic product (GDP) grew by 2.6% annually between 1990 and 2014, primarily driven by middle- and low-income countries, where GDP grew by approximately 5.1% annually. The rapid rise in incomes in emerging economies has fueled the rise of a global middle class, which in turn is accelerating dietary changes. The demand for food is shifting towards increased consumption of meat, dairy products, and other intensively produced foods, which has serious implications for the sustainable use of natural resources [14]. For Mexico, GDP increased from 1.1% in 2008 to 2.2% in 2018, and this is, interestingly, correlated to the water scarcity crisis and GHGE [2,55].

Besides economic growth, population growth is one of the principal concerns among the scientific community regarding food consumption and provision [14]. Worldwide, the population dynamics will radically change in terms of demographics in the coming decades. By the year 2050, the global population is projected to increase and reach nearly 9.7 billion people. This anticipated growth is expected to be concentrated predominantly in Africa and South Asia and in urban areas, where it will severely hinder development prospects. Local communities rely on agriculture for employment and income generation; however, further development of agriculture is impeded by the existing pressure on land and water resources [14]. The case of Mexico presents a different panorama since it has been reported that population growth will reach its peak by 2053 with 147 million inhabitants. For the first time in history, the population volume of Mexico will begin to decline, sustaining a decreasing volume. By 2070, the Mexican population will reach the figure of 141.4 million

people [56]. Nevertheless, even with those figures, considering the actual environmental crisis that the country faces, the planetary boundaries will not allow it to feed such a population [57].

3.2. Factors Influencing Food Systems Provision

Although currently the world has enough food production to feed everyone, it is not well supplied and distributed [58], and according to demographics, growing food production will have to increase by 50% in 2050 to feed the global population [14]. Both at the macro and micro levels, regions regularly experience food shortages due to multiple unfavorable food production conditions. First, environmental degradation and labor or intrusion into the food supply chain have caused difficulties in proper production. Also, climatic events have risen significantly in the last decade and disrupted the supply chain. Among these are severe weather phenomena such as extreme weather conditions, droughts, floods, heat waves, and cold snaps. It is estimated that, globally, droughts and heat waves combined could cause an approximate 10% decline in crop production at the national level. In addition, economic crises, political conflicts, insecurity, sanctions, and health crises (i.e., epidemics) have worsened the situation [59–62].

As per the Global Report on the Food Crisis 2020, extreme weather events during 2019 notably impacted food security across regions, including the Horn of Africa, Southern Africa, Central America, and Pakistan. Meanwhile, ongoing economic crises persisted in Venezuela, Haiti, Sudan, and Zimbabwe. Additionally, armed conflict and political instability emerged as major contributors to food insecurity in the Middle East, various Asian nations, and the Lake Chad Basin and central Sahel regions [60].

In Mexico, climate change has started affecting one of the principal components of the population's diet and the cornerstone of agriculture: maize. This crop is grown in 35% of the cropland area of the country and 59% of the rainfed agriculture area. However, low precipitation in Mexico during 1997–1998 led to a 25% decrease in the total production of maize [63]. According to climate change effects, there is a prediction that representative concentration pathways (RCPs) will decline by the year 2100, leading to a 10% decrease in maize production in Mexico [63]. Other sectors, such as cattle and goat stocks, have also been affected by extreme weather events, such as the one reported in 2011 and 2012, where a decrease of 3% in stocks was reported [64]. Since 88% of the Mexican territory is considered to be in severe water scarcity, the food production projections are worrying, and deep transformations in the food system are urgently required [65].

3.3. Threats to the Food System: The COVID-19 Pandemic

Supply side components play an essential role in ensuring global food security. But what if food production declines, food stocks run out, or international trade declines worldwide due to increased protectionist policies? Such situations are unlikely. However, such a scenario has already occurred during the COVID-19 pandemic and armed conflicts in recent years that has shaken food value chains, driving up food prices and access to them. Hungry people in the world reached 828 million in 2021, an increase of 150 million people since the outbreak of the coronavirus disease (COVID-19) pandemic [66].

The United Nations provides new evidence showing that the world is far from ending hunger, food insecurity, and malnutrition by 2030 [43]. These potentially severe repercussions for the food supply were reflected in apparent ways in countries dependent on food imports and worsened food supplies in countries already experiencing severe food shortages. The poorest countries are likely to suffer disproportionately, just as the socioeconomic impacts of the 2020 COVID-19 pandemic are predicted to hit low-income countries more severely than elsewhere [58,61]. According to Sen's rights approach, famines are driven by distributive dynamics and socioeconomic issues rather than food availability [67]. Global and dynamic food systems are the most complex and vulnerable to new risks. Scientists must better understand, monitor, analyze, and communicate such vulnerabilities. Although

GDP has had a trend of increasing in recent years, in 2020, due to the COVID-19 pandemic, a reduction of 8.3% was observed [55].

During the COVID-19 pandemic, numerous governments enforced preventative measures such as self-isolation protocols and varying degrees of national lockdowns. By April 2020, approximately one-third of the global population was under lockdown [68]. People were forced to stay home and practice online work and online learning. They could leave their homes only on pre-specified occasions, such as for medical reasons, essential work, physical activity, grocery shopping, and emergencies [69]. Such sudden changes in people's lives harmed their mental health and lifestyle habits, such as through increasing alcohol intake [70] and eating habits [71,72]. Furthermore, alterations in daily routine and cessation of work, which may be associated with stress and boredom, led to increased energy intake or overeating [73,74]. A high prevalence of sleep disorders was reported during the first COVID-19 lockdown [75–77], which could also be related to unbalanced eating patterns [78,79]. Overeating is directly related to an increased risk of developing obesity and subsequently an increased risk of cardiovascular disease (CVD) [80] and type 2 diabetes mellitus (DM2) [81,82]. Moreover, it is crucial to identify the pattern of alcohol consumption during confinement, as it correlates with a greater prevalence of adverse health effects and detrimentally impacts the quality of life (QoL) for both the consumer and their family members [73].

These events have shown us that the current food system is fragile and needs to rethink its strategies to reach the limit objective. As a solution, the concept of sustainability was raised, a term that involves aspects parallel to food in its definition, such as economics, ecology, society, and health [83]. Its main objective is to visualize food as a necessity that must be maintained for a long time without depleting the resources for its generation [84].

4. Food Systems towards Food Security, Healthy Nutrition, and Food Safety

Due to the complexity of elements influencing food systems, international organizations have worked on conceptualizing food systems and their related factors. Most conceptualizations include three basic elements to be considered in a proper food system: (1) food security, (2) healthy nutrition, and (3) food safety [85–88]. Each of them falls within the framework of the High-Level Expert Panel on Food and Nutrition Security [HLPE] proposed in 2017 [85], which provides the following food systems definition: “all components (environment, individuals, inputs, processes, infrastructure, institutions, etc.) and actions associated with the production, processing, distribution, preparation, and consumption of food, as well as the outcomes of these activities, encompassing socioeconomic and environmental impacts. Consequently, food safety, nutritious diets, and food security are inherently interrelated as they are essential for fostering a robust food system. Thus, adherence to these three principles is paramount in the field [36].

First, food security must be understood as the stable physical availability of food, as well as its economic and physical access and adequate utilization, to people to satisfy their dietary needs and food preferences to ensure an active and healthy life [89]. Second, healthy nutrition entails ensuring the sufficient provision, without surplus, of nutrients derived from nourishing and beneficial foods while also preventing the incorporation of harmful substances throughout the entirety of the value chain. In addition, this kind of nutrition must be composed of nutritious and healthy foods that provide nutrients with health benefits, such as vitamins and minerals, as well as essential amino acids, essential fatty acids, and dietary fiber, among others, while minimizing the potentially harmful elements, like anti-nutrients, saturated fats, sugars, and sodium [90].

Finally, food safety addresses foodborne illnesses and covers food handling, preparation, and storage [66]. In the realm of food security, there is a common misconception that food safety is inherently guaranteed. However, in regions where food availability is inadequate, strategies to tackle food insecurity often prioritize access to food without proper attention to safety measures. Even in countries with greater food security, resources may be disproportionately allocated to ensure the safety of exported food items, potentially

neglecting the safety of domestically sold food. Individuals experiencing food insecurity are particularly susceptible to the health risks posed by unsafe foods, including chemical, biological, and other hazards, which can lead to severe acute and chronic health issues, ranging from gastrointestinal problems to cancer and mortality [91].

Each objective revolves around allocating resources and authority within and among states, requiring decisions from international organizations and national governments [92,93]. Moreover, the three objectives are included in the United Nations' Sustainable Development Goals (SDGs) of Agenda 2030 [94]. While various facets of the unified process or objective set are occasionally amalgamated, as evidenced by terms like 'food and nutrition security', it is important to note that food security, food safety, and healthy nutrition possess distinct characteristics. Consequently, policymakers conceptualize and prioritize them differently [95,96].

4.1. Current Food Security Related to Food Systems

Inadequate nutrition is mainly related to malnutrition in all its forms: underweight, overweight, and obesity [85,97]. Food safety addresses foodborne illnesses and covers food handling, preparation, and storage [66]. The FAO points out that food security is a situation where all people always have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs and according to their food preferences, for an active and healthy life [43]. It encompasses food availability, access, utilization, and stability, the four dimensions of food security, food safety, and healthy nutrition. However, there are tensions between healthy nutrition and the various aspects of food security. Food security has to include both food production and consumption; by definition, both have to be resilient, not compromising food production and availability for future generations [98].

Despite the world's food systems apparently fulfilling their purpose of feeding everyone efficiently, since people consume an average of 2881 kcal/person/day from an average dietary energy requirement of 2353 kcal/person/day [99], there are still zones in the world where people are starving every day [100], and this shows how the global food supply chains are incredibly complex. Potential disruptions in food supply chains can be caused by various factors: disturbances in the food balance such as production, stock, international trade, population consumption patterns, and growth [101].

Mexico is an example of disparities in food security, healthy nutrition, and food safety. Although Mexico is a megadiverse country that offers optimal conditions for several crop types, farmers' socioeconomic situations range from low-income small producers with small-scale farms and low use of agricultural inputs to high-income producers with large-scale farms and substantial use of inputs [98].

Regarding food insecurity, in 2010, 44.3% of the population was suffering from any level of food insecurity. From that figure, 10.8% were identified with severe food insecurity, 14.0% with moderate food insecurity, and 19.5% with very low food insecurity. Thus, by 2010, 49.9 million people in Mexico experienced some degree of food insecurity [102]. According to the National Council of Evaluation (CONEVAL—in Spanish), between 2016 and 2020, food insecurity increased before the COVID-19 pandemic [103]. However, there are currently concerns about the way of measuring food insecurity, since it has been proposed that the instruments to measure food insecurity must be recalibrated to assess the changes in food consumption considering the changing patterns of purchasing power through the payment cycle [103].

Although the country is still facing important food insecurity issues, on the other hand, the country occupies the first place in obesity levels worldwide [104], with a prevalence of more than 75% in adults (overweight and obesity), and over 81% regarding abdominal obesity [105]. In addition, their energy intake surpasses their requirements, and not only energy intake is a worrying aspect, but the foods that constitute the energy intake. It has been reported that 10% of energy intake in Mexico comes from sugary drinks, surpassing by three times the recommended amounts [106]. Additionally, animal-origin products also surpass recommended intakes since 14.4% of energy intake comes from meats, espe-

cially red meat [106]. This puts pressure on food systems and is far off what international organizations promote to achieve a sustainable food system [14].

5. Sustainability of Food Systems

According to the FAO, a sustainable food system delivers food security and nutrition for all, aligning with economic, social, and environmental bases to ensure that food security and nutrition for future generations are not compromised. Therefore, a food system, to be sustainable, must cover economic, social, and environmental dimensions, and thus be profitable throughout (economic sustainability), have broad-based benefits for society (social sustainability), and have a positive or neutral impact on the natural environment (environmental sustainability) [14].

A sustainable food system based on the SDGs: The Sustainable Development Goals (SDGs), adopted in 2015, advocate for significant changes in agriculture and food systems to eradicate hunger, attain food security, and enhance nutrition by 2030. Nevertheless, in order to fulfill the SDGs, it is imperative to restructure the global food system to enhance productivity, inclusivity for impoverished and marginalized groups, environmental sustainability, resilience, and the ability to provide healthy and nutritious diets to everyone. This encompasses complex and systemic challenges that require combining interconnected actions at the local, national, regional, and global levels [14].

While new concepts continue to emerge, translating them into practice presents a significant political and technical hurdle. In addition, integrating and respecting each dimension of sustainability in a food system is a challenge that has not been achieved. In this regard, there is a constant competition between economic competitiveness and social and environmental elements in the systems [107]. This worry has been analyzed, and even new concepts, such as the sustainable economic competitiveness index (SECI), have been developed to be applied directly to the agri-food value chains [107]. For Mexico's context, applying such indexes would represent an opportunity to restructure and re-prioritize the final objective of the food system, which would have to be orientated for full-fill food security while respecting the environment but balancing the economic elements of the country [108].

Although food systems integrate the full food chain, the role of sustainable consumption has been highlighted in the last few years. Indeed, it has been reported that a healthy and sustainable diet puts less pressure on the environment and generally aligns with a sustainable food system [10,12]. In this context, it has been noted that generating a nutritious and sustainable diet requires 20% to 50% less agricultural land, depending on the dietary guidelines, compared to the current average diet of the Mexican populace [109]. However, changes and a more holistic and coordinated approach are needed in the food system. Those changes are urgent in several sectors, for example, in terms of land use, such as exchanging pasture for cropland as well as modifying the crop production type, for instance; this involves decreasing the amount of land allocated to sugar cane and livestock feed production while increasing land use for cultivating legumes and nuts. Furthermore, it is urgent to reduce supply chain losses and increase crop yields, which considerably reduces the demand for agricultural land [10,109].

5.1. Sustainable Food as a Solution

Among the proposals for improving food systems, the need for changes in consumption patterns has been repeatedly highlighted and is actually one of the SDGs [94,110]. Together with housing and mobility, food is one of three consumption areas with the most significant environmental impacts [110]. The impact is significant enough that both Agenda 21 and Agenda 2030 advocate for action to encourage consumption patterns that alleviate environmental strain and fulfill humanity's basic needs [111]. Shifting current dietary patterns towards a diet with low environmental impact can halve food system pressure on climate change and reduce other environmental impacts by 6–22% [41]. Recent studies emphasize the relationship between food, the environment, and dietary patterns. However,

changing current dietary patterns towards healthy and environmentally sustainable diets, which are aligned with the economy and culture of the population, is imperative for both human beings and the food system [112,113].

According to the FAO, sustainable food and agriculture are one in which food is nutritious and accessible to all. Natural resources are managed to maintain ecosystem functions to meet current and future human needs. So, the global food system must be in tune with sustainable diets [12,39,114], defined as diets with minimal environmental impact while supporting food security, nutrition, and the well-being of current and future generations. These diets prioritize protecting and preserving biodiversity and ecosystems, ensuring cultural acceptability, accessibility, economic fairness, affordability, nutritional adequacy, safety, and healthfulness. Additionally, they aim to optimize natural and human resources [113,115].

While the sustainable diet approach is an attractive strategy to restructure current food systems, the real question is whether this strategy alone is enough within a food system that requires feeding a world population within the planet's limits [57,116]. To achieve such a transformation, radical changes in people's dietary patterns are necessary, and thus, a joint work between professionals and consumers to promote more responsible dietary choices. However, giving responsibility to the consumer to encourage a sustainable food system is a proposal with multiple nuances that have been severely criticized.

Getting people to consume healthy, local, economically, and culturally acceptable food with less environmental impact is difficult. Food is no longer simply a means to satisfy hunger or nourish the body but is equally a source of pleasure and a way to mark social status [110]. We take the example of Mexico; currently, the country has the highest dietary water [53] and carbon footprints [117], in addition to having the highest overweight and obesity rates worldwide [118]. The Mexican dietary pattern presents a high consumption of animal-origin protein, such as meat, eggs, and dairy as protein sources [53], while including lots of ultra-processed foods, especially soft drinks, and high-sugar and -fat foods, thus abandoning the traditional diet and adopting a mainly Westernized dietary pattern [6,24,53,119,120]. As an example of this, we find that most developed and even developing countries are going through this nutrition transition, and although concepts and frameworks keep arising, health and environmental issues do too [49,50]. Therefore, it looks like the problem is no longer a conceptual or scientific evidence concern but a practical and political issue.

5.2. Food Sustainability in Mexico

Understanding the food system in Mexico is complex, since the bases for food production nowadays (i.e., natural resources) are every time more threatened and scarce, especially water [121,122]. Although the sixth goal of the SDG addressed the urgency to provide availability and the sustainable management of water and sanitation for all [94], and the legal management of water is specified in articles 4, 27, and 115 of the Constitution, which lay the foundations for the legislation of water [123,124], the current data shows that the water crisis is on the rise. In 2018, 18% of the underground aquifers were over-exploited, 5% had soil salinization problems, and 3% with marine intrusion problems. By 2021, 8491 droughts were registered, of which 71% were severe, 26% were extreme, and 3% were exceptional droughts, with total water scarcity in reservoirs, streams, and wells [125]. The nation's water basins face a projected shortfall of over 500 million cubic meters of water annually [126].

When analyzing the water crisis the country is facing, it could be possible to think that the Mexican agro-food system has stopped or, at least, has decreased production. However, during the last 20 years, Mexico has become the largest producer and exporter of avocados worldwide. Between 1991 and 1998, export volumes from México almost quadrupled, increasing from 13,000 tons to 47,000 tons, and have continued to grow since [1]. This product is considered the "green gold" in the world market, since it contributes to 34% of production, 46.3% of the volume of exports, and 12% per year [127,128]. This fruit, which is

part of the healthy and sustainable traditional Mexican diet, synthesizes the contradictions of agriculture and the main challenges facing the diet of Mexicans, not only in its economic and productive dimension but also in the social and environmental dimensions [129,130].

The expansion of avocado cultivation has led to the availability of land in numerous indigenous and peasant communities, where levels of extreme poverty persist at alarming rates. At the same time, food insecurity and health problems are common among farm workers, who are often community members. The expansion of avocado production has also exacerbated violence in a region already violated by criminals and drug traffickers present in the region [24]. Furthermore, this fruit is the primary driver of deforestation in the tropics. The swift expansion of avocado cultivation in central Mexico following the implementation of the North American Free Trade Agreement (NAFTA) serves as a compelling case for reevaluating the sustainability of avocado consumption within the Mexican diet [1,24,131].

Additionally, Mexico is one of the leading countries that have implemented highly technical agricultural production systems to increase production. These systems pertain to crop covers constructed from translucent synthetic materials, such as greenhouses and macro tunnels, which are utilized to regulate the temperature of crops such as avocado orchards. These systems heavily rely on the use of agrochemicals to mitigate or prevent crop losses [132,133]. In Mexico, 60.0% of the 22 pesticides considered harmful to health and the environment are used [134]. There is no precise data on the amount of pesticides currently used in the country, but in 2005, the consumption of around 50,000 annual tons of active ingredients was reported. In 2007, it was estimated that 100,000 tons of these compounds were sold, which was equivalent to 4% of world consumption [135]. Pesticide use has generated problems ranging from toxicity to humans and wildlife to ecosystem disruption [136]. Mexican agricultural workers are the most exposed to different mixtures of pesticides, including organophosphates, organochlorines, carbamates, and pyrethroids, increasing the incidence of diseases and cancer [137].

Many studies have shown the use of pesticides in producing avocados and many greenhouse products such as berries, fruits, and vegetables [138]. The pesticides with the most significant presence are neonicotinoids, followed by organophosphates, herbicides, and fungicides, which can affect human health and contaminate the environment [138,139]. Occupational pesticide exposure induces DNA damage, such as sister chromatid exchange, micronucleus formation, chromosomal aberrations, and even DNA adducts where the DNA strand breaks [140]. On the other hand, on 15 June 2023, the Food Safety News portal announced that approximately 35,000 lbs (15.87 tons) of frozen organic strawberries imported from Mexico were withdrawn from the market due to their possible contamination with the virus Hepatitis A [128].

One of the principal problems with the increase in food exports (in area and production) in Mexico is that this production has replaced essential and basic foods for self-consumption in Mexico, for example, the milpa base foods corn, and beans, which are fundamental components of Mexican gastronomy, cultural heritage, and identity [141]. The total area planted with corn in 2016 was 7,761,216.74 (hectares) ha, and by 2022 it was 6,904,042.77 ha, a decrease of 11%. Production has also presented a drop, going from 28,250,783.31 tons in 2016 to 26,553,239.30 in 2022. Beans followed a similar trend, having a drop of 9.7% from 2012 to 2022, with a planted area of 1632,150.47 ha to 1,472,462.29 ha. Their production also decreased from 1,088,766.73 in 2016 to 965,370.65 in 2022 [142].

Although the changes in production trends, maize, and beans are still planted in almost the entire territory. However, when comparing the production of fruit and vegetable crops, we find interesting trends that reflect the use of technologies in Mexican agriculture. Despite fruits and vegetable crops representing only approximately 13% of the planted area in Mexico (2.3 million hectares of fruit trees and 0.56 million hectares of vegetables), they contribute to 40% of the production value in the Mexican agro-system [1,21]. Mexico is the world's leading exporter of berries, tomatoes, and avocados, with 12 free trade agreements with 46 countries [143]. The economic contribution of these products

translates to a production increase, thus replacing the production of essential foods for a population that continues to face overweight and obesity problems and significant food dependency, besides increasing pressure on a country's environmental resources, worsening the climate crisis.

5.3. Adopting a Sustainable Diet in Mexico

Modifying the population's eating behavior is one of the most significant challenges worldwide. No matter how many strategies are proposed and implemented, malnutrition rates continue to increase, as does environmental deterioration [57]. The most promising proposal is to implement multidisciplinary programs based on behavior modification techniques that address the population individually and collectively [144]. However, what is the point of promoting sustainable eating without a sustainable food system, especially if no sovereignty and food security can be achieved [145]?

One of the most important aspects to be addressed in sustainable diets, which is often overlooked, is contextualization. Indeed, the EAT-Lancet diet, which is one of the most remarkable proposals of a 'universal' sustainable diet, is sometimes widely generalized and loses its focus on the actual sustainability framework [57,146]. While it is true that this proposal calls for contextualization when implementing its guidelines in specific countries or regions, most emerging studies tend to only compare recommendations to actual intakes or to promote its recommendations directly [147,148]. However, each region must work on adapting their traditional diets according to sustainable diet guidelines and, of course, consider all the important contributions that models such as the EAT-Lancet diet have brought to us [57]. In this regard, Mexico is an excellent example of recovering its traditional diet and directing it towards a sustainable one.

The traditional Mexican diet is based on the milpa diet, a healthy eating model based on Mexican food's culture and regional characteristics [149,150]. This diet integrates the products of milpa (corn, beans, zucchini, and chili) and promotes traditionally natural food techniques and dishes. The milpa diet also includes a wide variety of fresh fruits and vegetables, such as citrus fruits, papaya, *quelites*, red tomato, and *nopales*, as well as rich-protein seeds and healthy fats, such as avocado, among other foods [151]. The milpa diet has evolved throughout history and is now complemented by European food that was brought to the region during colonization. Those include meats and dairy, significantly expanding the nutritional and culinary profile [152,153].

Due to its characteristics, the optimal health of the pre-Hispanic Mexican population was attributed to the milpa diet for decades. Currently, a growing amount of scientific evidence suggests betting on this dietary pattern to improve Mexicans' health [154]. In addition, the sustainability of the traditional Mexican diet has been explored, and, if properly and individualized structured, it can be considered a sustainable option because of its low environmental impact and economic and cultural attributes [144]. However, although recovering the traditional diet is the current commitment by scientists and the Mexican government, the real challenge is how it can be achieved [144], especially considering current Western dietary patterns that have modified the preferences of the population. However, the rapid evolution of affluent consumption due to urbanization and globalization should not be considered a cultural food preference [98].

6. Proposals for Change

As can be seen, the food system, both globally and in specific cases such as Mexico, has significant contradictions between the essential elements to achieve sustainable food systems. For this reason, the proposals to solve these issues must be oriented at various levels and sectors, considering public policies and government agreements, in addition to considering the primary needs but also secondary needs of a growing population on a struggling planet [155].

With this work, we do not want to just keep re-exposing the problem, that is, every time, making it more notable and recognized internationally. But, we would like to bring

up proposals for a better future outlook. First of all, at this point, it is clear that policies, regulations, and restructuring are necessary. However, it cannot be ignored that the current Mexican food system hides multiple economic interests that have brought development and employment to the country (without considering the type and quality of jobs, of course). In this regard, a balance between economic and social concerns vs. benefits must be analyzed, and specific indexes, similar to the aforementioned SECI, must be developed for specific contexts, such as Mexico, to balance the sustainability of such elements [107].

In addition, Mexico is right now a key productive country for the products mentioned before, which have become essential, or at least highly consumed worldwide (i.e., berries, avocados, tomatoes, cucumber, etc.). Therefore, we would like to end this paper by saying that our objective is not to eradicate the production of foods that have brought economic development to the country but to start distributing the land based on available resources, zones of scarcity, and, of course, based on the minimum dietary nutritional needs of the population. In this regard, future studies are needed to estimate the minimum amounts of hectares and tons of production of each basic food product per capita, that must be produced by each hectare and ton of export products. In this way, we consider that a balance between production for self-consumption and exports is urgent. However, sustainable food production techniques are not optional for the country or the whole world if we want to preserve the planet that has let us destroy it.

In addition, the government should adopt policies to diversify risks by combining sourcing strategies from local or shorter supply chains and systems for integration with regional or international food markets. It is essential to use resource use intensity indicators to measure the environmental footprints of both locally produced and imported products, more sustainable consumption, designing and reusing their current agricultural policies to achieve the triple benefit of greater productivity/efficiency, resilience, and environmental stability [156]. Of course, such restructuring requires deep analysis not only from a sustainability perspective but from an economic and political perspective. Therefore, economists and Mexican politicians must start relating to the complexity of the current food system and start analyzing the proposals made here.

Finally, once we have a sustainable food system that considers food security, healthy nutrition, and food safety, behavioral interventions both at individual and population levels are needed to promote the maintenance of the systems by a population, demanding and consuming sustainable foods and thus increasing production. For implementing such interventions, investments in multidisciplinary specialist teams are required from the health sector of the country, as well as from the environment-related organizations, and must be supervised and approved by economists and political experts. The feasibility of such interventions requires deep analysis, but their implementation is necessary [144].

Although this work addresses a wide spectrum of the factors around food system sustainability in Mexico and provides insights to promote SDGs related to food security (SDG 2), healthy lives (SDG 3), water (SDG 6), sustainable economic growth (SDG 8), sustainable consumption (SGD 12), and climate change (SGD 13), this work also has some limitations. First, analyzing a system as complex as the food system in Mexico is difficult; as it addresses a lot of aspects, some of them get overlooked while others receive more attention. In this regard, we recognized a lack of an economic perspective, opening the necessity for further research exploring the economic effects of implementing a sustainable food system. Another important limitation is the lack of a clear framework when addressing the review topics. For this, further studies proposing models for implementing the proposed changes are urgent. Additionally, besides review articles, the country needs more original research exploring the effects of implementing the current proposals. However, this review provides ideas and proposals for future research development.

7. Conclusions

The history of food systems shown in this review presents how the system's evolution has led to a set of constant contradictions that have made the system lose the path of

feeding the population while respecting the environment to grow economic earnings without considering sustainability. This work summarizes the complexity of a food system that works constantly to increase production and sales, but on the other hand, it is called to be more sustainable. Food security, healthy nutrition, and food safety are critical aspects of food systems with important implications for the population and the planet's health. Furthermore, a sustainable food system cannot be sustainable without integrating the environmental factor into its definition. Although current efforts to promote sustainable food systems have not been effective, in this paper, we provided new (or reinforced) insights such as land distribution, policy regulation, and traditional diet recovery to transform food systems into sustainable ones.

In addition, the problems brought by the technification of agriculture orientated to the production for export proved that systems need deep restructuration and to reorder priorities. Mexico served as an example of a system that is suffering from several aspects, and not only the population is receiving the impacts, but the environment. With this work, we call to the need for policy reformulations that guarantee food security that can provide healthy nutrition and food safety to the population. In addition, the Mexican government is called to rethink current regulations, both regarding land use and agrochemical use. In addition, the lessons learned from COVID-19 must be remembered, and the countries must be prepared for such scenarios. Although the need for dietary changes toward sustainable diets is addressed, it is also important to visualize that sustainable food consumption is not possible without a system providing it. Additionally, ensuring the population adheres to sustainable diets needs deep structuration in the whole system, and furthermore, behavioral change interventions are needed to achieve such an objective.

Finally, this work provides new insights to achieve the SDG of Agenda 2030. To conclude, we present Figure 1, which illustrates a proposal for a sustainable food system that integrates a whole perspective of food systems, considers political conflicts and health emergencies, and addresses them from the perspectives of food security, healthy nutrition, and food safety. In addition, it includes the elements of a sustainable diet and concludes with the proposals addressed in the paper.

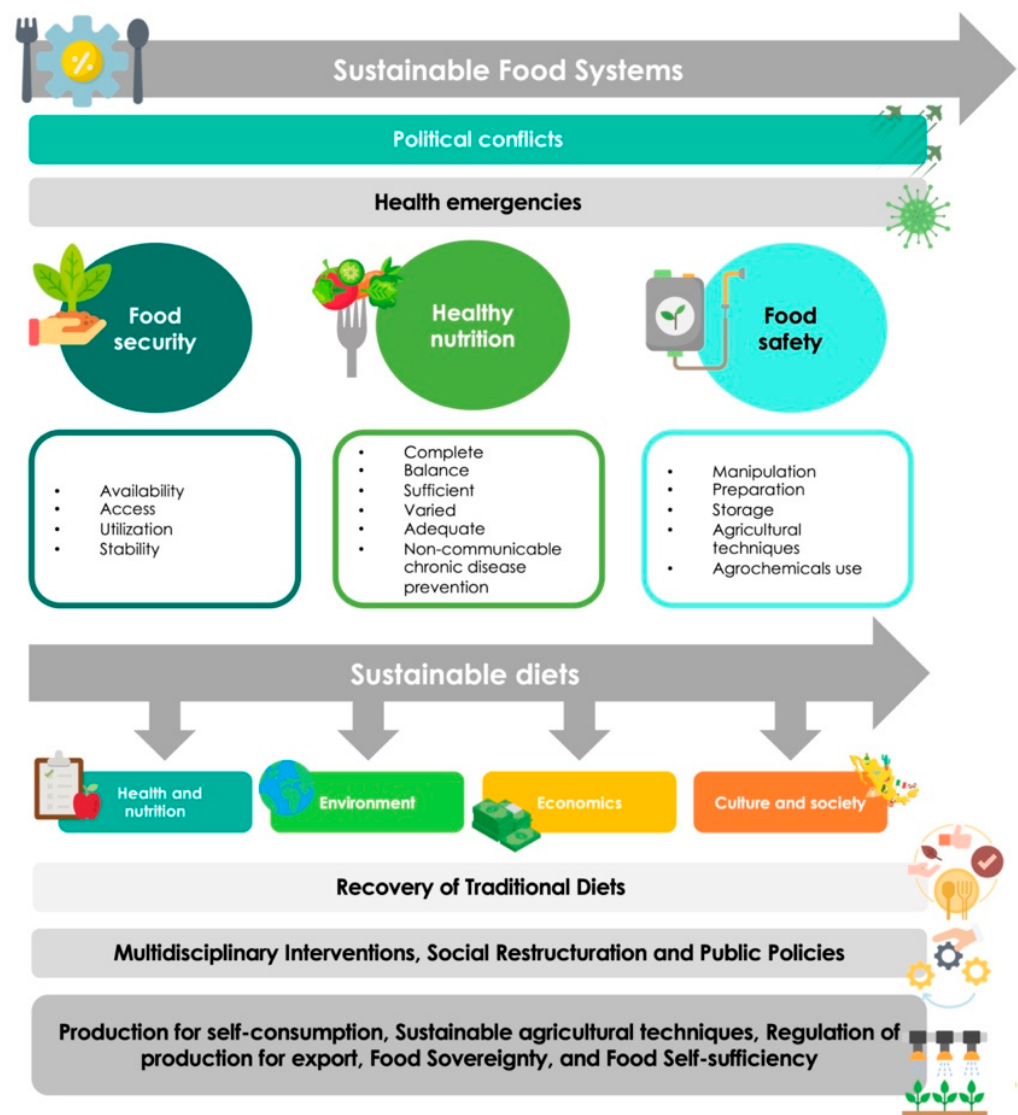


Figure 1. Sustainable food systems framework for Mexico's context.

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